Engineering & Product Development

Innovative Clean Air Technologies (ICAT) Program

CARB Contract Number
94-351

Clean Air Two-Stroke (CATS) For Utility Engine Applications

May 22, 1998

For:

California Air Resources Board
Research Division
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Sacramento, CA. 95814

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Prepared for the California Air Resources Board and the California Environmental Protection Agency

Disclaimer

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The support of this project by the California Air Resources Board is not an endorsement of the product

Acknowledgements

BKM, Inc. would like to recognize the following consortium companies and organizations for their monetary and technical support during the CATS Engine Development Program:

- California Air Resources Board
- Honglin, RPC
- Suzuki, Japan
- Tanaka, USA & Japan
- Tohatsu, Japan
- Yamaha, USA
- A Taiwan Company who wishes to remain anonymous

This report was submitted in fulfillment of CARB Contract No. 94-351, entitled "Clean Air Two-Stroke (CATS) for Utility Engine Applications" by BKM, Inc. under the partial sponsorship of the California Air Resources Board. Work was completed as of May 22, 1998.

Abstract

BKM has developed and demonstrated a unique electronic fuel injection system known as the Single Plunger System (SPS). The SPS is currently being applied to a low cost, single cylinder two-stroke engine that is applicable to mopeds, small outboard marine and utility engines.

The unburned hydrocarbons found in the exhaust of conventional two-stroke engines are due to the basic design and operating principles of the engine. These engines produce from 10 to 15 times the levels of unburned hydrocarbons compared to four-cycle engines. In the conventional carbureted two-stroke engine, the fuel/air mixture is pumped into the cylinder during a portion of the cycle in which both the intake and exhaust ports are open. This is known as the scavenging cycle, or removal of combustion byproducts from the previous engine cycle.

The SPS direct fuel injection system has demonstrated that it is capable of reducing unburned hydrocarbons emissions by approximately 80% by eliminating the scavenge loss of fuel, therefore meeting the 1999 CARB emissions standards for utility engines.

BKM formed a consortium of industry and governmental agencies to provide funding for the program by offering non-exclusive license agreements to the industry members. Current members include:

BKM, Inc.	CARB
Honglin Mach. Factory (PRC)	Yamaha Motor Corp. USA
Suzuki Motor Corporation	Tohatsu Corporation
Tanaka Kogyo Co. Ltd.	Taiwan Motorcycle Company who wishes to remain anonymous

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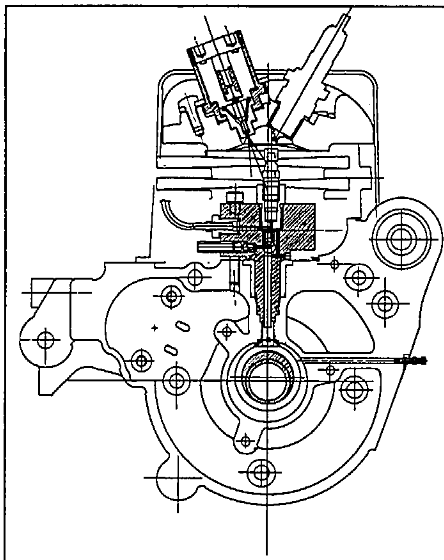
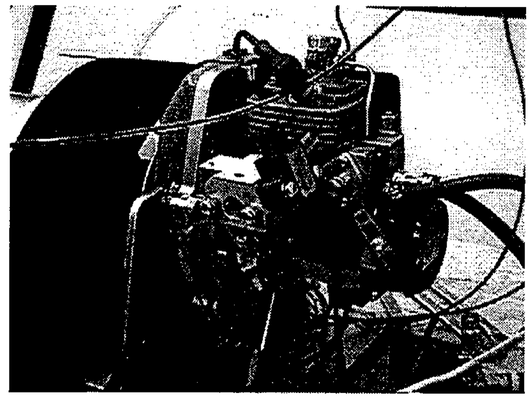


Suzuki Moped Engine



Tanaka Utility Engine

<u>Description</u>

BKM, Inc. is an engineering and product development company with a 22-year history, which includes the design of both commercial two-stroke engines and state-of-the-art high pressure fuel injection systems. BKM has developed a unique Electronic Direct Fuel Injection (EDFI) system that is applicable to low cost, single cylinder two-stroke engines. BKM has developed and demonstrated a prototype of a single cylinder engine based on a novel EDFI system tailored to small, low cost and high production volume two-stroke engines. BKM is currently operating a 46cc utility engine for developmental test purposes and is in the process of installing an EDFI engine in a moped.

<u>Specifications</u>

A 46cc handheld equipment engine, manufactured by Tanaka Kogyo, Ltd. was selected for the prototype fuel system application design and performance demonstration. Performance goals included:

Power: Equal to standard carbureted engine

Exhaust Emissions (SAE J 1088):

	THC	CO	NOx
g/kW•hr	67	174	5.4

Performance and Emissions (Test Results):

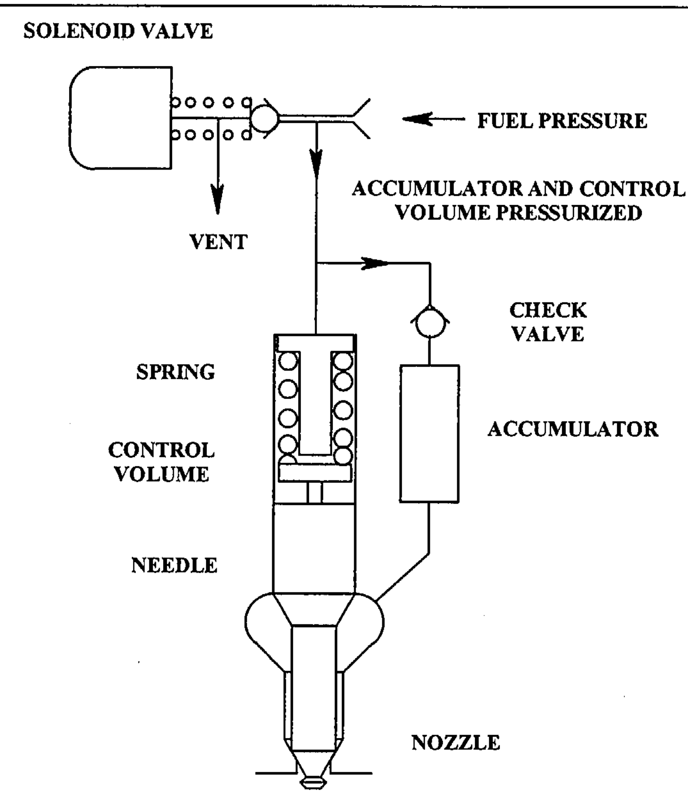
	Power, kW 7,000 rpm	BSFC g/kW•hr	THC g/kW•hr	CO g/kW•hr	NOx g/kW•hr
Baseline	tbd	tbd	tbd	tbd	tbd
EDFI	tbd	tbd	tbd	tbd	tbd

Sponsorship

The funds required for the initial stage of the program were secured by forming a consortium and offering non-exclusive license options to several engine builders as well as securing funding through the ARB's ICAT program. The consortium members who have secured a technology license option include the following:

Honglin Mach. Factory (PRC)
Suzuki Motor Corporation
Tanaka Kogyo Co. Ltd.
Yamaha Motor Corp. USA
Tohatsu Corporation
Taiwan Motorcycle Company (anonymity requested)

Additional Details



BKM's EDFI System

BKM's Electronic Direct Fuel Injection system operates as follows: Fuel pressure is provided to the fuel injector by means of a single plunger pump integrated into the design and timed to the engine cycle.

Due to the compressibility of the fuel, the mass of fuel in the accumulator increases as the accumulator pressure increases. When the accumulator pressure and the inlet pressure equalize at the maximum inlet pressure value, a check valve at the accumulator entrance closes, thereby trapping high pressure fuel within the accumulator.

A solenoid valve is the interface between the injector and the electronic controller. When the solenoid is energized, pressure on top of the needle valve is vented, and a pressure imbalance is produced across the needle valve, which lifts the needle and opens the nozzle tip to the fuel stored in the accumulator.

Injection takes place until the pressure in the accumulator drops to the needle valve closing pressure, preset by spring force. Injection duration depends on total nozzle flow area and the pressure drop from peak closing pressure to needle closing pressure.

The hydraulic system includes a single plunger pump providing pressurized fuel to the injector, and a return fuel line from the injector to the low pressure side of the system. Engine power or injection delivery is controlled by regulation of the charging pressure or by the "skip fire" sequencing of injection events.

The advantages of this operating principle include the following:

1. High operating speeds can be attained, since injector charging occurs over a large portion of the engine cycle.
2. Injection timing is optimized at all speeds and loads with electronic control.
3. Skip-fire control provides part load combustion improvement.
4. Spray quality at starting and low engine speeds is maximized because injection pressure and duration are independent of engine speed.
5. A non-coalescing "expanding cloud" injection spray results from the decreasing injection rate during the injection event.
6. Injection can occur mechanically, for starting without electric power.

Direct Applications

This technology is applicable to all low cost gasoline fueled two-stroke engines. Applications include but are not limited to the following:

Utility Lawn & Garden	Mopeds	Snowmobile Engines
Personal Water Craft	Scooters	Portable Generators
Outbaord Marine Engines	Motorcycles	Aircraft

Applications Under Development

- Handheld Utility Engine (46cc)
- Moped (50cc)
- Motorcycle (125cc)

Emissions Reductions

The BKM direct fuel injection system has demonstrated that it is capable of reducing unburned hydrocarbon emissions by approximately 80% by eliminating the scavenging loss of fuel. Further reductions are feasible with the addition of a small oxidation exhaust catalyst.

1. Introduction

1.1. Scope and Purpose

This project has demonstrated a low emissions, small two-stroke engine designed for compliance with Air Resources Board (ARB) 1999 utility engine emissions requirements. This goal is being accomplished by developing and demonstrating an innovative and low cost fuel injection system applied to a small single cylinder two-stroke engine. The system will be feasible for serial production utility lawn and garden engines as well as motorbike and marine engines.

1.2. Background

Due to the light weight and simple construction of the two-stroke cycle gasoline engine, it has been instrumental in the development of the handheld power equipment industry, including applications such as lightweight chainsaws, string trimmers, hedge trimmers and blowers, as well as the two-wheeler transportation market. However, the exhaust emissions from conventional two-stroke engines are very high due to the basic design and operating principles of the engine. These engines produce from 10 to 15 times the levels of unburned hydrocarbons compared to four-cycle engines.

In November, 1991, the U.S. Environmental Protection Agency (EPA) completed the Nonroad Engine and Vehicle Emission Study in compliance with the Clean Air Act, section 213(a). According to the Nonroad Study, nonroad engines and vehicles contribute an average of ten percent of volatile organic compounds (VOC's) in the 19 ozone nonattainment areas included in the study. Small spark ignition engines are the source of half of those nonroad VOC emissions.

On December 14, 1990, the California Air Resources Board (CARB), approved a two-tier exhaust emission standard for small utility engines less than 25 horsepower. The first tier, which took effect in 1995, has been met by some manufacturers using refinements to conventional technology. Existing engines have demonstrated the 1995 emissions levels by lean adjustment to carburetion, improved tolerance control, porting modifications, carburetor quality control and adjustment restrictions.

In a conventional, carbureted two-stroke engine, the fuel air mixture is pumped into the cylinder during a portion of the cycle in which both the intake and exhaust ports are open. The primary activity during this portion of the engine cycle is the scavenging, or removal of combustion byproducts from the previous engine cycle. This process results in the loss of approximately 30% of the fuel, which escapes out the exhaust port prior to ignition. This loss of both fuel and fresh air is referred to as "scavenge loss". Figure 1 illustrates the scavenge loss of a contemporary two-stroke utility engine.

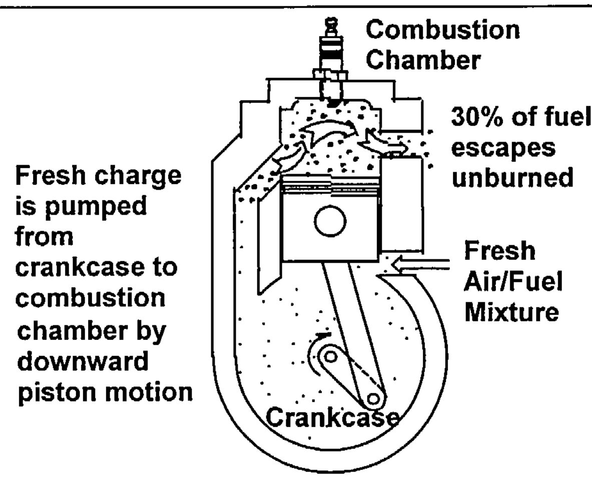


Figure 1 - Two-stroke Engine Scavenging Loss

The high level of exhaust emissions and poor fuel economy typical of small piston ported two-stroke spark ignited engines mandates the need for improved combustion over the operating range of the engine. Direct, in-cylinder injection has been demonstrated to significantly reduce unburned hydrocarbon emissions by timing the injection of fuel in such a way as to prevent the escape of unburned fuel from the exhaust port during the scavenging process.

Research, by Sato and Nakayama of Fuji Heavy Industries (1), Nuti from Piaggio (2), Plohberger et al from AVL (3) Kuentscher from University of Engineering, Zwickau (4) and Heimberg of FICHT GmbH (5), has provided confirming data to support the use of direct injection to improve two-stroke emissions and fuel consumption. These research programs generally applied high pressure liquid fuel injection systems similar to those used by diesel engines, but modified to produce small droplets of gasoline. The fuel injection systems applied in these research programs are cost prohibitive for small low cost engines due to the sophistication and complexity of the hardware and control system. Nevertheless, the data supports the technical merits of the fuel injection concept. Sato and Nakayama of Fuji Heavy Industries reported an 87% reduction in unburned hydrocarbons using this technique. Nuti reported similar results. The Servojet Common Rail fuel injector developed by BKM is another alternative and is described in United States Patent No. 4,628,881 "Pressure Controlled Fuel Injection For Internal Combustion Engines". In addition, Orbital Engine Company of Australia has developed an injection system that requires the addition of compressed air injection control to help atomize a low pressure injection of fuel. The cost and complexity of this system may be unreasonable for low cost utility and moped/motorcycle engines. Illustrations of these various research systems are shown in Figures 2 through 7.

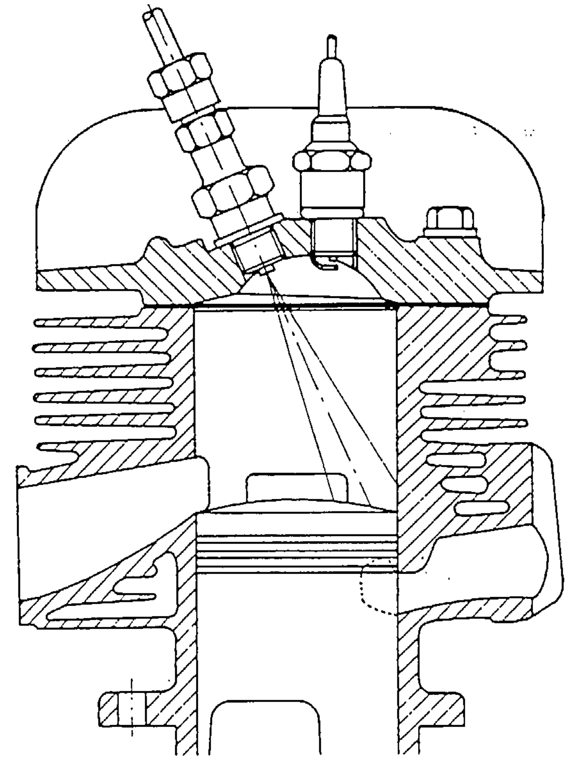


Figure 2 -- Gunma University Research System

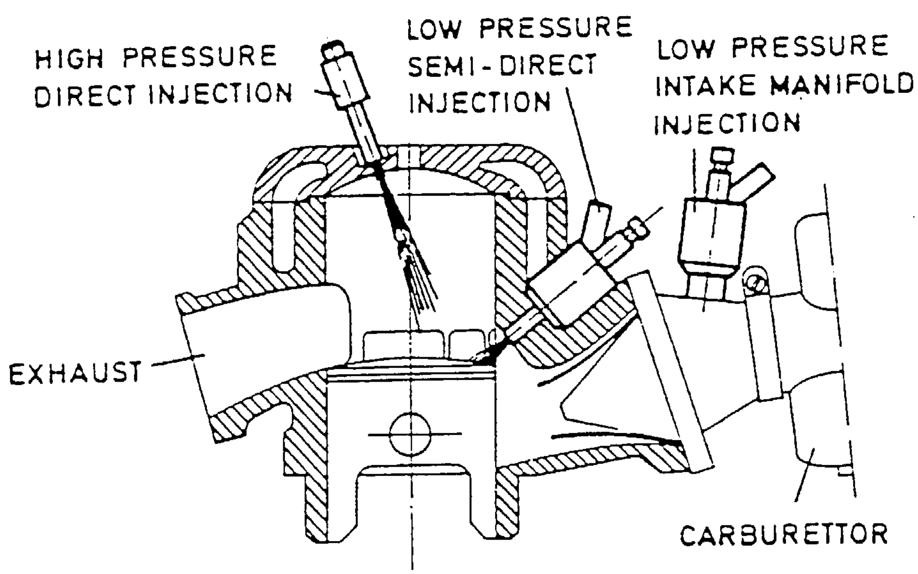


Figure 3 - AVL Research System

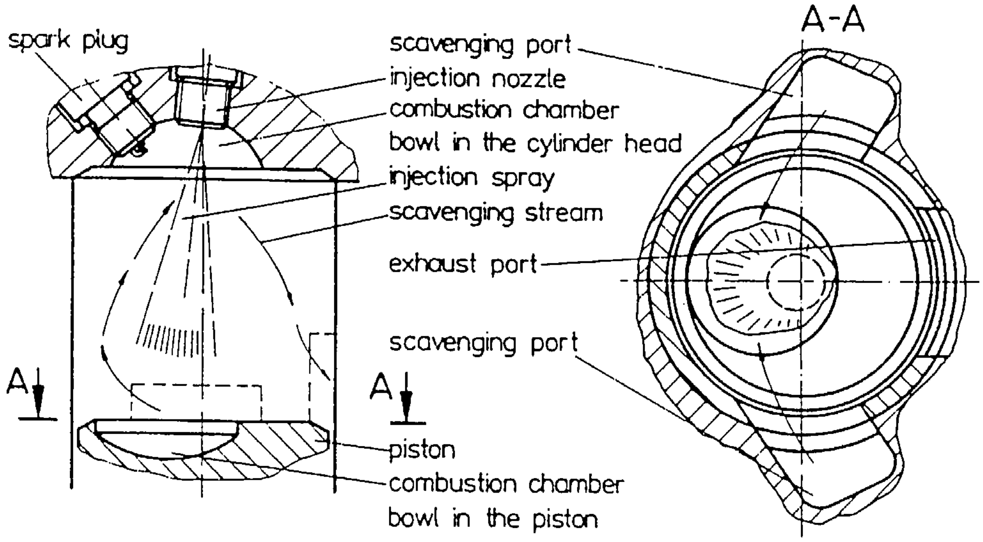


Figure 4 - Zwickau (GDR) University Research System

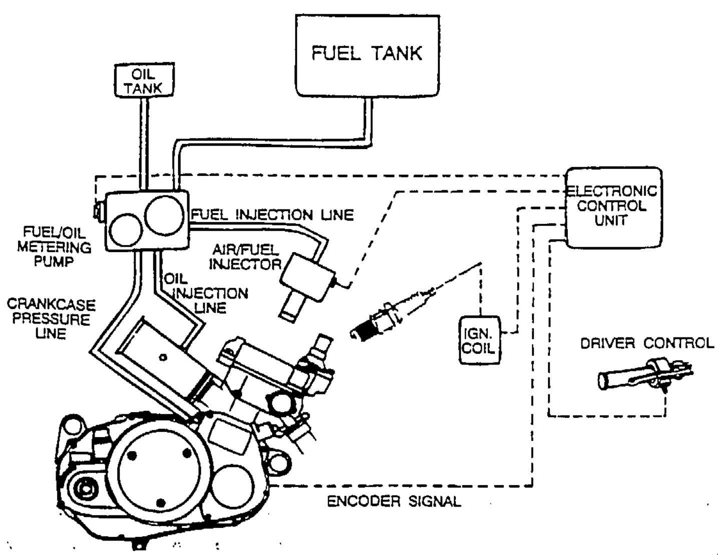


Figure 5 - Orbital Fuel Injection System

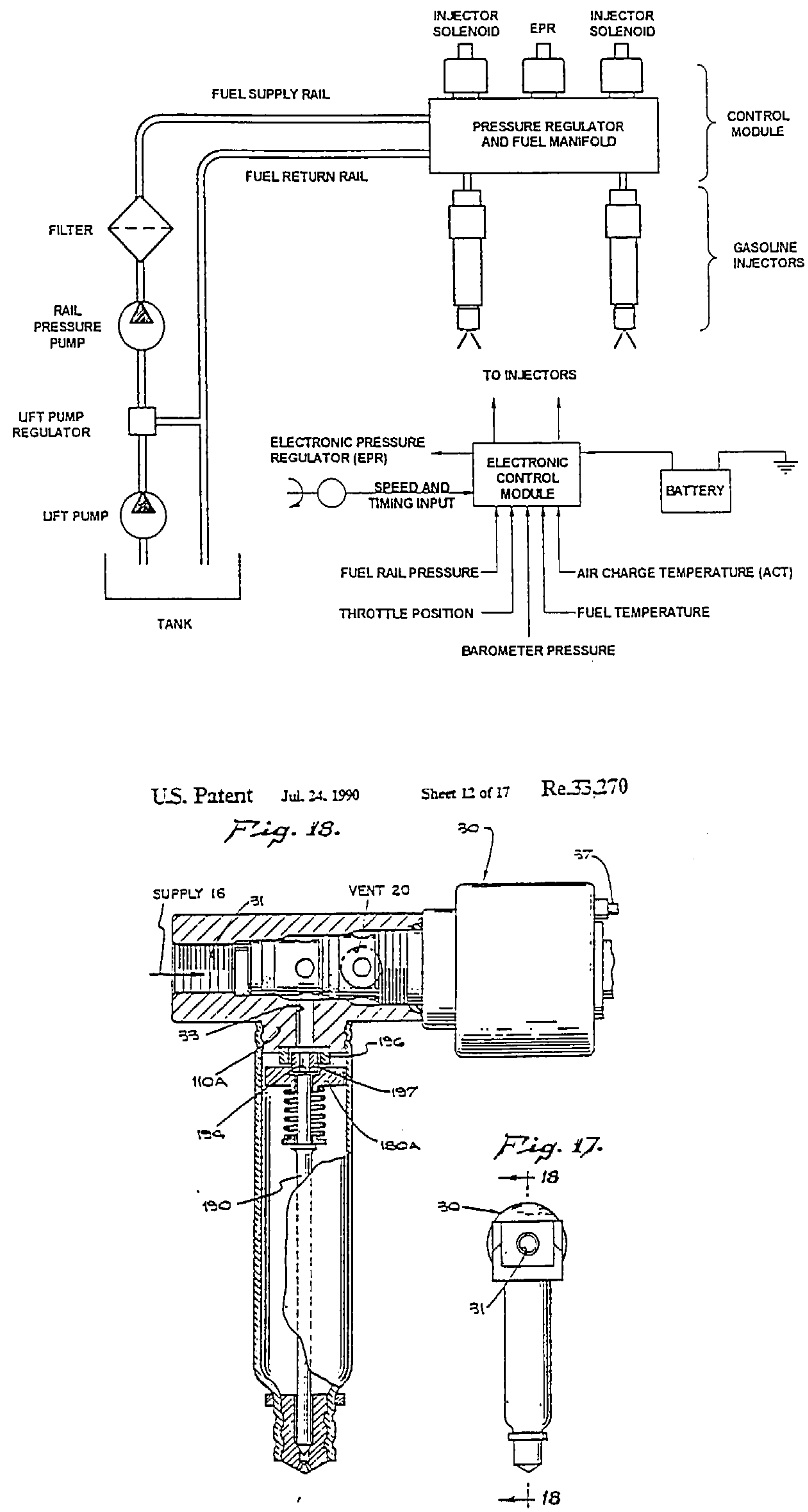


Figure 6 - BKM Common Rail Fuel Injector and System

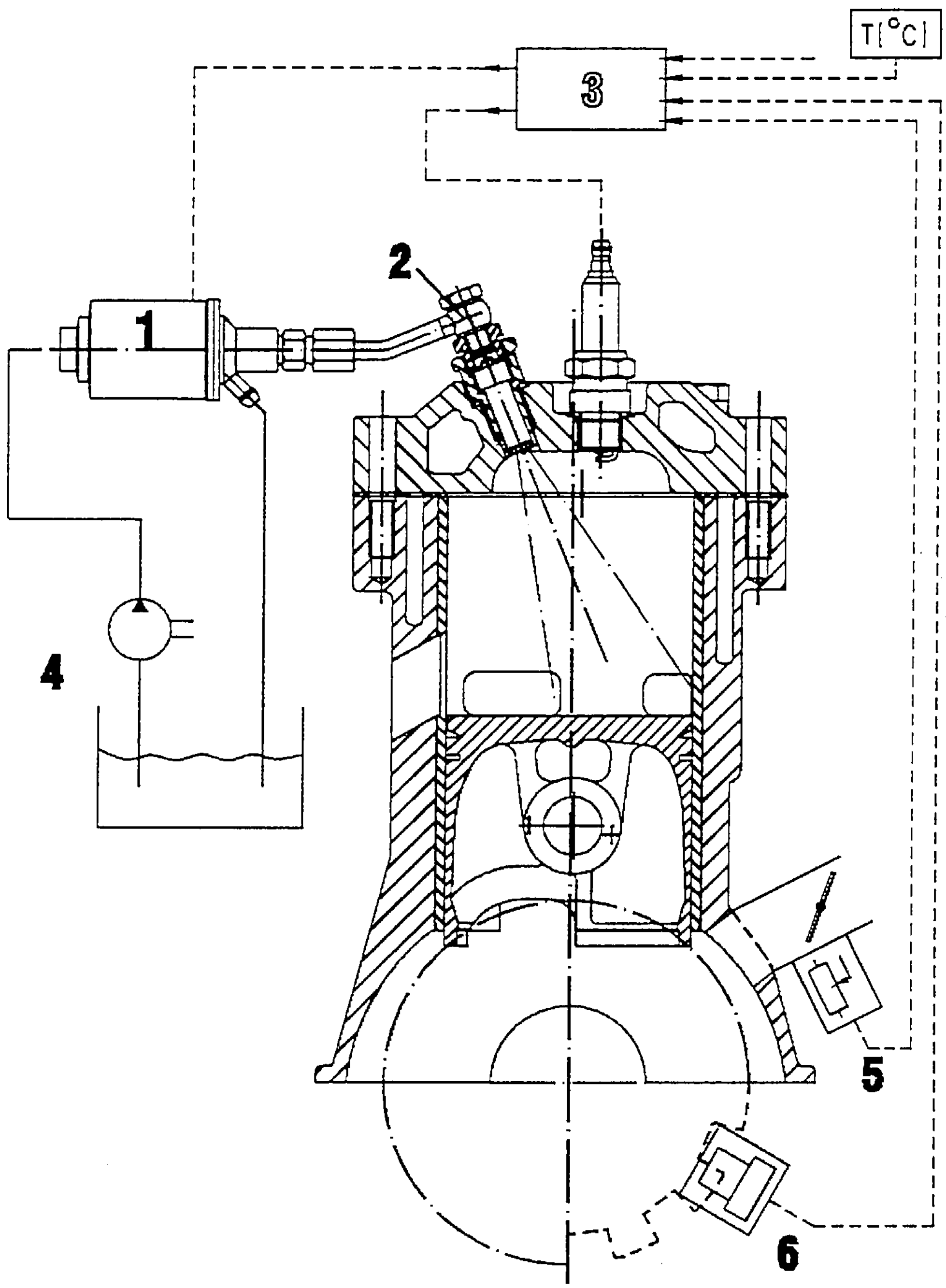


Figure 7 - Ficht Fuel Injection System

Figure 8 illustrates the typical relationship between exhaust emissions and the air/fuel ratio, defined by the excess air factor lambda (λ). Lambda is the ratio between actual air/fuel ratio and stoichiometric air/fuel ratio. Stoichiometric air/fuel ratio is the theoretically perfect ratio for most efficient and complete burning. Lambda less than 1.0 is a rich mixture and lambda greater than 1.0 is a lean mixture.

$$\lambda = \frac{(Air / Fuel)_{actual}}{(Air / Fuel)_{stoichiometric}}$$

In a naturally aspirated engine such as the low cost two-stroke, air supply is dependent on the piston motion and engine power is proportional to the amount of fuel burned. Therefore, a rich mixture increases power and a lean mixture reduces power.

As shown in Figure 8, most contemporary two-stroke engines operate in the range of 0.70 to 0.75 lambda in order to optimize power and reduce combustion temperature. Unfortunately, this condition results in very high CO emissions as well as adding to the already high unburned HC emissions. The Oxides of Nitrogen (NOx) emissions however, are very low due to the low temperature of this rich combustion mixture.

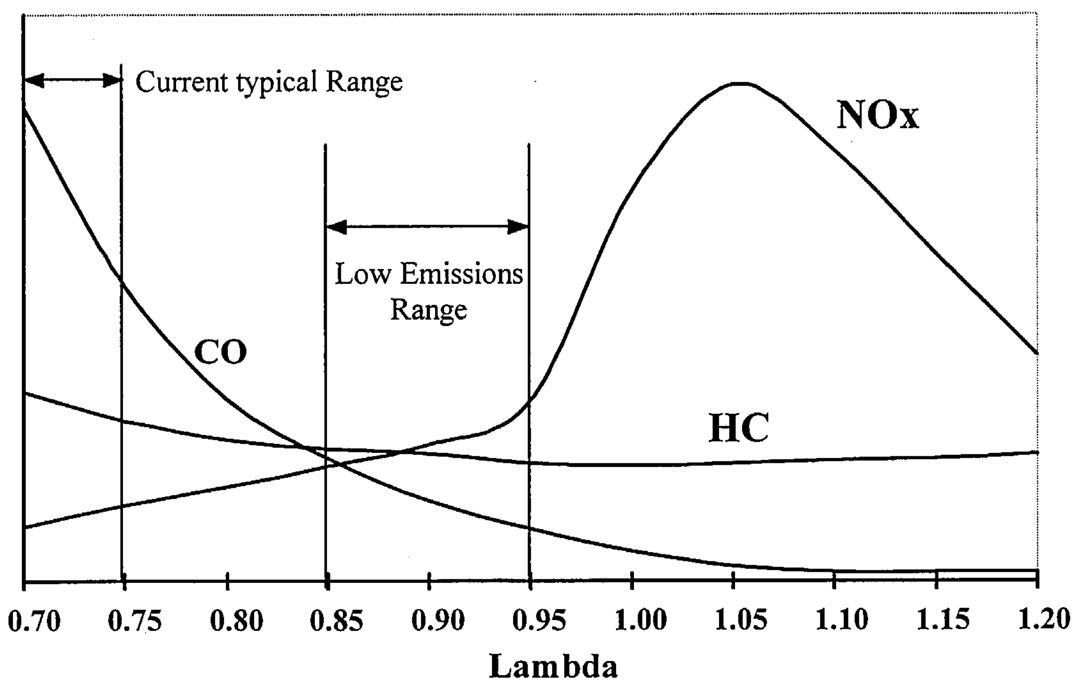


Figure 8 - Influence of Excess Air Factor, Lambda, on Emissions

Exhaust emissions can be minimized if lambda is very lean (greater than approximately 1.5). Such lean air/fuel ratios may be achievable using direct injection of fuel as proposed. However, without additional air charge boosting, maximum engine power is reduced to an unacceptable level. In the range of lambda 0.85 to 0.95, emissions can be minimized without significant power loss. It has been demonstrated that the combination of in-cylinder fuel injection (reduced scavenge loss) and operation in this air/fuel ratio range (λ=0.85-0.95) results in emissions levels within the range of CARB regulations for small two-stroke utility engines.

Compounding the basic two-stroke inefficiencies described above, it is normal for crankcase scavenged two-stroke engines to misfire at part load. Part load operation of spark ignited engines involves reducing both the fuel flow and throttling the air flow through the engine in an attempt to maintain an ignitable, stoichiometric air/fuel mixture. Misfire at part load in a two-stroke engine is caused by the presence of residual exhaust gas, degraded scavenge efficiency and resulting degraded air/fuel ratio control. This part load misfire contributes greatly to added unburned fuel emissions and increased fuel consumption. Both Sato and Plohberger presented data confirming that direct in-cylinder injection alone did not solve this part load misfire problem.

The dynamic fueling range is another challenge for small engine fuel injection equipment. The fuel injector must accommodate both the full load fueling rate, as well as the minimum fueling rate required to idle the engine. A major difficulty with conventional fuel injection concepts for small two-stroke engines is the inability to provide precise well-atomized fuel sprays at these very small fuel deliveries, particularly as fuel consumption and emissions are reduced. These required idle fuel deliveries can be as low as 1.0 cubic millimeter of gasoline per engine cycle.

1.3. Technical Approach

A cost effective hardware concept and control method has been devised to operate low cost two-stroke spark ignited engines, which are fueled by electronically actuated accumulator type fuel injectors. This system is referred to as a Single Plunger System (SPS) to differentiate it from the contractor's previous Common Rail System (CRS) development for multi-cylinder engines. During the project, the injection system hardware has been dramatically simplified compared to existing concepts, for compatibility with small engine market requirements. Prior to the ICAT program, BKM was granted U.S. Patent Number 5,438,968, which completely describes this low cost fuel system solution. In addition, BKM has been instrumental in the design and development of small two-stroke engines for the outdoor power equipment industry, under contracts to original equipment manufacturers. Combining these two areas of experience was a natural motivation for this program and has already resulted in demonstrable benefits for the small two-stroke engine.

1.3.1. Injector Operation

The BKM SPS electronic gasoline injector consists of three elements:

1. Solenoid valve
2. Accumulator
3. Nozzle tip

These elements are shown schematically in Figure 9.

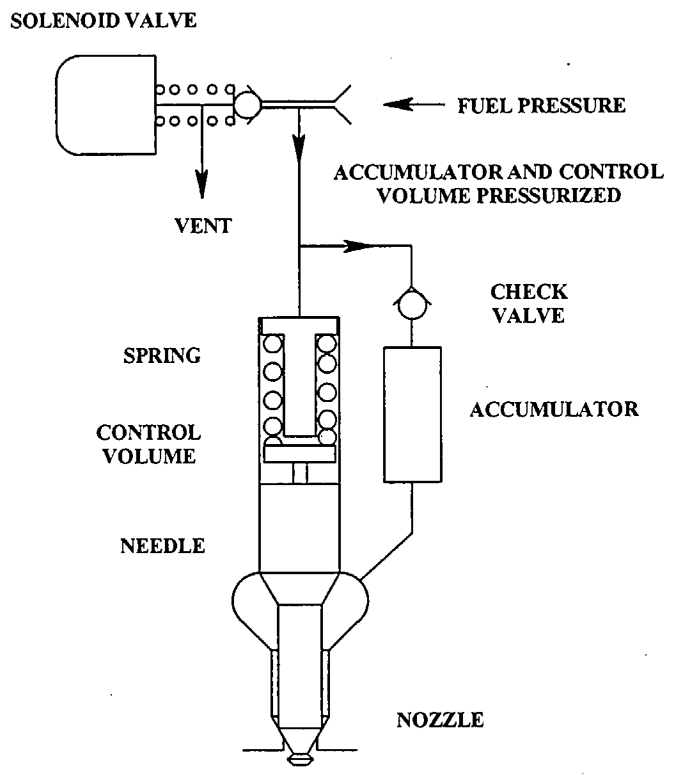


Figure 9 - Injector Schematic

Fuel pressure is provided to the injector by means of a single plunger pump, integrated into the engine design and timed to the engine cycle. Due to the compressibility of the fuel, the mass of fuel in the accumulator increases as the accumulator pressure increases. When the accumulator pressure and inlet fuel pressure equalize at the maximum inlet pressure value, a check valve at the accumulator entrance closes, thereby trapping high pressure fuel within the accumulator. The solenoid valve is the interface between the injector and the electronic controller. When the solenoid is energized, pressure on top of the needle valve is vented, and a pressure imbalance is produced across the needle valve, which lifts the needle and opens the nozzle tip to the fuel stored in the accumulator.

Injection takes place until the pressure in the accumulator drops to the needle valve closing pressure, preset by spring force. Injection duration depends only on total nozzle flow area and the pressure drop from peak pressure to needle closing pressure. The hydraulic system includes a single plunger pump providing pressurized fuel to the injector, and a return line from the injector to the low pressure side of the system. Engine power or injection delivery is either controlled by the regulation of the rail pressure or by the "skip-fire" sequencing of injection events. For pressure regulation, a portion of the pump plunger motion is wasted by holding the solenoid valve open longer than necessary from the previous injection event, thereby limiting the pressure buildup to a calibrated value based on solenoid valve timing. This patented control method provides for both injection timing as well as injection quantity on a cycle-by-cycle basis. The injector charging event and control by pressure regulation are illustrated in Figure 10.

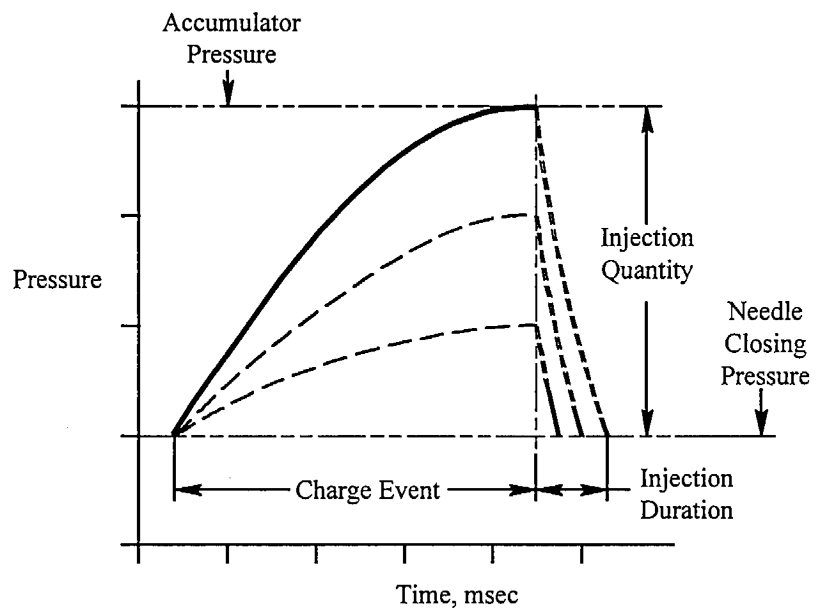


Figure 10 - Injector Charging and Pressure Metering

As mentioned above, the "skip-fire" sequencing of injection events can be used for control purposes. In its basic form, skip-fire is also used to provide improved combustion efficiency at part load operation. In this demonstration program, skip-fire has been limited to provide improved efficiency at idle only, with good results.

The SPS injector spray characteristic produces very small droplets of gasoline, which promotes good fuel and air mixing and consistent combustion. These small droplets are maintained by means of non-uniform velocity with respect to time, as illustrated in Figure 11. The first droplets leaving the nozzle have the fastest injection rate, followed by progressively slower rate droplets. BKM refers to this non-coalescing spray characteristic as "expanding cloud" fuel injection. The result is a finely atomized spray and optimized mixture preparation.

Advantages of this operating principle include the following:

1. High operating speeds can be attained, since injector charging occurs over a large portion of the engine cycle.
2. Injection timing is optimized at all speeds and loads with electronic control.

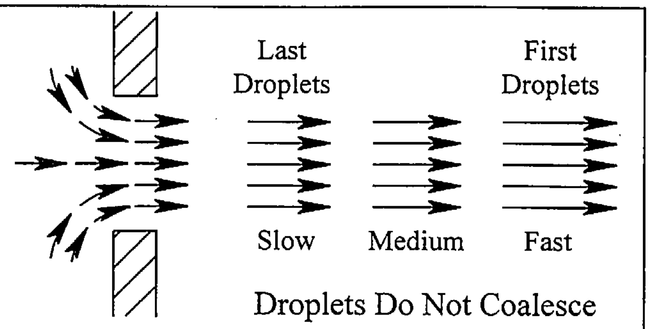


Figure 11 - Droplet Velocity

3. Skip-fire control provides part load combustion improvement.
4. Spray quality at starting and low engine speeds is maximized because injection pressure and duration are independent of engine speed.
5. A non-coalescing "expanding cloud" injection spray results from the decreasing injection rate during the injection event.
6. Mechanical starting, without electricity, has been provided by including a control volume venting passage which opens as the cam driven plunger reached its lowest position. Venting with the electronic solenoid valve prior to this mechanical opening provides direct electronic timing control.
7. Cycle-by-cycle control of fuel delivery and injection timing.

An overall scheme of the fuel system is illustrated in Figure 12.

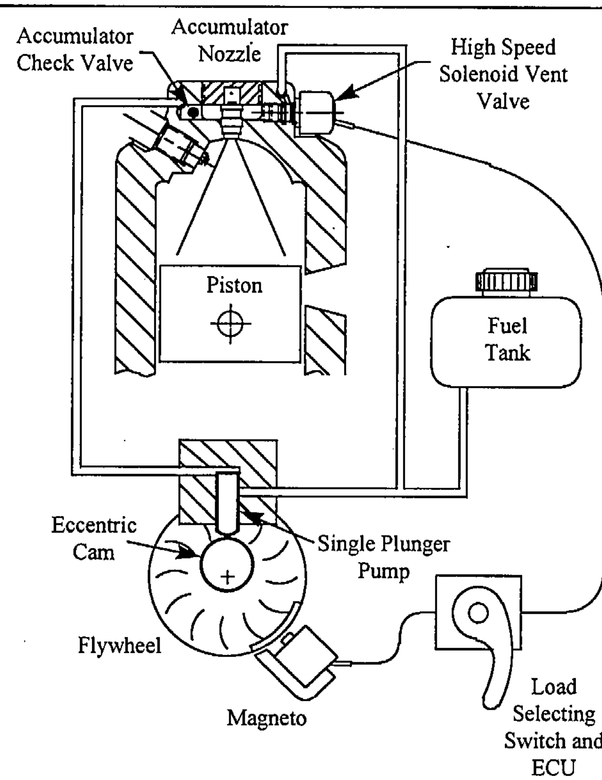


Figure 12 - Single Plunger System (SPS) Configuration

2. Materials and Methods

The program was divided into the following tasks:

1. Bench Test and Development of Major Components
2. Design the Prototype Development Engine
3. Development of sensors, controls and software
4. Prototype Manufacturing
5. Test Planning and Setup
6. Performance and Emissions Optimization
7. Durability and Emissions Degradation Testing
8. Reports / Meetings

2.1. Bench Test and Development of Major Components

2.1.1. Fuel Injection System

System concept design included the definition of basic fuel injector and pump components as well as variations to be evaluated, such as methods to control injection quantity. Another alternative related to the ability to initiate injection hydromechanically for starting. In each case, these design alternatives offer advantages and disadvantages which were evaluated.

An injection system bench test rig was designed and constructed for the functional development and parametric studies of injector and pump system. The objective of this unit was to provide a flexible test rig capable of determining the optimum placement of components, the advantages and disadvantages of design configuration variables, as well as establishing design criteria for the sizing, timing and tolerances to be used for subsequent engine design. Some of the design configuration variables were discussed above. Additional alternatives which merit study, such as the location of the injector solenoid valve related to the nozzle, were included in the design of this flexible test rig.

A schematic for this injection system test rig is illustrated in Figure 13. The detail design, including cam drive and solenoid valve location alternatives, is shown in Figures 14 and 15.

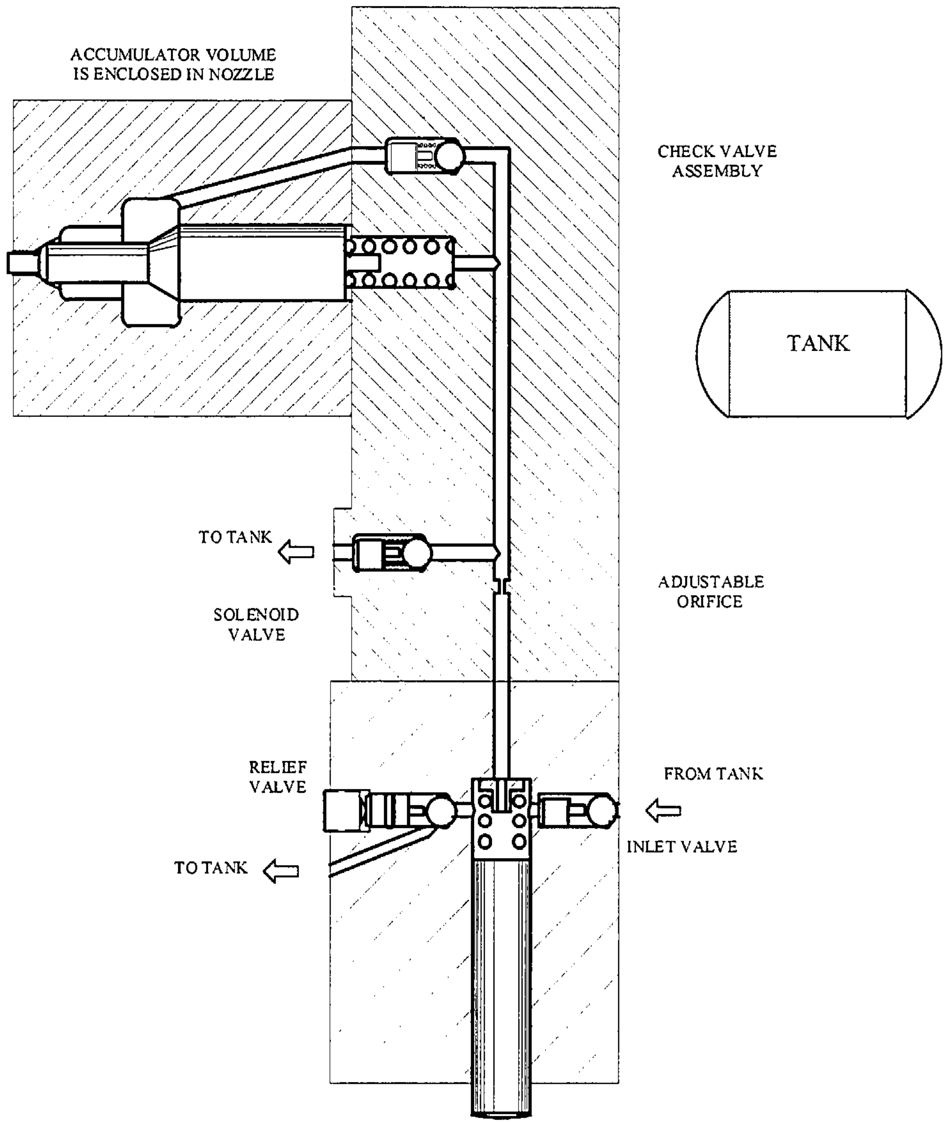


Figure 13 - Fuel Injection Bench Test Schematic

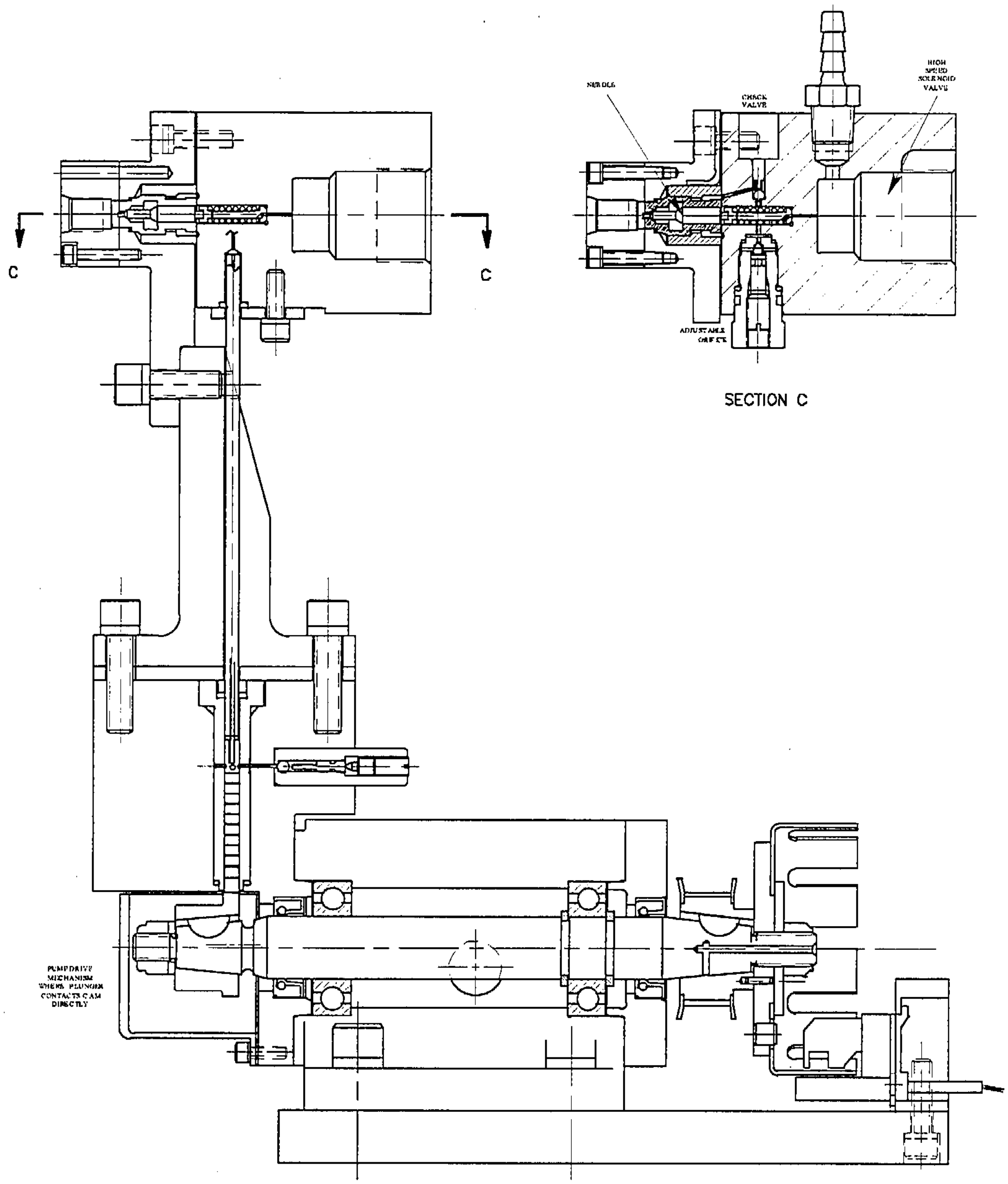


Figure 14 - Fuel Injection Bench Test Rig Design

A series of pump operational tests were conducted on the fuel system bench test rig. Results were encouraging, as the cycle-to-cycle peak pressure appeared to be controllable by a pressure relief valve as planned. These tests were conducted with the fuel lines to the injector blocked, to isolate the pump evaluation from the rest of the system. Problems with the inlet check valve, air entrainment (priming problems) and miscellaneous leaks were incurred and either corrected or compensated for, with solutions proposed for future design activity.

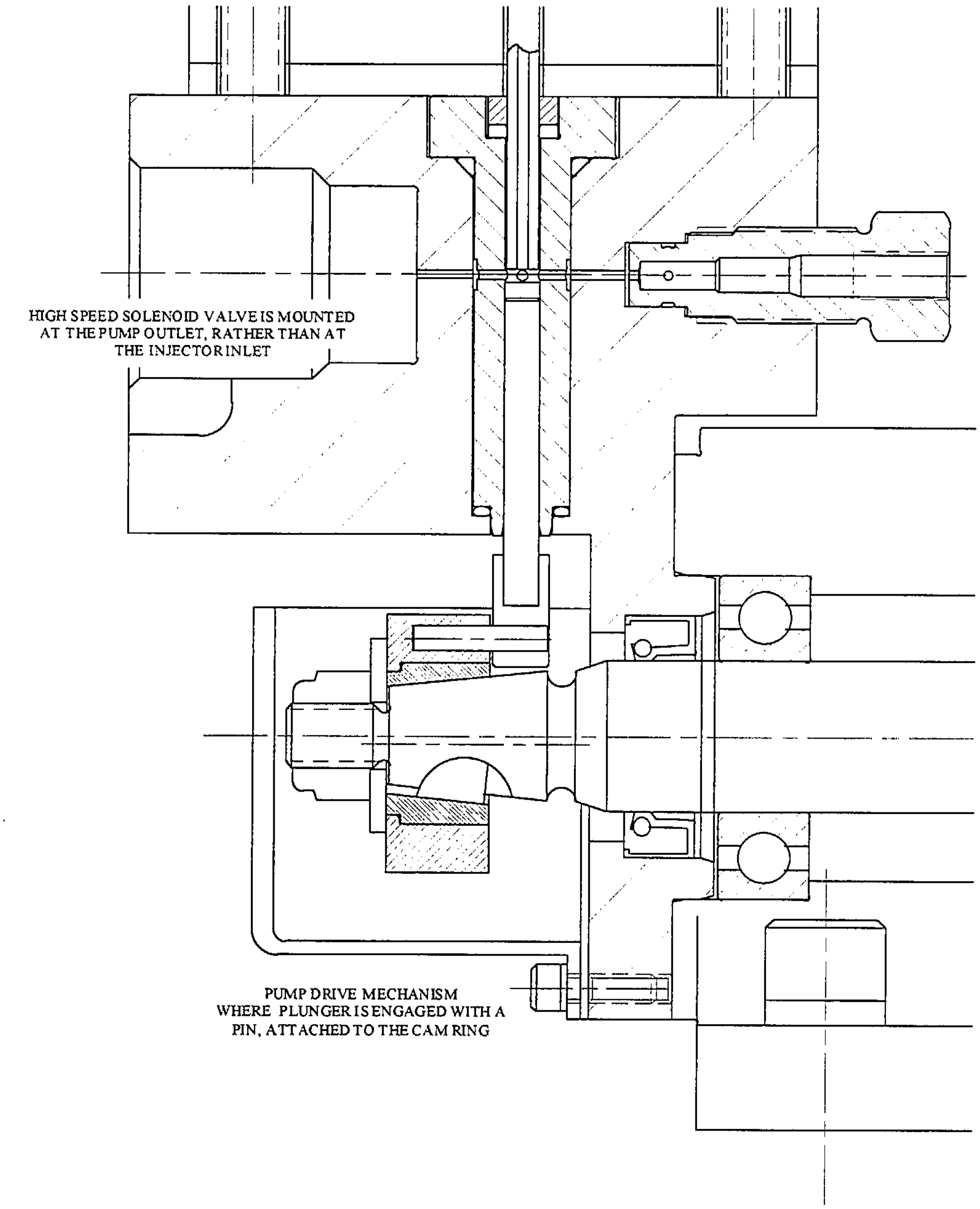


Figure 15 - Alternative Cam Drive Design and Solenoid Valve Location

The system successfully demonstrated injection of fuel under engine starting conditions as well as high speed operation. Initial design changes were incorporated and retested relating to cam and plunger durability improvement and cost reduction. Four areas of required development were identified and have been addressed in subsequent engine design activity.

1. The sensitivity of the adjustable peak pressure control regulator indicates that peak injection pressure control and therefore injector calibration will be difficult to achieve consistently with the current design. A less sensitive pressure relief valve design could be developed by revising the relief valve spring rate, seat area and the adjustment thread pitch. However, the need for rapid, cycle to cycle fuel delivery adjustment emphasized by commercial project partners has led to a revised fuel quantity control strategy using the existing solenoid valve. In this strategy, a portion of the pump plunger motion is wasted by holding the solenoid valve open longer than necessary from the previous injection event, thereby limiting the pressure buildup to a calibrated value based on solenoid valve timing. This revised strategy was subsequently patented and incorporated in the control design.

2. The prototype solenoid valve appeared to stick open and fail to close under some operating conditions. This problem has been resolved by revised electronic driver circuit design and was determined not to be a solenoid valve hardware issue. However, detail setup dimensions for the valve, such as spring pre-load, were determined to be critical for consistency of operation.

3. Priming the system with the original design of fluid passages proved to be unacceptably difficult. The addition of a check valve at the pump outlet provided self-priming capability and was also been incorporated in the subsequent engine application design.

4. The addition of the self-priming check valve eliminated an important feature required for starting engines without the need for battery power. To compensate for this loss, an alternative hydromechanical starting feature requiring drilled holes in the pump housing was incorporated in the engine application design.

In order to prevent undue delay in the engine application design as well as risk to the project budget, the improvements proposed to the bench test injection system rig were incorporated directly into the test engine design for validation during subsequent engine testing.

2.1.2. High Speed Solenoid Valve

The high speed solenoid valve and a breadboard driver circuit for injector activation was designed in prototype form for development testing. Sample prototype valves were manufactured for testing. For this design, the following specification was developed:

Type	-	2-way normally closed
Rated pressure	-	14 MPa (2,000 psi)
Minimum Flow Area	-	0.5 mm^2

Function	-	Accumulator injector vent
Liquid compatibility	-	Gasoline
Life expectancy	-	4.0×10^8 cycles
Timing precision	-	± 25 microseconds
Response time	-	Less than 2.0 milliseconds
Operating frequency	-	10 to 250 Hz
Voltage	-	12 VDC
Power requirement	-	Less than 8 watts at 5 % duty cycle
	-	Less than 50 watts at 30% duty cycle
Storage temperature	-	-50 to + 105 °C
Operating temperature	-	-40 to + 200 °C
Mechanical shock	-	100 g
Mechanical vibration	-	50 g at 5 to 200 Hz
Humidity	-	100 %
Cost, including royalties (production rate greater than 500,000 units/year)	-	Less than $4.50

An instrumented test block was manufactured to allow testing with hydraulic pressure applied. Results of this initial test were encouraging as the frequency capability of the valve exceeded 300 Hz, which was faster than required for injector operation.

As previously discussed, the solenoid valve appeared to stick in the open position as well as fail to completely close under some injector operating conditions. The problem was symptomatic of an electronic driver circuit problem, which resulted in revised component specifications in the circuit design. Subsequent testing did not indicate continuation of the problem.

After initial functional testing, additional tests were conducted to study total energy consumption requirements for coordination with alternator power generation specifications and development testing targets. In addition, the revised fuel delivery control strategy previously mentioned warranted further study of valve opening and closing accuracy and delay periods. These tests were subsequently conducted with satisfactory results.

2.1.3. Lubrication System

Two different lubrication concepts were evaluated.

1. For the lowest cost handheld engines, a venturi effect system was considered. This calibration involved determining a proper size inlet orifice between the oil supply sump and the engine intake air passage. A simple, low opening pressure check valve was placed in the oil supply line between sump and venturi. This system was similar in concept to the basic fuel control concept of a carburetor. The fuel injected project engine, based on an existing 46cc Tanaka brush cutter engine, was equipped with this lube oil system and calibrated for the required oil flow during subsequent engine testing.

2. In the case of motorbike or marine engines, several candidate engines for fuel injection already utilize a separate oil injection pump and oil reservoir. For these engines, no further design integration activity is anticipated other than calibrating the pumps for minimum oil flow rate requirement. This will be an engine specific calibration and will be delegated to individual engine builders.

A small, potentially low cost model of the oil injection pumps found on the more sophisticated engines was eventually identified. This pump is currently used on a 25cc Kioritz utility engine produced for applications in Japan. Coordination with the vendor Mikuni and Walbro have resulted in identifying the models applicable for these handheld utility engines and samples were obtained. A design to integrate this pump into the Tanaka prototype fuel injected engine was completed.

2.1.4. Electronic Control Unit (ECU)

During the preliminary work on this project, prior to the CARB ICAT contract, a developmental circuit board had been designed. In the course of the ICAT program, revisions to controller specifications related to control strategy resulted in reconsideration of the controller design. In addition, a more conservative approach to providing a controller in the early stages of fuel system development resulted. In order to accelerate availability of a development controller and to concentrate on software calibration and validation, a decision was made to conduct initial testing with an existing, commercial multi-cylinder engine controller designed specifically for control flexibility and laboratory calibration. In parallel with the calibration development using this large ECU, a new prototype small engine ECU was designed. This design activity was initiated by reviewing the cost and performance trade-off of several candidate microprocessors.

Another aspect of the overall ECU design was the driver circuit for the two-way latching solenoid valve developed for the fuel injector actuation. A breadboard version of this driver circuit was developed and used successfully for operation of the solenoid valve. It was also used:

a) for optimization of component sizing, such as the capacitors used to magnetize and de-magnetize the latching solenoid
b) to develop turn-on and turn-off dwell times for minimum energy consumption
c) to establish compatibility with "alternator only" variable voltage electrical supply.

2.1.5. Electrical Power Generator

Attempts were made to take advantage existing flywheel mounted ignition system magnets as a potential energy source for providing power to the ECU and solenoid valve. Several iterations of simple coil and core assemblies were constructed and tested using the 46cc test engine flywheel magnets. In all cases, electrical power generation fell far short of the estimated requirement.

A small alternator assembly using a full circle magnet group and tailored to fit on small engines was obtained for evaluation. This alternator was adapted to a variable speed test rig for initial fuel system and solenoid driver circuit development and also adapted to the prototype engine design. The alternator provided up to 90 watts of power at 10,000 rpm. In conjunction with solenoid and solenoid driver circuit design, it was determined that the minimum alternator speed to activate the solenoid was approximately 2,500 rpm. This performance was compatible with the 3,000 rpm 3,000 rpm idle speed for the prototype engine. Note that the fuel system design still allows for engine starting without activation of the solenoid valve. Although this alternator provides a comfortable margin compared to the predicted high speed power consumption, the minimum speed to provide solenoid actuation power is considered the critical factor.

The test alternator is self contained, including a steel cup used to house the circular magnet group. It is anticipated that this magnet group may also be integrated into the flywheel design on production design applications. Value engineering to minimize coil windings, core mass or magnet group strength will be postponed until all other system functions are validated.

2.2. Design the Prototype Development Engine

A decision was made early in the project to consider basing the prototype engine design on an existing production engine in order to maximize the use of available parts not related to the fuel system integration. Evaluation of possible engine types revealed that the handheld utility engines presented the largest number of challenges. A decision was made to answer these challenges by selecting this engine type. These challenges include the lubrication system, as most other engine types already use oil delivery pumps, and the electrical power generation system, as several other applicable engines already use battery systems with recharging alternators. Although these recharging alternators may require size increase to add power capacity, the constant voltage output of the battery is not as severe a challenge for the fuel system control design as the variable voltage output of a simple alternator. A Tanaka 46cc engine was selected for the prototype design basis.

The prototype fuel injection and ancillary systems design was competed for this 46cc utility engine. Key views extracted from the design layout are shown in Figures 16 thru 18. The lower, crankcase section of the engine includes installation of the alternator, cam driven fuel injection pump and a crankcase pressure pulse driven fuel transfer pump. Several iterations of the fuel injector design were evaluated for cost and size comparison. The features evaluated in these designs include number of parts, number of machined surfaces (including lapped surfaces for high pressure sealing), spring design and ease of assembly.

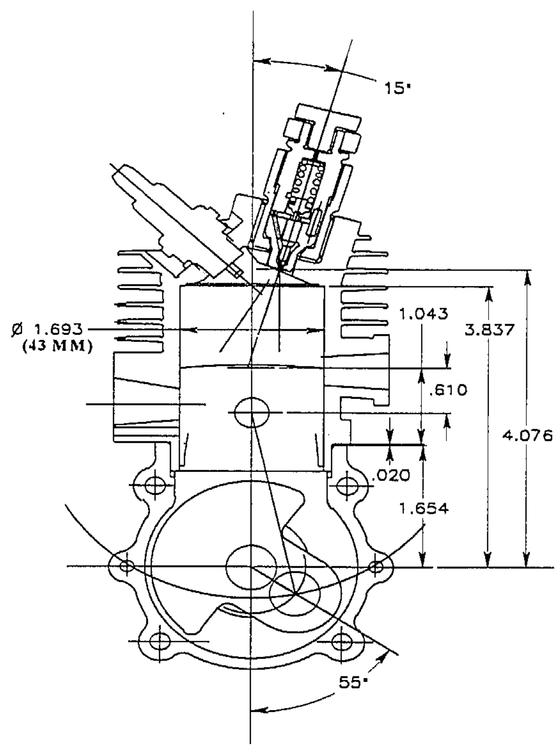


Figure 16 - Cross Section Through Engine and Injector

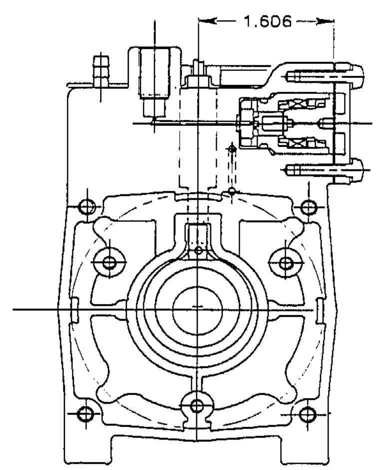


Figure 17 - Cross section Through Cam and Solenoid Valve

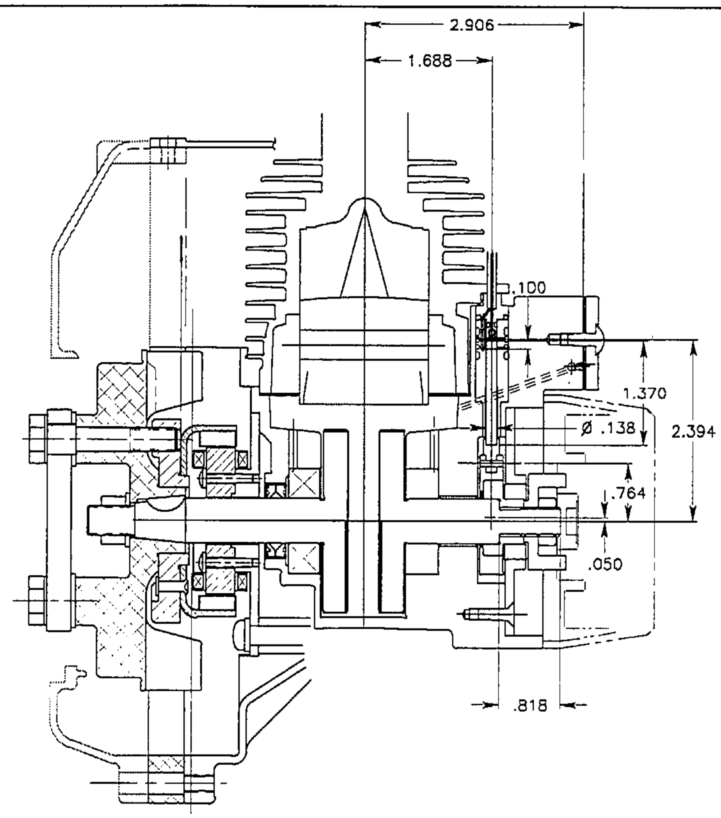


Figure 18 - Cross Section Through Crankcase, Flywheel, Alternator and Pump

Two separate analytical tools were developed to provide engine builders with a design tool as well as to assist with evaluation of development testing results. These programs will be transferred to system licensees as a design aid to various engine configurations. The following is a description of both calculations.

1. A static, preliminary calculation was created in the form of a spreadsheet (Microsoft Excel) which includes all major dimensions, volumes, spring settings and so on which determine injector calibration and performance. This is a very handy tool for establishing and verifying initial design details for the injector. The variable values which can effect the injector output, duration and pressures can be selected within practical ranges.

2. A dynamic injection system simulation program was created to aid in the determination of design arrangement and dimensions for the specific engine to be tested. This FORTRAN based program results in time based graphical results of pressures, motions and flow rates for critical areas within the system. This tool is extremely valuable for predicting injector performance and for identifying potential imperfections in system design or operation prior to fabrication and testing. Sample outputs from this program are shown in Figures 19, 20 and 21 for a fuel delivery and injection timing sensitivity study.

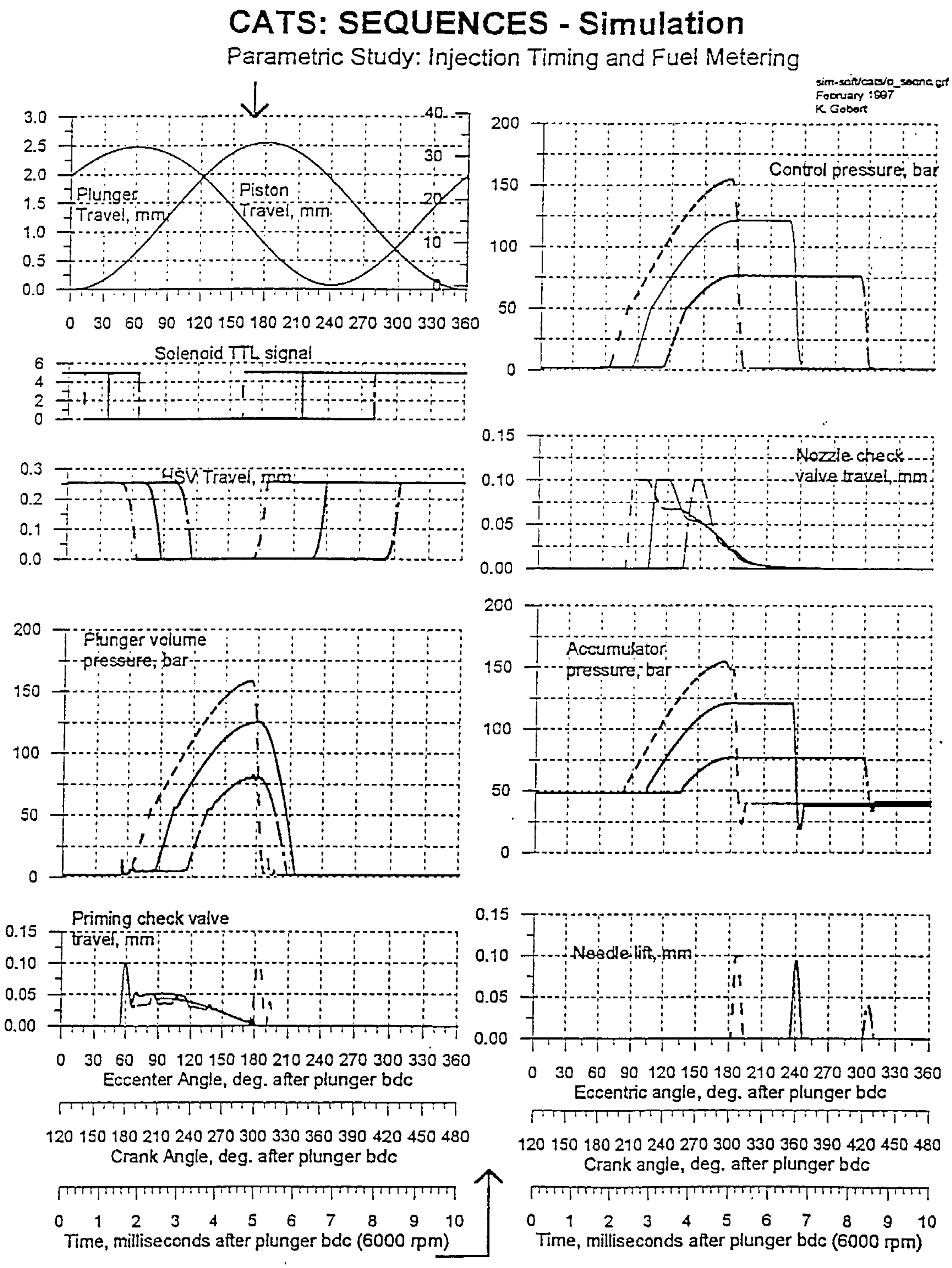


Figure 19 - Parametric Study: Injection Timing and Fuel Metering

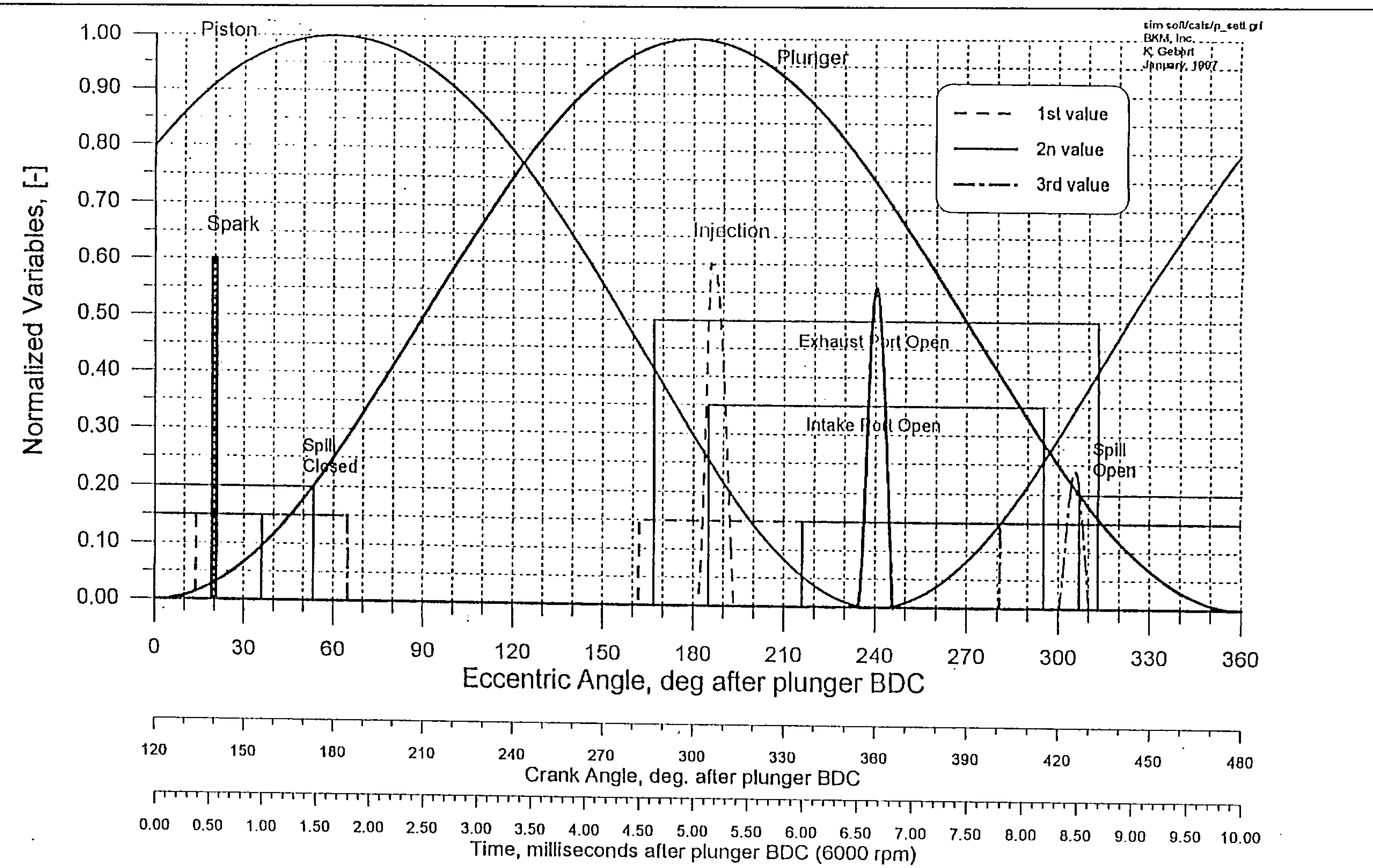


Figure 20 - Setting and Control: Parametric and Sensitivity Study

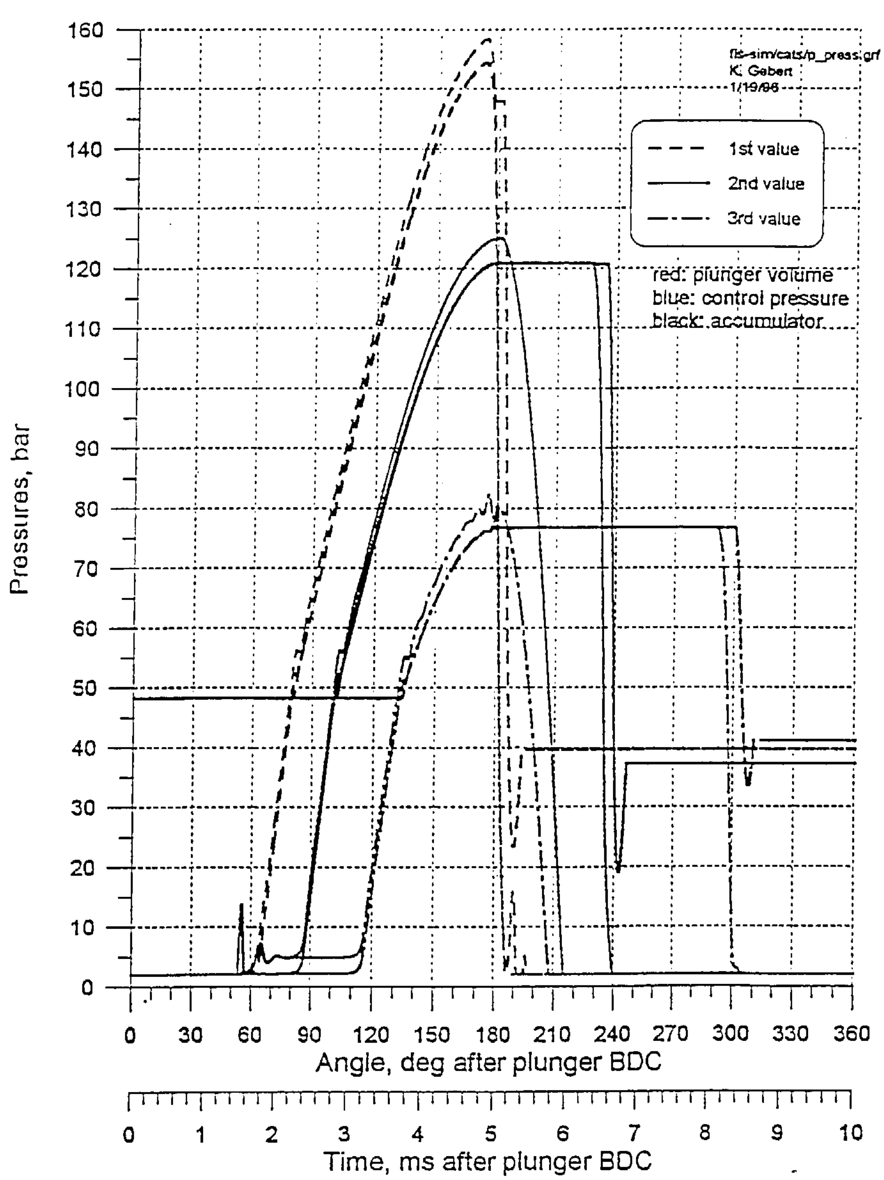


Figure 21 - Pressure Histories: Parametric Study

In addition to the design activity, an extensive market survey was completed. This report will assist with future commercialization activity. The survey involved collecting technical information worldwide regarding utility engine specifications and application details in order to assist in the prioritization of marketing opportunities for the low emission two cycle engine. A summary of this market survey is included in Appendix A.

2.3. Development of sensors, controls and software

As previously discussed, the development and demonstration testing of the fuel injection system will be controlled by a commercially available laboratory ECU with flexible calibration features. The design of a prototype, small single cylinder ECU based on low cost components was competed. A "wire wrap" or non-printed circuit board version of this controller was constructed for design validation. Adequate interface software was generated for validation of ECU function and for diagnostic purposes. The development of this ECU involved considerably more effort than presented in the ICAT proposal, partly due to the change in solenoid valve type and fuel delivery control strategy introduced after initial design activity. As a result, actual engine operation software was not completed within this program. BKM will continue with the development of this software and hardware subsequent the ICAT schedule. The availability of the commercial laboratory controller for calibration and demonstration removed the urgency to complete this production intent controller.

Sensors for engine speed and position, throttle position, engine temperature and barometric pressure were identified and coordination meetings with vendors were conducted. During fuel system development, standard available components were used, as vendors were understandably reluctant to invest in engine specific sensor tooling prior to production commitments. Discussions indicate, however, that the sensors may be value engineered for size and cost pending results of the program and commercialization activity.

2.4. Prototype Manufacturing

Drawings for major engine and fuel injector parts were completed and released for manufacturing. The commercial partner Tanaka provided crankshaft assemblies and completed engine cylinders with injector mounting provisions. The crankcase casting was produced by a California prototype casting firm and machined by the contractor. Most machined components for the injection system were produced by BKM. The injector nozzle assemblies, which require specialized tools for grinding were coordinated with both domestic and overseas vendors. Spare parts were manufactured or procured on a part by part basis. Component quantities varied according to cost, complexity and risk of developmental changes.

The unique latching high speed solenoid valve developed for this program is being supplied by Sturman Industries in Colorado. Completion of the solenoid valves included test and serialized documentation of function, including oscilloscope pressure traces and response times. As previously mentioned, the development test ECU is being provided by the BKM. In parallel, the prototype small engine ECU was fabricated for functional testing.

2.5. Test Planning and Setup

A 5 hp eddy current dynamometer was provided by the contractor for engine testing. The overall test stand layout was designed as well as detail hardware required for engine mounting and dyno coupling. The test cell electronic controller for the engine was setup and connected for engine operation as well as for the monitoring of engine control software.

Initial engine development test plans were formulated. These plans include items in the following outline:

I. Debug system and fix leaks
II. Motoring tests
  A. Verify pump function
    1. measure peak pressure, various speeds
  B. Verify mechanical injection
    1. Measure injection quantity
    2. Measure injection timing
    3. Measure injection duration
  C. Electronically control the injection event
    1. Measure fill delay
    2. Measure vent delay
    3. Measure injection quantity for various fill times
    4. Measure injection duration for various fill times
    5. Check for consistency of injections
III. Engine calibration
  A. Hardware preparation
    1. Calibrate throttle position sensor
    2. Install CO probe into engine exhaust
    3. Verify oil pump flow control, 0.2 to 0.7 cc/min
  B. Starting
    1. Adjust throttle to obtain best starting
    2. Adjust mechanical injection timing to obtain best starting
  C. Initial calibration of injection timing
    1. Good conventional idle
    2. Safe WOT sweep, near rich misfire limit
    3. Estimate timings for remainder of map
  D. Transfer pump
    1. Determine transfer pump flow requirement

E. Idle calibration
   1. Find optimum idle throttle position, # of cycles skipped and rpm, all with optimum injection timings
   2. Investigate closed loop idle speed control with number of cycles skipped as the control parameter
F. WOT Calibration
   1. Find peak power with baseline CO emissions
   2. Evaluate reduced air/fuel ratio, until 2% CO emissions. Consider power, temperature, fuel consumption, piston condition (seizure)
G. Part load calibration
   1. Adjust map for combustion quality and minimum fuel consumption
H. Future combustion development
   1. Spray variations
      a) Location
      b) Direction
      c) Cone angle
      d) Pressure combinations
   2. Combustion chamber
      a) Piston bowl
      b) Squish velocity

2.6. Performance and Emissions Optimization

Note: At the time of this draft report, engine performance and fuel consumption optimization testing of various injector and combustion chamber designs was still underway. Results have been encouraging, with startability, power and engine response equal to or better than the standard carbureted engine. However, full emissions testing has been withheld pending completion of test matrix iterations and conclusion regarding best injection spray, injection timing, combustion system design and ignition characteristics.

The first operation of the 46cc fuel injected engine occurred on August 23, 1997. As a result of the initial engine testing, the following design revisions were implemented.

1. Due to pump leakage in the area of the spill port, the prototype pump efficiency is lower than anticipated, resulting in lower pressure than required for full power fuel delivery. In parallel with efficiency improvement changes, a cylinder/plunger assembly with increased displacement was designed and fabricated to allow for continued testing and power development. A revision to the internal volume of the injector nozzle, which results in increased fuel delivery capability was also accomplished.

2. Due to percolation of the fuel in low pressure passages of the plumbing circuit, caused by high temperatures associated with the aluminum crankcase, it was decided to provide back pressure by installing a pressure

relief valve at the venting outlet of the solenoid valve. Various values of back pressure were tested. Presently, it has been determined that a value of 80 psi is very effective in preventing fuel percolation during engine running and soak back temperature conditions.

3. Based on visible evidence on the piston crown subsequent to engine running, it has been decided to prepare variations in piston crown shape for testing, to encourage retention of the fuel spray and fuel air mixture in the center portion of the combustion chamber. Carbon buildup near the piston crown perimeter indicates that some fuel adheres after initial contact, then disperses across the piston crown until reaching the outer edge, near the cylinder wall. An improvement will be accomplished by designing a combustion bowl or cup in the central area of the piston crown. A design which does not change the compression ratio of the engine will be developed for initial testing.

Subsequent testing has resulted in design changes to the pump design, location (for heat isolation), fuel spray, piston crown and combustion chamber design. Several fuel spray and combustion bowl arrangements have been evaluated in order to achieve best fuel/air mixing and fuel distribution within the combustion chamber. Evaluation of spark ignition timing, ignition duration and spark energy have also been included in the test program. Whereas the results of this test program represent a best combination of parameters for the particular 46cc engine application, similar studies may be required for engines of differing physical and performance characteristics.

Performance goals included:

Power: Equal to standard carbureted engine

Exhaust Emissions (SAE J 1088):

	THC	CO	NOx
g/kW•hr	67	174	5.4

<u>Performance and Emissions (Test Results):</u>

	Power, kW 7,000 rpm	BSFC g/kW•hr	THC g/kW•hr	CO g/kW•hr	NOx g/kW•hr
Baseline	tbd	tbd	tbd	tbd	tbd
EDFI	tbd	tbd	tbd	tbd	tbd

Test summaries and comments are included in Appendix B.

2.7. Durability and Emissions Degradation Testing

Formal durability and degradation testing has been withheld pending completion of performance and emissions optimization and validation. This testing is extremely important to both BKM and the engine manufacturers involved in the project funding and licensing. This testing will be conducted independently by BKM at the conclusion of performance demonstration. BKM is considering the involvement of College of Engineering - Center for Environmental Research and Technology (CE-CERT), University of California, Riverside for this test activity.

2.8. Reports / Meetings

During this two year program, BKM has held three program review meetings at approximately six month intervals. These participant "summit" meetings were attended by ARB representatives, as well as engineers and executives from the consortium funding manufacturing companies. Minutes and presentation materials from each of these meetings is available on request.

Comprehensive presentations by BKM engineering staff on all technical aspects of the project were provided at these meetings. In addition, these meetings provided a forum for interchange and discussion between BKM, the manufacturers and ARB. Equally interesting was the interaction between competitive manufacturing company representatives.

The consortium final program meeting will be scheduled in late July or early August 1998 for presentation of project results. All consortium members will be invited.

3. Results

Note: At the time of this draft report, engine performance and fuel consumption optimization testing of various injector and combustion chamber designs was still underway. Results have been encouraging, with startability, power and engine response equal to or better than the standard carbureted engine. However, full emissions testing has been withheld pending completion of test matrix iterations and conclusion regarding best injection spray, injection timing, combustion system design and ignition characteristics.

<u>Performance goals:</u>

1. Power: Equal to standard carbureted engine

2. Exhaust Emissions (SAE J 1088):

	THC	CO	NOx
g/kW•hr	67	174	5.4

Performance and Emissions (Test Results):

	Power, kW 7,000 rpm	BSFC g/kW•hr	THC g/kW•hr	CO g/kW•hr	NOx g/kW•hr
Baseline	tbd	tbd	tbd	tbd	tbd
EDFI	tbd	tbd	tbd	tbd	tbd

4. Discussion

A detail discussion of the technology and how it works has been provided in Section 1.3.. Applying this technology allows manufacturers of 2-stroke handheld utility engines to comply with the California tier 2 standards for handheld utility engine exhaust emissions. This technology also provide manufacturers of 2-stroke engine powered motorbikes, marine engines and other applications to significantly reduce exhaust emissions.

As discussed in the following Section 6, the degree to which this technology will provide environmental, economic and industrial benefits to California and to the BKM will depend on acceptance of the results of this demonstration program by the engine manufacturers. Therefore, the next phase of the commercialization process will be to repeat the previous manufacturer contacts for the purpose of presenting these results and discussion of their concerns, costs, sources and so on.

Assuming the technology is generally accepted, licensed and produced for the utility engines sold in California, the optimistic projection of impacts on California are significant, as outlined in the proposal for this ICAT program. These impacts may be summarized as follows:

Utility lawn and garden equipment engine (ULGE) applications in which two-stroke engines are typically used includes chainsaws, string trimmers, leaf blowers, lawn vacuums, small generators and pumps, and walk behind mowers. Two-stroke engines dominate applications requiring a lightweight highpower powerplant. The BKM fuel injection technology is universally applicable to all current two-stroke powered products. In addition, the technology applies equally well to larger applications such as two-stroke mopeds, scooters, motorcycles and outboard engines. In these more sophisticated and demanding applications, the addition of catalytic converters may also be applied.

This technology focuses on pollution prevention by reducing emissions at the source. Emissions from small two-stroke engines will be dramatically reduced by redesigning the engine and its systems. In particular, emissions of HC, NOx and CO will comply with CARB regulations set for 1999 production handheld utility engines. This program will have broadbased application since technology licensing and engine sales will apply worldwide to all low cost two-stroke engine applications.

a) Environmental: From the study generated by Booz • Allen & Hamilton for CARB in support of the CARB utility engine emission regulation, it can be shown that handheld two-stroke equipment and chainsaws are responsible, in California alone, for approximately 43 tons per day of unburned hydrocarbon (HC) and 495 tons/day of carbon monoxide (CO) emissions. By complying with the CARB tier 2 regulations, this technology is capable of reducing these figures by 30 tons/day HC and 110 tons/day CO within California. The fuel consumption of these engines will also be reduced by 30 to 50%.

   According to the Nonroad Engine and Vehicle Emissions Study, completed by the EPA in November 1991 (docket A-91-24), nonroad engines and vehicles contribute an average of ten percent of the summer Volatile Organic Compounds (VOC) in 19 ozone non attainment areas. Small spark ignited engines are the source of half of these VOC emissions. In 16 CO non attainment areas, nonroad engines and vehicles account on average for nine percent of winter CO emissions. Small SI engines contribute 56 percent of these CO emissions. According to published EPA estimates, a chainsaw operating for one hour produces as much CO as a car driven 230 miles, and an outboard motor running for one hour releases as much HC as a car driven 2,500 miles. The proposed technology will potentially reduce the contribution of these emissions from two-stroke engines by 70 to 75 %.

   The actual impact on air quality in California will obviously depend on the market penetration of this technology on the engines sold in California.

b) Technical: As demonstrated during previous testing by the EPA, this technology can meet or exceed the 1999 CARB HC, CO and NOx exhaust emissions regulation for handheld two-stroke engines, which are compared to the CARB 1995 standards in the following table:

	HC, g/bhp-hr	CO, g/bhp-hr	NOx, g/bhp-hr
1999 CARB Regulation	50	130	4.0
1995 CARB, 20 to 50cc	180	600	1.0
Required Reduction	72%	78%	0%
1995 CARB, ^{3} 50cc	120	300	1.0
Required Reduction	58%	57%	0%

During EPA testing of a similar, but not production oriented fuel injection system, it was demonstrated that this fuel injection technology does not require the addition of a catalytic converter, and will therefore meet the exhaust gas and skin temperatures limits of 288 $^{\circ}$C required by the U.S. Forestry Service.

c) Economic: For portable power equipment, this program demonstrated a viable technology capable of meeting CARB utility engine regulations as well as the Forest Service exhaust gas temperature requirements. This program also demonstrated a viable technology for two-stroke mopeds, scooters and motorcycles. Current cost projections indicate that the incremental impact on engine manufacturing cost is on the order of $25 to $30 per engine cylinder if components are produced at rates higher than 500,000 units per year. This does not include mark up to the end customer or the cost to implement distribution and technician training. To achieve these rates, it is desirable to apply the system components to as many manufacturer's engines as possible.

5. Summary and Conclusions

(Pending completion of emissions testing)

6. Commercial Plan

In the original ICAT proposal, BKM outlined a commercialization plan headed by its marketing affiliate Environmental Engines Corp. (EEC). EEC was formed in the period between formulation of the ARB utility engine regulation and the regulation negotiation meetings between the Federal EPA and industry, which were held for the purpose of enacting similar utility engine exhaust emissions standards. When it became obvious that EPA was not intending to immediately follow the lead of ARB, EEC found it very difficult to continue fund raising and to attract the interest of utility engine manufacturers. EEC was eventually dissolved, returning all rights to the BKM technology back to BKM.

In the early marketing attempts, both EEC and BKM recognized that functional demonstration as well as economically feasible design would be required to attract further interest. This ICAT program has provided the opportunity to present this information.

The marketing challenge resulting from the lack of a Federal equivalent to the ARB standards remains the primary obstacle for introducing this technology to the utility engine industry. However, worldwide need for clean 2-stroke technology in the 2-wheeler transportation and marine engine industries has provided an opportunity to continue the system development. In conjunction with this ICAT program, BKM formed a consortium of engine and component manufacturers willing to participate in the funding of a demonstration in return for non-exclusive license options.

The impact on California by introducing the clean 2-stroke in these other industries will be minor compared to the utility engine potential. However, by taking advantage of these more immediate opportunities, BKM should achieve credible market experience and resolve technical, manufacturing source, and cost issues. This will allow BKM to approach the "wait and see" utility engine manufacturers with a production and market proven system. The degree to which the utility engine market adopts this fuel system will then be dependent on factors such as competitive technologies (catalytic converters, 4-stroke engines and so on) as well as the percent of total sales impacted by ARB equivalent exhaust emission standards.

It is projected that a minimum commitment level of 300,000 units per year spread over the population of licensees will be required for production costs of key components to be reasonable. At the present time, the companies listed below hold license options on the technology. These license option holders have until June 30, 1999 to exercise their license option without incurring additional costs, so that an indication of immediate production potential should be available at that time. Current projections by these companies regarding potential annual quantities is also shown.

Manufacturer	Annual Quantity
Complete systems:	
Yamaha (motorbikes)	2,000,000
Suzuki (motorbikes)	310,000
Tanaka (handheld utility engines)	50,000
Tohatsu (marine engines)	50,000
Anonymous Taiwan Manufacturer (motorbikes)	240,000
Components:	
Honglin - China market	5,000,000
Total	7,650,000

In the initial phase of commercialization, BKM will collect royalties of $2.00 for each engine cylinder using the technology, regardless of the source of parts. This royalty represents a potential, based only on the current license option holders and a conservative potential to secure 20% share of the engine listed above, of $3.06 million in annual revenue or an optimistic estimate of $15.3 million at 100% share. It is conceivable that this level of income could be generated within 3 years.

A subsequent opportunity to supply components to the licensees will also be explored. As a requirement in all license option agreements, engine builders have insisted on the option to manufacture components internally. As a practical matter, they also understand the benefit of procuring components from a single source, to take advantage of part commonality and large production volume cost structure. Therefore, the opportunity for parts manufacturing is very real and desirable.

It is BKM's objective that a single reputable supplier, with worldwide customer support capability, shall become the supplier of record for the entire system, even though certain components may be supplied by specialized second tier manufacturers, including BKM. BKM has discussed the supplier opportunity with several prominent manufacturing companies. It is somewhat premature for any to commit resources and reputations on the system which is at this demonstration phase, but the level of interest is encouraging. As an example, a letter received from Walbro indicating their interest to become the supplier is included in Appendix C. Obviously, interest in the fuel system by a major engine manufacturer would be beneficial to negotiations with potential suppliers.

The ultimate opportunity to supply complete engines is difficult to predict at this time. If a Federal utility engine regulation existed making this technology desirable for the entire U.S. market, the potential for engine production would be reasonable. Similar worldwide regulations would increase the opportunity. Should these incentives come to pass, a 20% market share of the nearly 5 million engines manufactured annually for sale to equipment assemblers would represent approximately $75 in annual sales.

One of BKM's commercial partners, Honglin Machinery Factory, has independently designed test hardware and conducted development testing of the fuel injection pump and injector system. The purpose of this activity was to become intimately familiar with the fuel system design and hardware calibration challenges, as well as to complement the work by BKM. Honglin then incorporated the design into a 125cc motorbike engine and has brought this hardware to BKM for integration of electronics, training on software calibration procedures and operational testing of this motorcycle on a BKM motorcycle chassis dynamometer. The engineers and hardware will then return to China for continuation of performance optimization and for demonstration to potential licensees.

Similarly, Suzuki and BKM have completed an application design for a commercial 50cc moped for functional testing and training at BKM. This hardware will also return to the manufacturer for continuing study and optimization. An illustration of this design is shown in Figure 22.

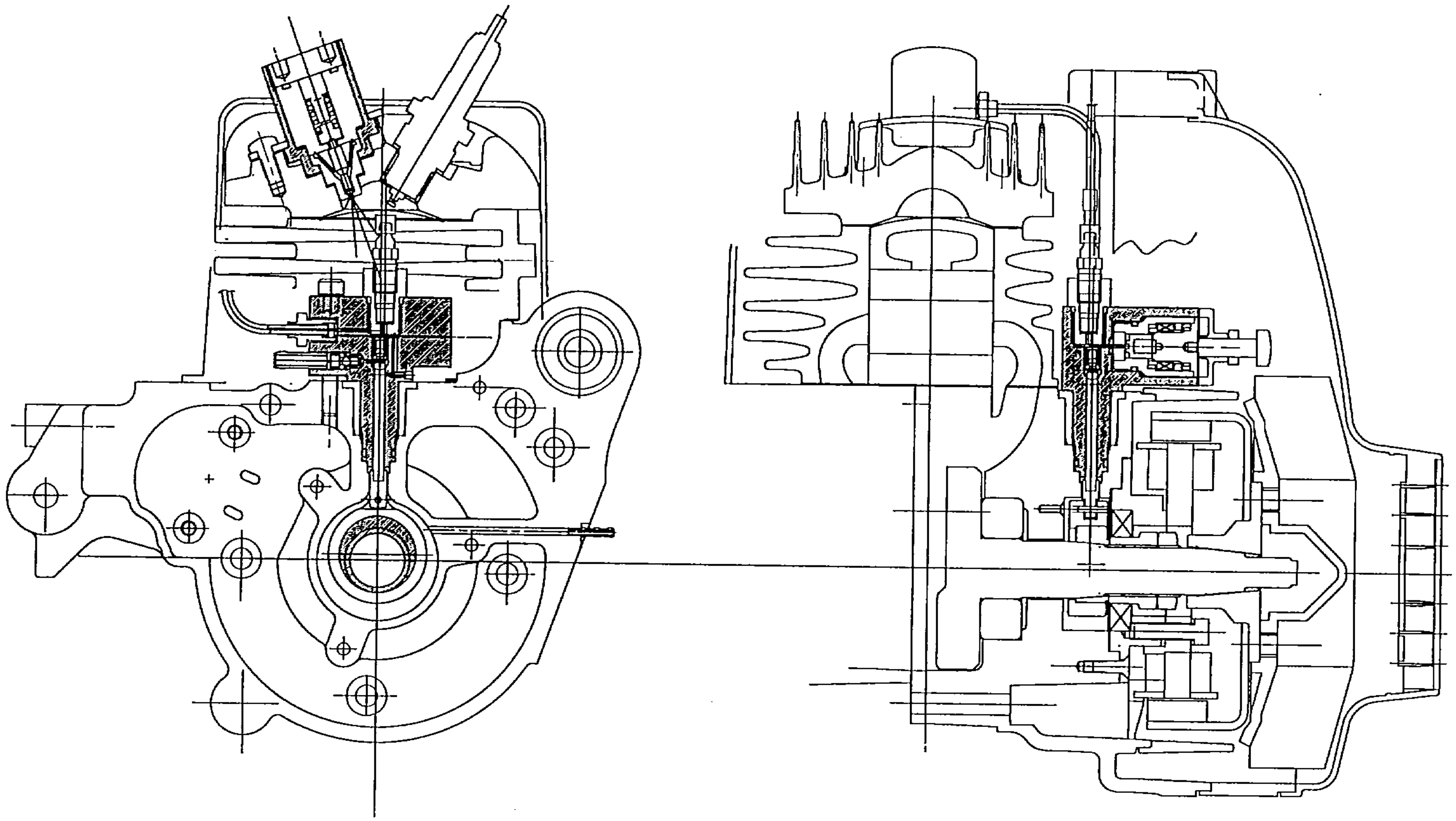


Figure 22 - 50cc Moped Application Design

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(2) M. Nuti, "Direct Fuel Injection: An Opportunity for Two-Stroke SI Engines in Road Vehicle Use", SAE paper 860170.

(3) D. Plohberger, K. Landfahrer, L. Mikulic, "Development of Fuel Injected Two-Stroke Gasoline Engine", SAE paper 880170.

(4) V. Kuentscher "Application of Charge Stratification, lean Burn Combustion Systems and Anti-Knock Control Devices in Small Two-Stroke Cycle Gasoline Engines", SAE paper 860171

(5) W. Heimberg "FICHT Pressure Surge Injection System", SAE paper 931502

List of Inventions Reported and Publications Produced

Patents:

No new patents have been issued as a direct result of this ICAT funding. Existing patents which formed the basis of the ICAT proposal and licensing opportunities with the consortium member cofunders include the following:

I. Patent Number 5,438,968 - Two Cycle Utility Internal Combustion Engine
II. Patent Number 5,685,273 - Method And Apparatus For Controlling Fuel Injection In An Internal Combustion Engine

Publications:

No publications have been created yet as a result of this ICAT funding. However, BKM intends to explore an opportunity to publish a paper on the results of this project for presentation at the Small Engine Technology Conference (SETC), to be hosted by Society Of Automotive Engineers (SAE) in the fall of 1999.

Glossary of Terms, Abbreviations, and Symbols

ARB	Air Resources Board
CARB	California Air Resources Board
CATS	Clean Air Two-Stroke
CO	Carbon Monoxide
CRS	Common Rail System
ECU	Engine Control Unit
EDFI	Electronic Direct Fuel Injection
EEC	Environmental Engine Corporation
EPA	Environmental Protection Agency
Expanding Cloud	Non-coalescing fuel spray
HC	Hydro Carbons
ICAT	Innovative Clean Air Technologies

MPa	Mega Pascals
Nox	Oxides of Nitrogen
Scavenge Loss	Removal of the combustion byproducts from the previous cycle
SPS	Single Plunger System
λ	Lambda, Lambda is the ratio between actual air/fuel ratio and stoichiometric air/fuel ratio.
VOC	Volatile Organic Compounds

Appendix A - Market Survey Summary

RECOMMENDED ENGINE SPECIFICATIONS

A stated objective of the California Air Resources Board's Innovative Clean Air Technology (ICAT) program is to assist companies to develop technologies that will support the ARB's clean air goals and also result in job creation in the state of California. Under its contract, BKM, Inc. is to develop a two stroke engine that will reduce emissions and also reduce fuel consumption.

Prototype Engine Specification Recommendation

Displacement

Prototype engines will be used to demonstrate low emissions and reduced fuel consumption.

These features, while important to several major high volume engine markets, impact them somewhat differently.

Low emissions are a major concern to the hand held Utility and Lawn and Garden Power Equipment market because of impending emissions legislation.

Low fuel consumption is a major economic benefit to markets for powered two wheel vehicles.

To make prototype engines most practical for evaluation in both of these markets, engines with a displacement in the range of 2.8 cubic inches (45.9 cc) to 3.0 cubic inches (49.1 cc) is recommended.

Range of Displacement Options

The basic design for the prototype engines should be produceable in a full range of displacements.

Excluding chain saws, 93% of all models of hand-held engine products are in the 1.0 to 3.0 cubic inch displacement range. 73% are in the 1.0 to 1.99 range and 20% in the 2.00 - 2.99 cubic inch range.

Prototype design, regardless of displacement selected, should permit use of the low emission, low fuel consumption technology.

All displacement variables will be contained within the short block to provide a maximum of flexibility in engine components.

Commonality to Industry Standards

Most OEM engine users currently design their products to conform to the PTO mounting configurations of currently available engines. This provides interchangeability of engine sources and also creates optional engine models when required for marketing or price variations.

Major engine suppliers, Kawaski, Mitsubishi, Fuji Robin, Komatsu Zenoah, U.S. Engines and Tecumseh offer small engine models that are compatible to these standards.

This commonality not only gives flexibility to OEM product producers, but also gives them the competitive advantage of economy of scale to participate in the high unit volume products like trimmers, brushcutters, blowers, etc.

Engine Mounting Considerations

General industry standards provide two options for clutch or other mounting dimensions. The specific dimensions are detailed in the section "Mounting Details".

Basically, engines under 2.0 cubic inches (32.8 cc) use a smaller clutch and require a mounting bolt circle of 3.23 inches (82mm). Engines larger than 2.0 cubic inches require a mounting bolt circle of 3.94 inches (100 mm).

Manufacturers of Engines for Interplant Transfers.

The standard industry specifications may or may not be compatible with equipment manufactured by companies that produce their own engines.

However, since these companies have demonstrated the desire and capacity to design, tool and produce their own engines, they can reasonably be expected to license the technology and produce low emission, low fuel consumption engines if the market requires it. In addition, as they now do, these companies can purchase standard OEM engines for their low volume product lines (i.e.) Poulan uses some Kawasaki and Fuji engines; Makita uses Fuji Robin, Tanaka uses some McCulloch engines, etc.

Commonality of Parts

The design of the short block and engine configurations should focus on maximizing the commonality of parts.

On the short block, it would be desireable for each short block design to provide two engine displacements with only a change in the bore diameter and the piston and ring, plus any change that may be required in the accumulator, etc.

This maximization should also apply to engine components, such as blower housings, air cleaners, mufflers, starter handles, starter hubs, pawls, etc. Such commonality provides a strong selling point for the engines for parts and service distributor. They see and sell benefits in reduced inventory requirements.

Piston Rings

A single piston ring is acceptable on engine models with a displacement of 2.0 inches (32.78cc) or less.

Pistons on engines in excess of 2.0inches should include two rings.

Cylinder Casting

On the castings for engines that exceed 2.0 cubic inches in displacement, it is recommended that the casting include a boss in the proper location for the optional mounting of a decompression valve.

Power Ratio

It is recommended that the power of the prototype engines be in excess of .8 horsepower per cubic inch of displacement. Maximum output should be achievable in the 7000 - 8000 RPM range.

Weight

The weight should not exceed 3.3 pounds per cubic inch.

Engine Assembly

OEM engine applications require a number of configurations. To provide these economically, it is recommended that the design of the engine include components that can be asembled in a variety of configurations rather than separate engines. Under this proposal, there would be no changes in the short block except for crankcase ends. All other changes would be accomplished by assembly variations and optional attachments.

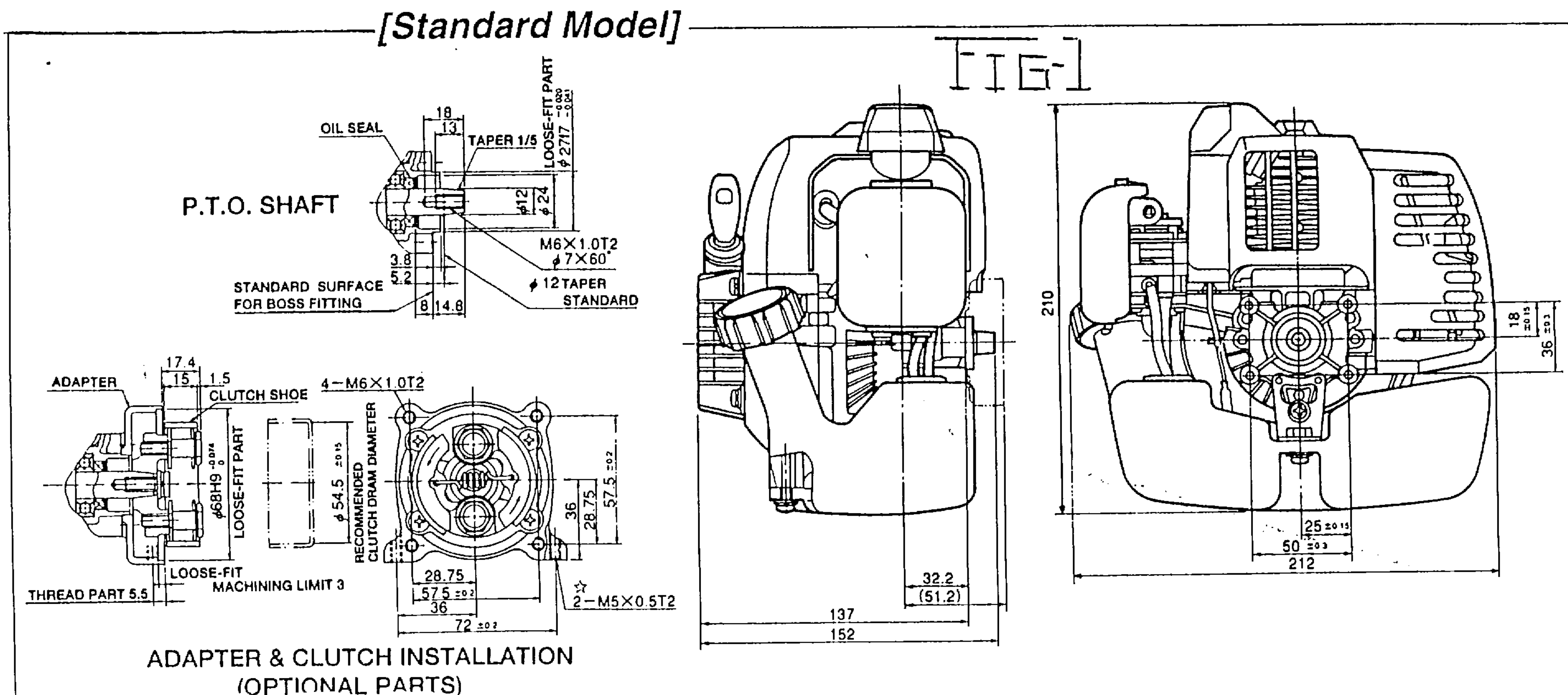
In other words, engine variation would include a common set of conponents that can be assembled to provide any one of four configurations

These include:

1.) Standard Model (FIGURE 1)
2.) Vertical Model (FIGURE 2)
3.) Pump Equipped Model (FIGURE 3)
4.) Brushcutter Model (FIGURE 4)

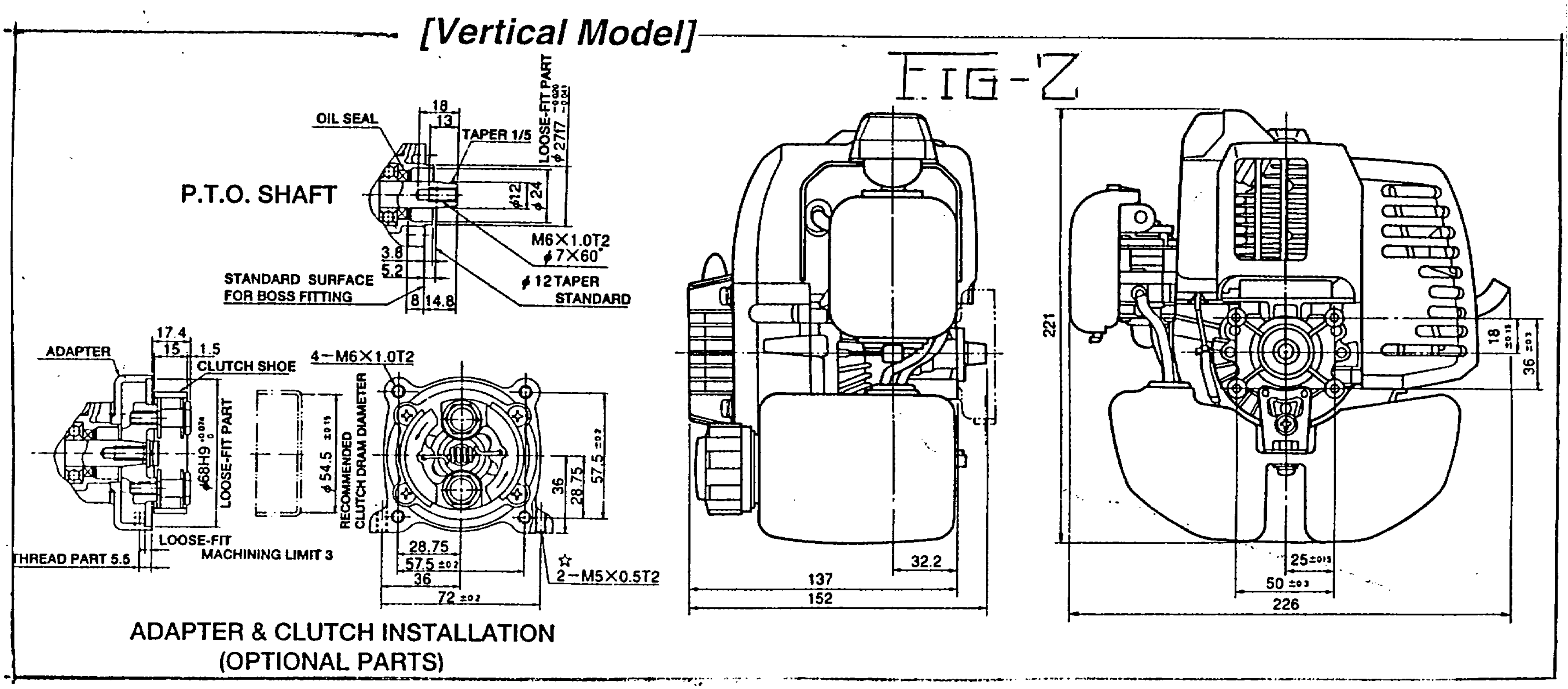
STANDARD MODEL (FIGURE 1)

This is a conventional engine configuration. The PTO is tapered to accept various optional drives. The standard model can be used for direct drive applications. With the optional adaptor and clutch installations (FIGURE 5) it can be used for brushcutter or trimmer applications, drills, pruners, edgers, and similar equipment. The fuel tank filler cap is located for maximum adaptability and for multi-attitude operation.



VERTICAL MODEL (FIGURE 2)

This model in assembly is identical to the Standard Model. The only change is in the fuel tank, This mounts in a top fill position, This provides an easy conversion of a standard engine for applications like augers, trimmers, mowers, air effect mowers, cultivators, hedge trimmers, sprayers, foggers, etc. This model is also compatible to the optional adaptor and clutch installation for clutch drive applications.

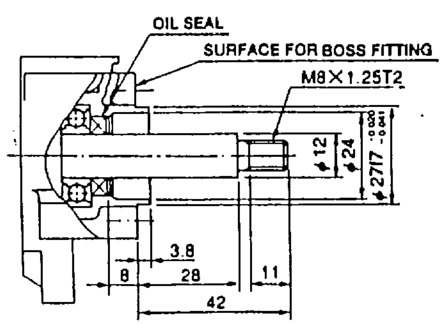


PUMP EQUIPPED MODEL (FIGURE 3)

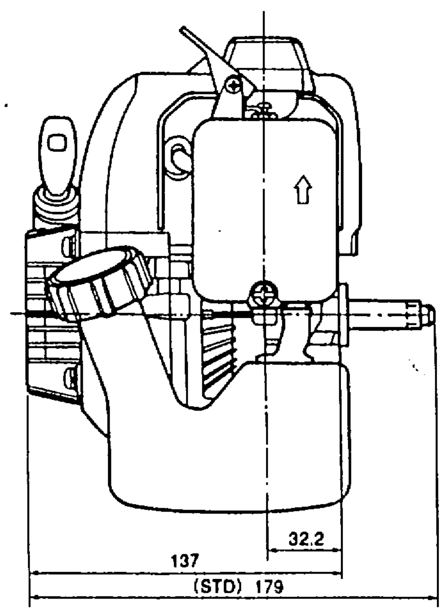
This model is also similar to the Standard Model in assemly except that it does not have the tapered shaft. The PTO shaft has extra length (FIGURE 6) and is not adaptible to the optional clutch adaptor and clutch installation. It converts the basic engine for use with various pump type applications, such as water pumps, fuel pumps, gold dredges, winches, hoists, etc.

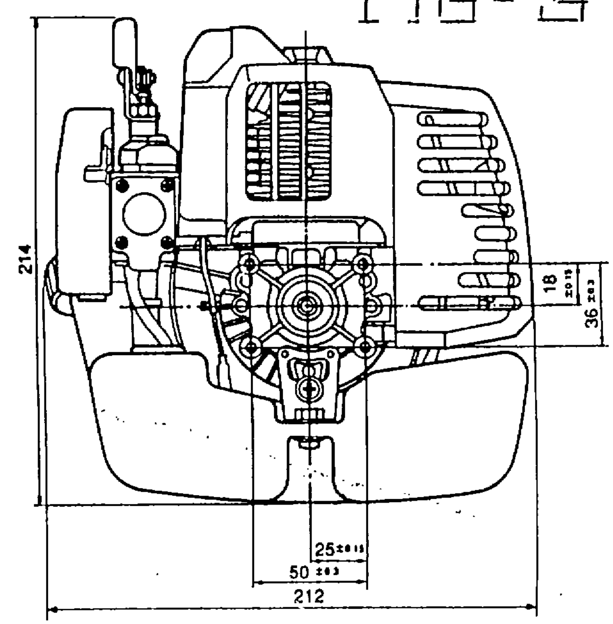
[Pump Equipped Model]

FIG - 3



P.T.O. SHAFT





BRUSHCUTTER MODEL (FIGURE 4)

The Standard engine with the clutch mounting adaptors is usable for all models of trimmers and brushcutters. However, since some manufacturers prefer flexibility in clutch case design, the Standard Engine components can also be assembled to provide the clutch and PTO on the blower housing side. In this arangement, the clutch mounts directly to the base of the flywheel and the customer's clutch case mounts to the face of the flywheel (FIGURE 7).

In this arrangement the starter would be mounted opposite of the blower housing. In this design, it is recommended that the bolt circle on the blower housing duplicate the standard mounting details. This provides reversability to move the starter unit to either the blower housing or opposite location (FIGURE 9.

[Bush Cutter Model]

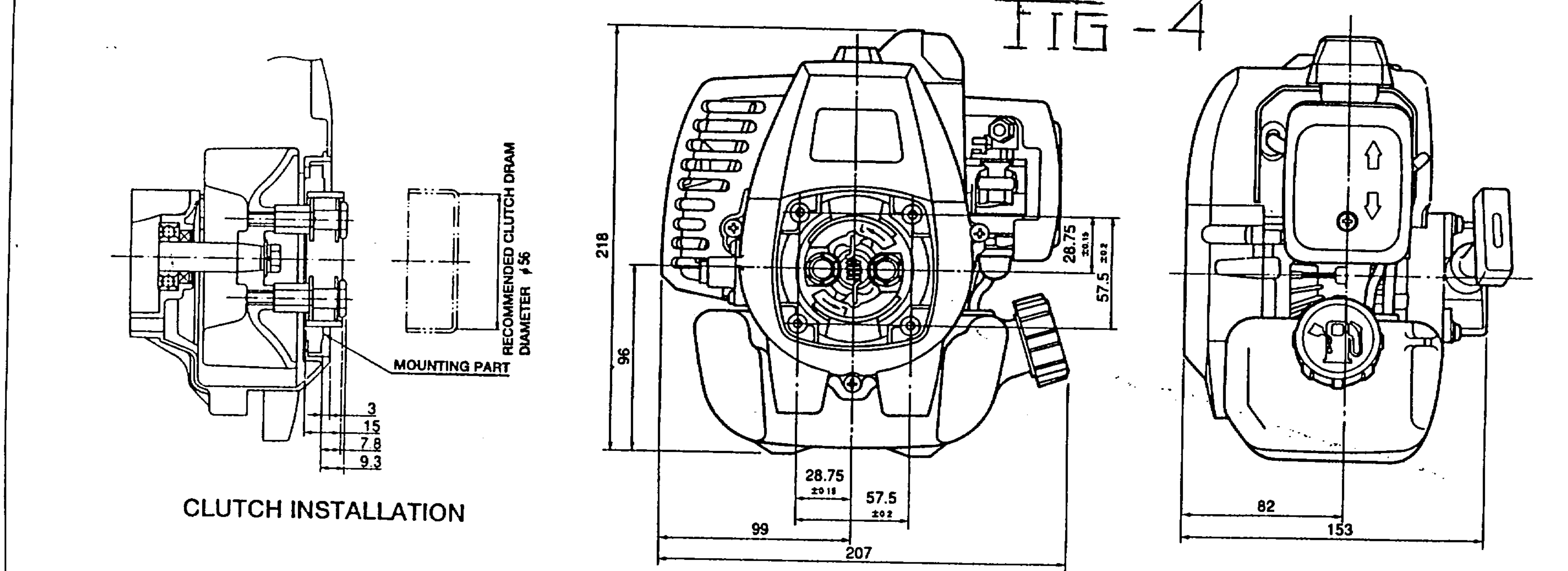
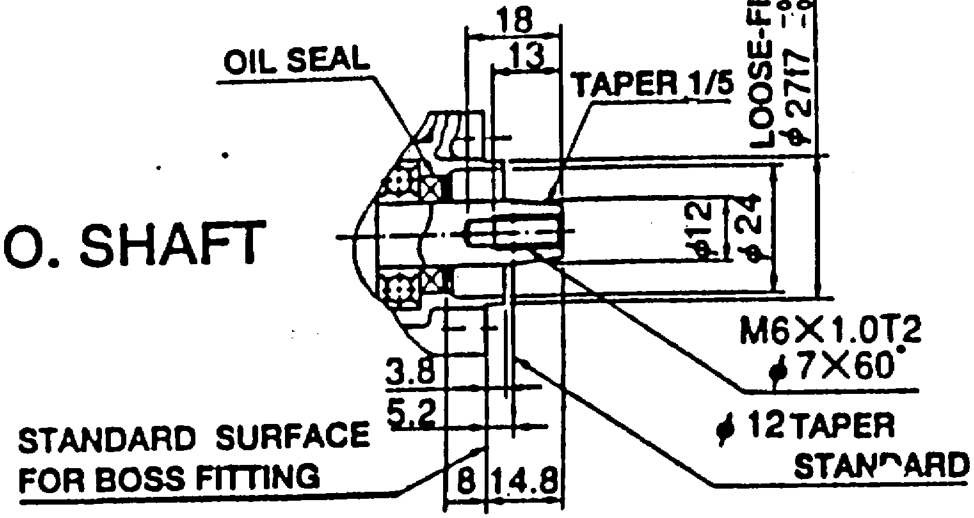


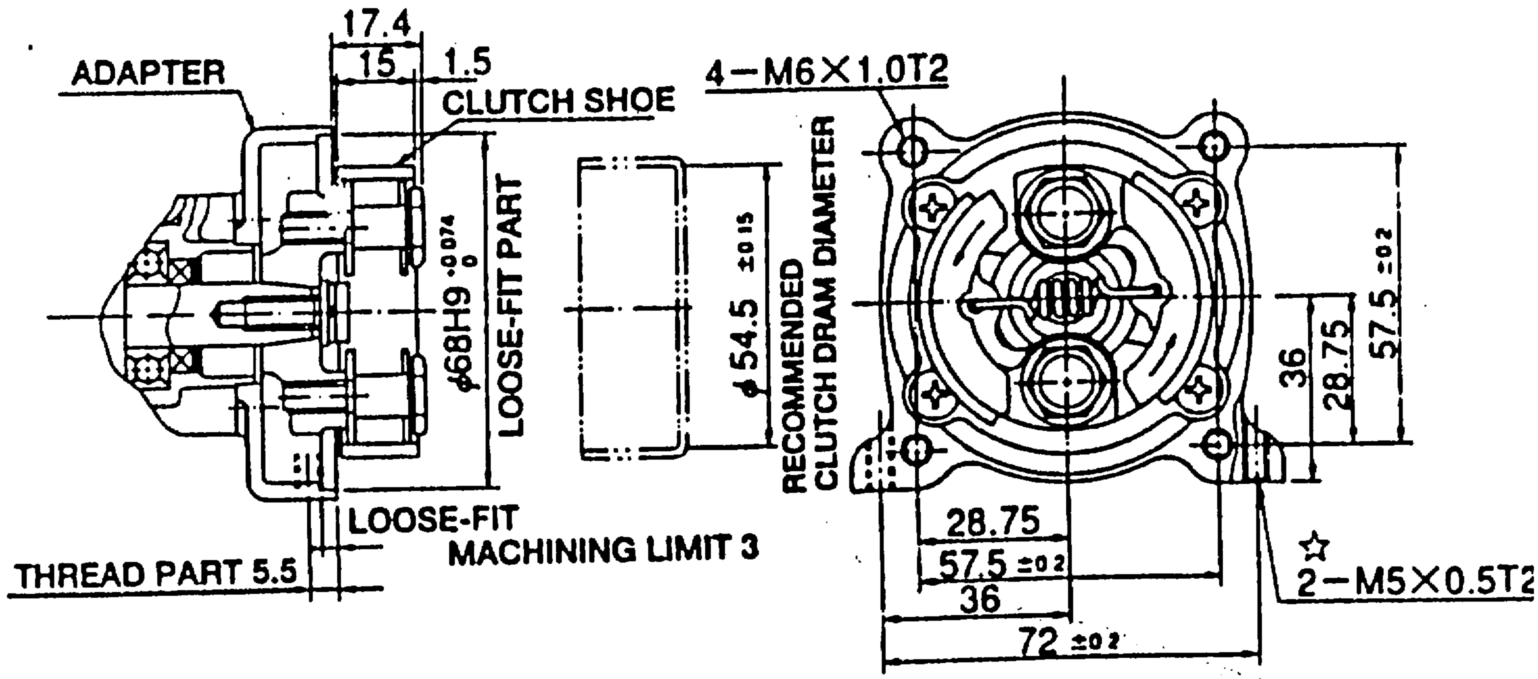
FIG - 4

FIG-5

[Standard Model]

P.T.O. SHAFT

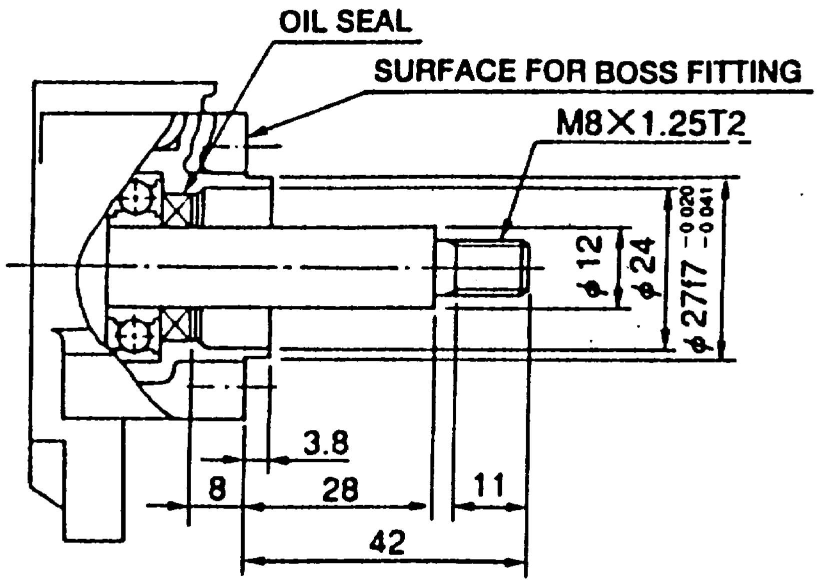




ADAPTER & CLUTCH INSTALLATION
(OPTIONAL PARTS)

FIG - 6

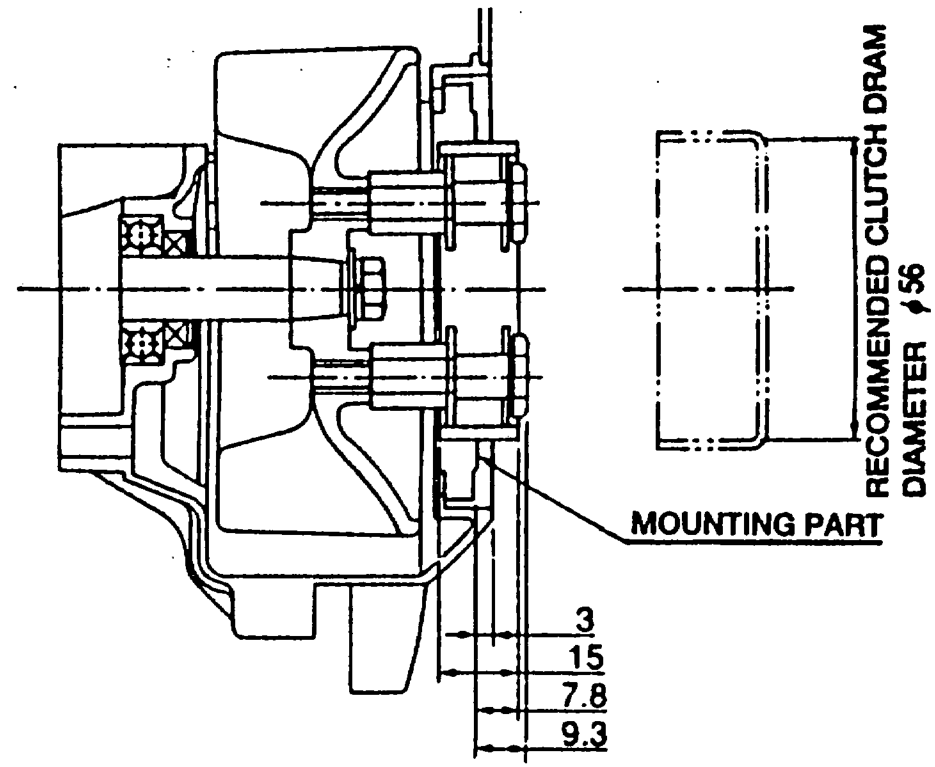
[Pump Equipped Model]



P.T.O. SHAFT

FIG - 7

[Bush Cutter Model]



CLUTCH INSTALLATION

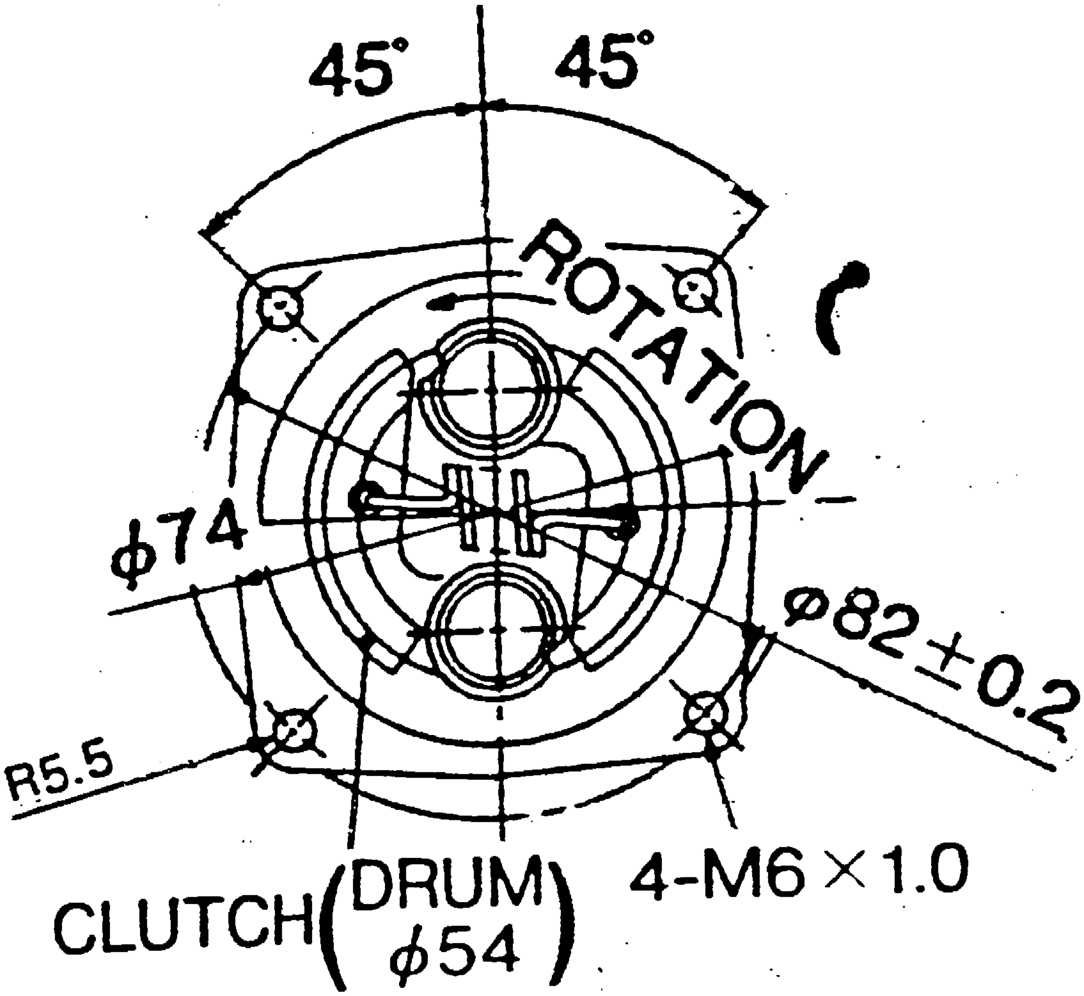
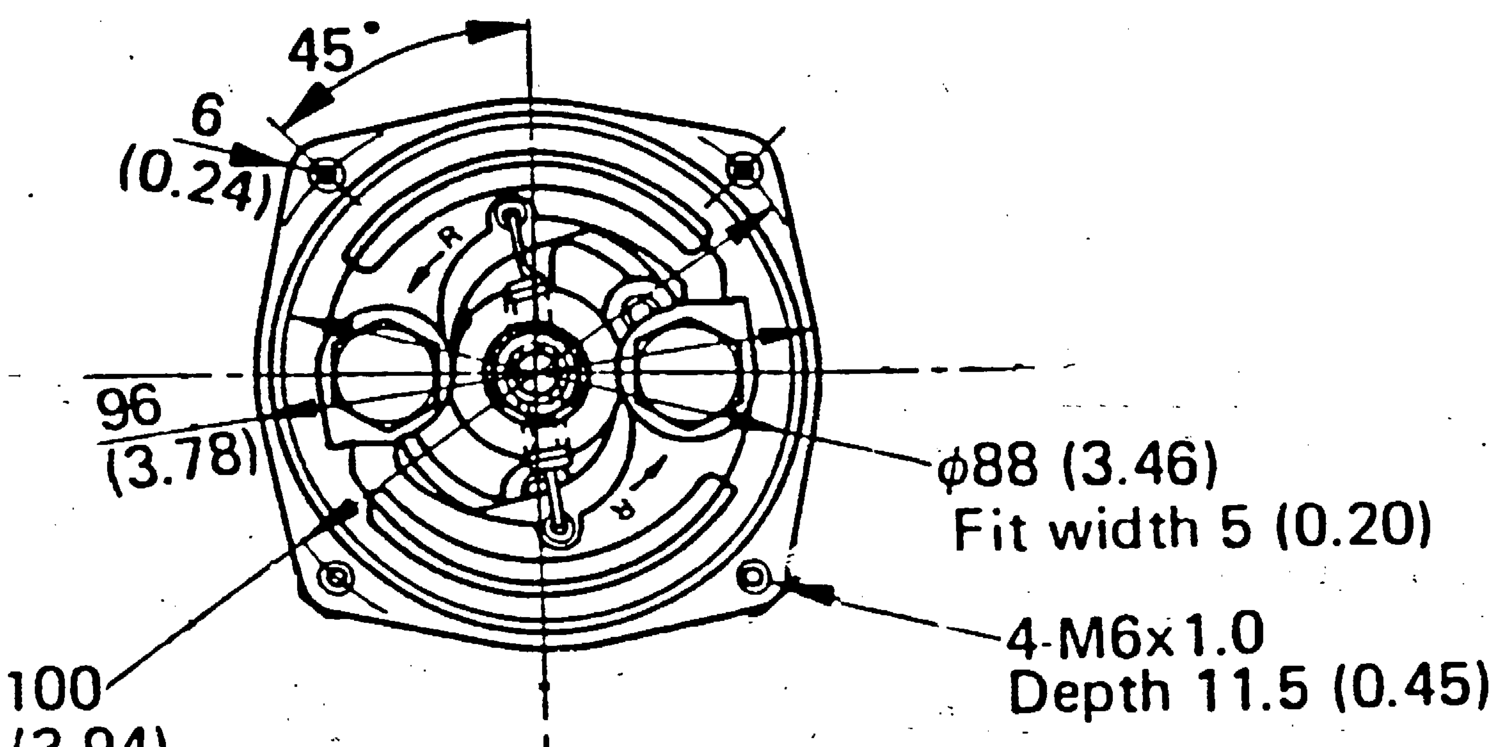
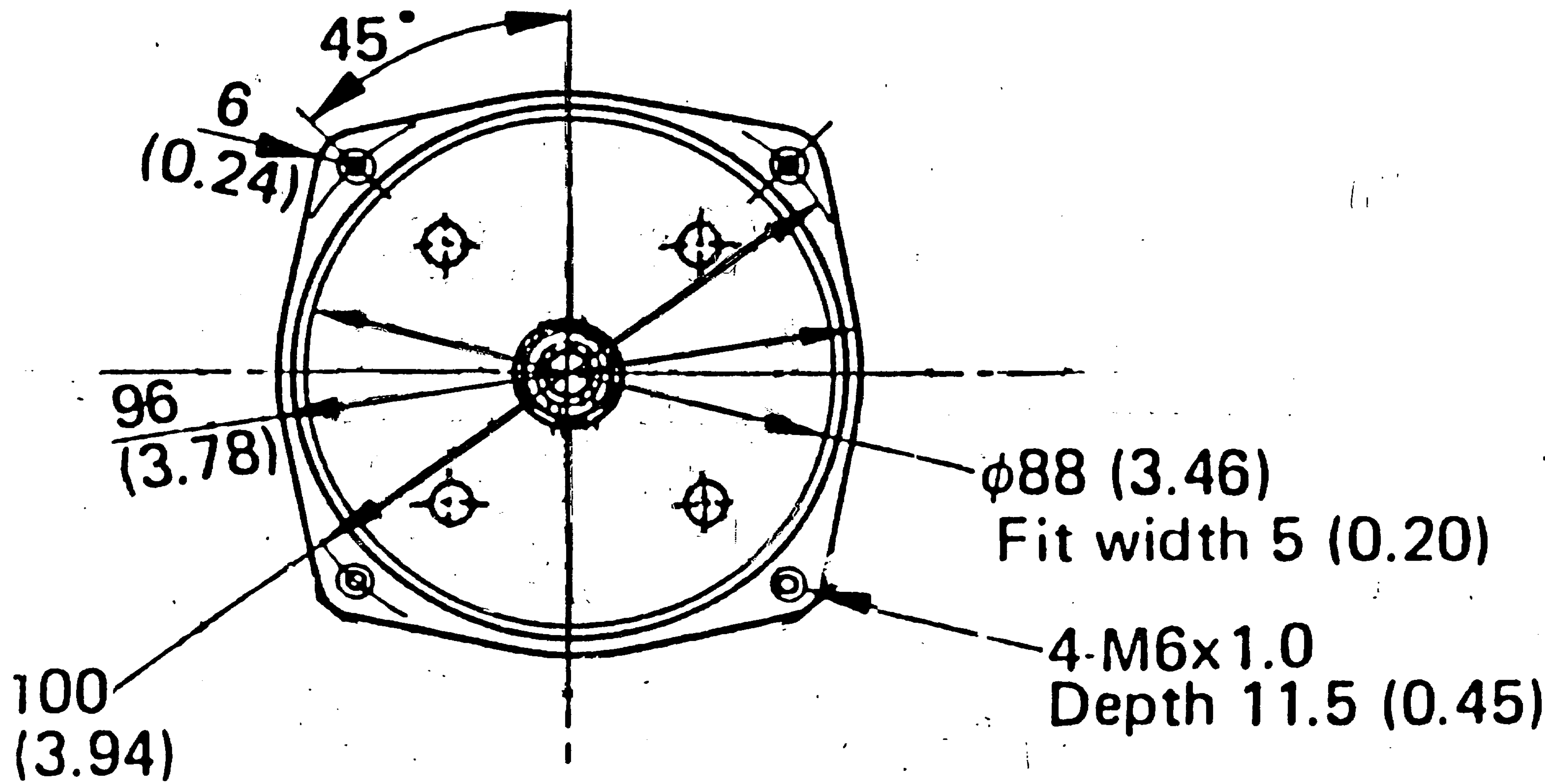

45°
45°
ROTATION
ϕ74
ϕ82±0.2
R5.5
4-M6×1.0
CLUTCH (DRUM ϕ54)

FIG-B


45°
6
(0.24)
96
(3.78)
ϕ88 (3.46)
Fit width 5 (0.20)
100
(3.94)
4-M6×1.0
Depth 11.5 (0.45)


45°
6
(0.24)
96
(3.78)
100
(3.94)
φ88 (3.46)
Fit width 5 (0.20)
4-M6x1.0
Depth 11.5 (0.45)

B. SCOPE OF STUDY

POWERED HAND HELD PRODUCTS

304 models of; trimmers, brushcutters, blowers, cultivators, edgers, drills, augers, pole saws, pumps, vacuums, pruners, hedge trimmers, sprayers and high pressure washers, produced by 24 manufacturers for their own products were reviewed. Specifications, to the extent contained in literature, were recorded. A print out of specifications on all models is included in this section.

Many of the models in each manufacturers section included duplicate displacements. Models where the variables were in attachments only, were eliminated. For example; Ryobi offered a total of 10 models of trimmers but all used the same engine. Thus all but one model were eliminated. The net total of displacements was 130. A separate print out of this modified list is included.

GAS POWERED CHAIN SAWS

A total of 142 models of chain saws, offered by 16 manufacturers are included in the print out for this section. Chain saws, in addition to variations in displacement, may also vary by other features such as; decompression valves, automatic oilers, fuel and chain oil capacity. Only displacements, not including variable features, were eliminated in the second print out. This modified print out includes a total of 121 models.

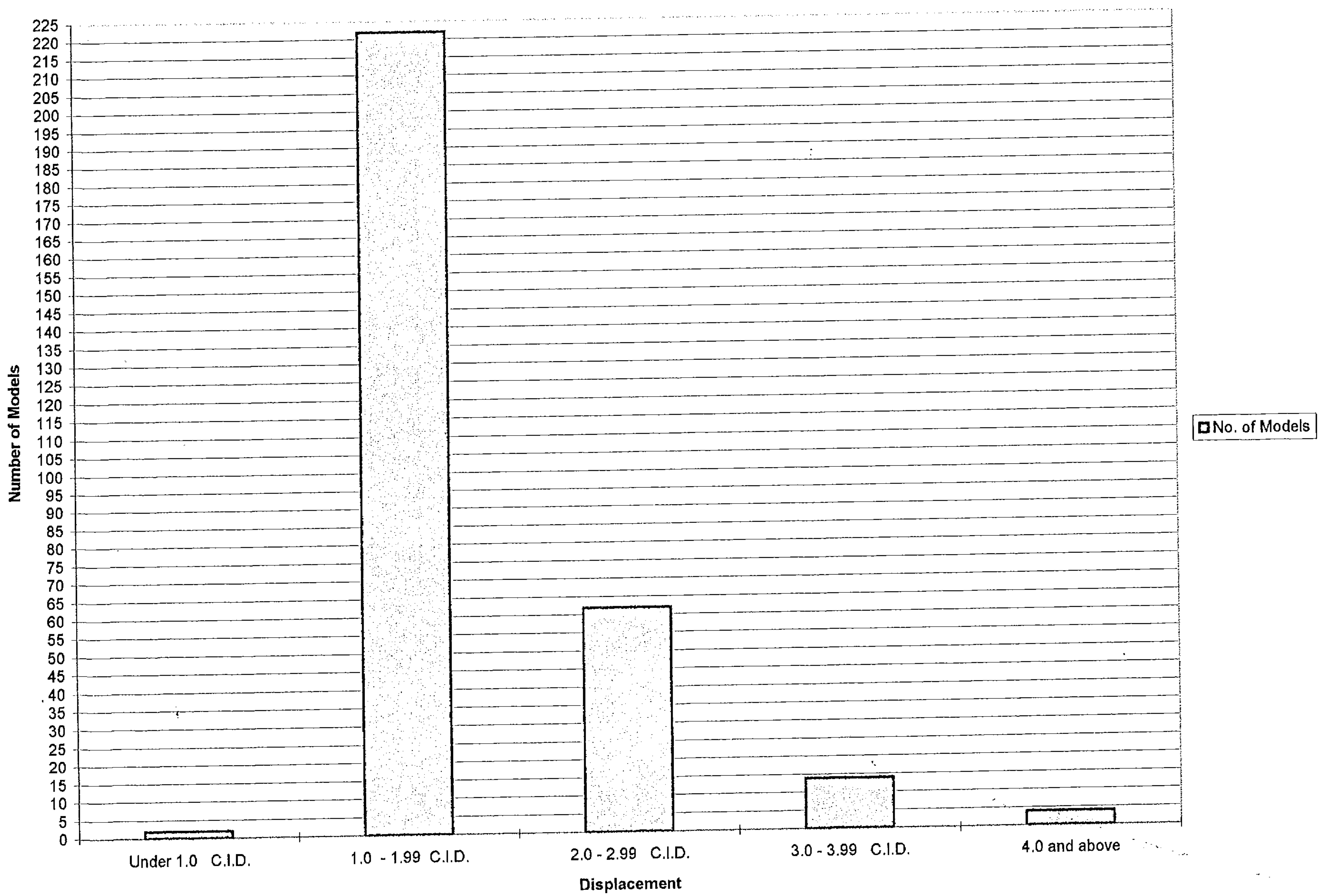
ENGINES FOR ORIGINAL EQUIPMENT PRODUCTS

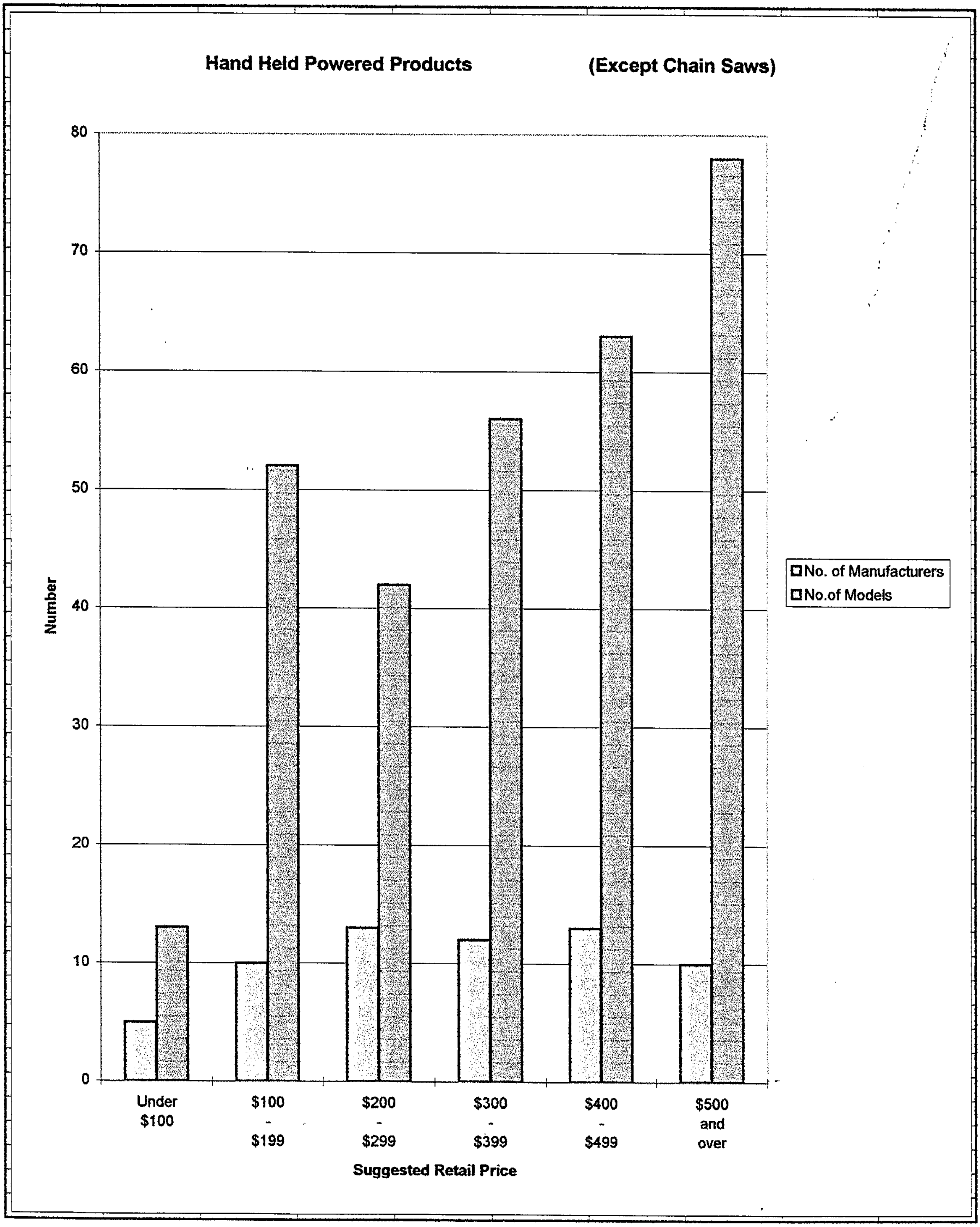
This section contains Specifications on 78 models of 2-cycle small engines produced by 14 manufacturers. Included are manufacturers of engines produced exclusively for OEM use, as well as, engines produced by manufacturers of engines for their own product lines. Some of these are also offered on an OEM basis.

This list includes two print outs covering the same 78 engine models. In the first print out models are sequenced in an ascending order by cubic inch of displacement. The second print out is sequenced in ascending order by horse power produced per cubic inch of displacement.

Chain Saw Models By Cubic	Inch Displacement	
Displacement	No. of Models	
1.0 - 1.99 C.I.D.	4	
2.0 - 2.99 C.I.D.	62	
3.0 - 3.99 C.I.D.	43	
4.0 - 4.99 C.I.D.	17	
5.0 - 5.99 C.I.D.	12	
6.0 - 6.99 C.I.D.	1	
7.0 - 7.99 C.I.D.	2	
8.0 and up	1	
Powered Product Models By	Cubic Inch Displacement	
Displacement	No. of Models	
Under 1.0	2	
1.0 - 1.99	222	
2.0 - 2.99	62	
3.0 - 3.99	14	
4.0 and above	4	
Suggested Retail Prices		
Hand Held Powered Products	(Except Chain Saws)	
Price	No. of Manufacturers	No. of Models
Under $100	5	13
$100 - $199	10	52
$200 - $299	13	42
$300 - $399	12	56
$400 - $499	13	63
$500 and over	10	78
Suggested Retail Prices	Chain Saws	
Price	No. of Manufacturers	No. of Models
Under $200	5	21
$200 - $299	7	22
$300 - $399	13	30
$400 - $499	11	16
$500 - $599	8	14
$600 and over	14	29

Powered Product Models By Cubic Inch Displacement




Hand Held Powered Products
(Except Chain Saws)
Number
80
70
60
50
40
30
20
10
0
Under $100
$100 - $199
$200 - $299
$300 - $399
$400 - $499
$500 and over
Suggested Retail Price
No. of Manufacturers
No.of Models

HAND HELD POWER EQUIPMENT (EXCEPT CHAIN SAWS)

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Dolmar	MS-340	2.01 CID	2.24 HP		1.110/CID	.150	BC
Dolmar	MS-3300	2.01 CID	2.24 HP		1.110/CID	.120	BC
Dolmar	MS-4000	2.37 CID	2.52 HP		1.060/CID	.140	BC
Dolmar	MS-4500	2.74 CID	3.22 HP		1.170/CID	.180	BC
Echo	GT 2000	1.29 CID	.80 HP	8,000	.620/CID	.086	TR
Echo	SRM 2100	1.29 CID	.80 HP	8,000	.620/CID	.071	TR-BC
Echo	SRM 2110	1.29 CID	.80 HP	8,000	.620/CID	.063	TR-BC
Echo	PE 2000	1.29 CID	.80 HP	8,000	.620/CID	.065	ED
Echo	PB 2100	1.29 CID	.80 HP	8,000	.620/CID	.090	BL
Echo	PB 210E	1.29 CID	.80 HP	8,000	.620/CID	.086	BL
Echo	HC 1500	1.29 CID	.80 HP	8,000	.620/CID	.081	HT
Echo	HC 1600	1.29 CID	.80 HP	8,000	.620/CID	.069	HT
Echo	HC 2000	1.29 CID	.80 HP	8,000	.620/CID	.069	HT
Echo	ES 2100	1.29 CID	.80 HP	8,000	.620/CID	.088	VC
Echo	GT 2400	1.44 CID	1.0 HP	8,000	.694/CID	.095	TR
Echo	SRM 2400	1.44 CID	1.0 HP	8,000	.694/CID	.078	TR-BC
Echo	PE 2400	1.44 CID	1.0 HP	8,000	.694/CID	.075	ED
Echo	PB 2400	1.44 CID	1.0 HP	8,000	.694/CID	.014	BL
Echo	HC 2410	1.44 CID	1.0 HP	8,000	.694/CID	.072	HT
Echo	ES 2400	1.44 CID	1.0 HP	8,000	.694/CID	.059	VC
Efco	E 8260 LAV	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR-BC
Efco	E 8260 TA	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR-BC
Efco	E 8260 DAV	1.58 CID	1.0 HP	7,000	.632/CID	.073	TR-BC
Efco	E 8260 BAV	1.58 CID	1.0 HP	7,000	.632/CID	.079	TR-BC
Efco	E 8350 LAV	2.13 CID	1.48 HP	7,500	.694/CID	.102	TR-BC
Efco	E 8350 BAV	2.13 CID	1.49 HP	7,500	.694/CID	.091	TR-BC
Efco	E 8460 BAV	2.56 CID	1.8 HP	6,700	.703/CID	.101	TR-BC
Efco	E 8510 BAV	3.06 CID	2.1 HP	6,700	.686/CID	.117	TR-BC
Fradan	BB 50	2.50 CID					BPB
Fradan	ST 30	1.86 CID					ST
Fradan	SE 30	1.86 CID					ED
Fradan	BC 30	1.86 CID					BC
Green Machine	2600	1.37 CID	1.0 HP	7,500	.720/CID	.100	ST BC
Green Machine	2800	1.59 CID	1.3 HP	7,500	.810/CID	.100	ST BC
Green Machine	3000 J	1.59 CID	1.3 HP	7,500	.810/CID	.080	ST BC
Green Machine	3000 B	1.59 CID	1.3 HP	7,500	.810/CID	.070	ST BC
Green Machine	4000 J	2.47 CID	2.0 HP	7,000	.800/CID	.110	ST BC
Green Machine	4000 B	2.47 CID	2.0 HP	7,000	.800/CID	.100	ST BC
Green Machine	1940	1.83 CID	1.13 HP	7,500	.601/CID	.080	ST BC
Green Machine	2840	1.59 CID	1.3 HP	7,500	.810/CID	.090	ST BC
Green Machine	4600 BP	2.45 CID	1.85 HP	7,000	.755/CID	.100	BL
Green Machine	3000 HB	1.83 CID	1.13 HP	7,500	.810/CID	.100	BL
Green Machine	2600 H	1.59 CID	1.3 HP	7,500	.810/CID	.090	HT
Green Machine	1900	1.37 CID	1.0 HP	7,500	.720/CID	.070	ED
Hoffco	PH 980	5.2 CID	4.1 HP	5,000	.788/CID	.130	AV
Hoffco	PH 1700 A	6.0 CID	3.8 HP	4,500	.683/CID	.090	AV
Hoffco	Li'l Hoe	2.0 CID	1.6 HP	6,000	.800/CID	.060	CU
Hoffco	WW 88	5.2 CID	4.1 HP	5,000	.788/CID	.150	TR BC
Hoffco	GT 21	1.29 CID	.80 HP	8,000	.620/CID	.060	TR
Hoffco	GT 211 A	1.29 CID	.80 HP	8,000	.620/CID	.060	TR
Hoffco	JP 220 F	1.49 CID	1.2 HP	7,000	.805/CID	.100	TR BC
Hoffco	JP 260 C	1.29 CID	.80 HP	8,000	.620/CID	.060	TR BC
Hoffco	JP 300 F	1.49 CID	1.2 HP	7,000	.805/CID	.090	TR BC
Hoffco	JP 390 C	1.86 CID	1.8 HP	7,000	.816/CID	.130	TR BC

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Hoffco	JP 490	3.0 CID	1.6 HP	6,000	.800/CID	.090	TR BC
Hoffco	SE 301 F	1.35 CID	1.1 HP	7,000	.814/CID	.070	ED
Homelite	hx 16	.98 CID	.45 HP	6,000	.459/CID		HT
Homelite	ht 22	.98 CID	.45 HP	6,000	.459/CID		HT
Homelite	Z 725 ee	1.52 CID	.85 HP	7,500	.559/CID	.078	TR-BC
Homelite	Z 725 cea	1.52 CID	.85 HP	7,500	.559/CID	.053	TR-BC
Homelite	hit 15	1.52 CID	.85 HP	7,500	.559/CID	.089	TR-BC
Homelite	hb 100	1.52 CID	.85 HP	7,500	.559/CID	.088	BL
Homelite	d 25 mhv	1.52 CID	.85 HP	7,500	.559/CID	.077	BL
Homelite	Z 25 ehv	1.52 CID	.85 HP	7,500	.559/CID	.070	BL
Homelite	st 385	1.83 CID	1.13 HP	7,500	.617/CID	.086	TR-BC
Homelite	d 830 oca	1.83 CID	1.13 HP	7,500	.617/CID	.070	TR-BC
Homelite	d 830 sba	1.83 CID	1.13 HP	7,500	.617/CID	.070	TR-BC
Homelite	d 630 ed	1.83 CID	1.13 HP	7,500	.617/CID	.113	TR-BC
Homelite	d 830 sd	1.83 CID	1.13 HP	7,500	.617/CID	.094	TR-BC
Homelite	d 830 sb	1.83 CID	1.13 HP	7,500	.617/CID	.086	TR-BC
Homelite	PLT 3400	1.83 CID	1.13 HP	7,500	.617/CID	.086	TR-BC
Homelite	PLT 3600	1.83 CID	1.13 HP	7,500	.617/CID	.083	TR-BC
Homelite	d 30 mha	1.83 CID	1.13 HP	7,500	.617/CID	.103	BL
Homelite	d 30 mhv	1.83 CID	1.13 HP	7,500	.617/CID	.103	BL
Homelite	bp 250	1.83 CID	1.13 HP	7,500	.617/CID	.088	BL
Homelite	htc 12	1.83 CID	1.13 HP	7,500	.617/CID	.047	CL
Husqvarna	21 LCN ✓	1.3 CID	.60 HP	7,500	.460/CID	.070	TR CL
Husqvarna	Mondo ✓	1.3 CID	.70 HP	9,000	.538/CID	.076	TR CL
Husqvarna	32 L	2.0 CID	.90 HP	7,500	.450/CID	.072	TR CL
Husqvarna	32 LC	2.0 CID	.90 HP	7,500	.450/CID	.072	TR CL
Husqvarna	122 L	1.4 CID	.70 HP	10,800	.500/CID	.073	TR CL
Husqvarna	225 L	1.5 CID	1.2 HP	11,000	.800/CID	.076	TR CL
Husqvarna	225 LD	1.5 CID	1.2 HP	11,000	.800/CID	.074	TR CL
Husqvarna	225 RJ	1.5 CID	1.2 HP	11,000	.800/CID	.074	TR CL
Husqvarna	225 RD	1.5 CID	1.2 HP	11,000	.800/CID	.069	TR CL
Husqvarna	225 R	1.5 CID	1.2 HP	11,000	.800/CID	.076	TR CL
Husqvarna	232 L	1.9 CID	1.5 HP	10,800	.789/CID	.117	TR CL
Husqvarna	232 R	1.9 CID	1.5 HP	10,800	.789/CID	.107	TR CL
Husqvarna	235 R	2.2 CID	1.8 HP	11,000	.810/CID	.115	TR CL
Husqvarna	240 RBD	2.2 CID	1.8 HP	11,000	.818/CID	.062	TR CL
Husqvarna	240 R	2.4 CID	2.4 HP	12,500	.818/CID	.062	TR CL
Husqvarna	245 R	2.7 CID	2.7 HP	12,500	1.000/CID	.147	TR CL
Husqvarna	245 RX	2.7 CID	2.7 HP	12,500	1.000/CID	.150	TR CL
Husqvarna	250 RX	3.0 CID	3.3 HP	12,500	1.100/CID	.170	TR CL
Husqvarna	265 RX	4.0 CID	4.7 HP	11,000	1.175/CID	.200	TR CL
Husqvarna	18 H	1.1 CID					HT
Husqvarna	25 H	1.6 CID					HT
Husqvarna	26 H	1.6 CID					HT
Husqvarna	250 PS	3.0 CID	2.4 HP	11,000	.800/CID	.147	PS
Husqvarna	235 P	2.2 CID	1.8 HP	10,500	.818/CID	.110	PS
Husqvarna	122 HB	1.3 CID	.70 HP	9,000	.538/CID	.063	BL
Husqvarna	132 HBY	1.9 CID	1.5 HP	10,800	.789/CID	.121	BL
Husqvarna	140 B	2.4 CID	2.4 HP	12,000	1.000/CID	.123	BPBL
John Deere	T 30 c	1.83 CID	1.3 HP	7,500	.617/CID	.125	TR
John Deere	T 30 s	1.83 CID	1.3 HP	7,500	.617/CID	.104	TR
John Deere	T 30 sb	1.83 CID	1.3 HP	7,500	.617/CID	.098	TR
John Deere	T 23 s	1.38 CID	1.0 HP	7,500	.720/CID	.080	TR
John Deere	T 26 sb	1.59 CID	1.3 HP	7,500	.810/CID	.100	TR
John Deere	T 40 sb	2.47 CID	2.0 HP	7,000	.800/CID	.100	TR

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Jonsered	RS 51 PRO	3.1 CID	3.4 HP	9,300	1.096/CID	.175	TR-BC
Jonsered	RS 44	2.7 CID	2.7 HP	9,000	1.000/CID	.150	TR-BC
Jonsered	GR 50 PRO	2.97 CID	2.94 HP	9,000	.989/CID	.154	TR-BC
Jonsered	GR 41	2.45 CID	2.52 HP	9,000	1.028/CID	.132	TR-BC
Jonsered	GR 36	2.2 CID	1.7 HP	9,000	.772/CID	.140	TR-BC
Jonsered	GR 32 D	1.9 CID	1.6 HP	9,000	.842/CID	.115	TR-BC
Jonsered	GR 32 L	1.9 CID	1.6 HP	9,000	.842/CID	.115	TR-BC
Jonsered	GR 26 D	1.6 CID	1.2 HP	9,000	.750/CID	.126	TR-BC
Jonsered	GR 26 L	1.6 CID	1.2 HP	9,000	.750/CID	.095	TR-BC
Jonsered	GR 26 Combi	1.6 CID	1.2 HP	9,000	.750/CID	.095	TR BC ED HT
Jonsered	GT 24 L	1.29 CID	.98 HP	9,000	.759/CID	.092	TR-BC
Jonsered	GT 22 L	1.29 CID	.98 HP	9,000	.759/CID	.098	TR-BC
Jonsered	GT 21 L	1.29 CID	.98 HP	9,000	.759/CID	.103	TR
Jonsered	HP 36	1.9 CID	1.6 HP	9,000	.842/CID	.101	PR
Jonsered	BP 40 Combi	1.9 CID	1.6 HP	9,000	.842/CID	.101	TR ED HT
Jonsered	HT 24	1.29 CID	1.03 HP	8,000	.798/CID	.091	HT
Jonsered	HT 22	1.29 CID	1.03 HP	8,000	.798/CID	.091	HT
Jonsered	HT 2	1.09 CID	.84 HP	6,500	.770/CID	.088	HT
Jonsered	BV 32	1.93 CID	.91 HP	6,500	.471/CID	.072	BL
Jonsered	WP 25	1.29 CID	1.03 HP	8,000	.798/CID	.083	PU
Makita	RBL 250	1.9 CID	1.2 HP	7,000	.805/CID	.250	BL
Makita	RBC 221	1.32 CID	1.0 HP	7,000	.757/CID	.227	TR
Makita	RST 250	1.49 CID	1.2 HP	7,000	.805/CID	.127	TR BC
Makita	RBC 251	1.49 CID	1.2 HP	7,000	.805/CID	.133	TR BC
Makita	RBC 25 A	1.49 CID	1.2 HP	7,000	.805/CID	.120	TR BC
Makita	RB 25 A	1.49 CID	1.2 HP	7,000	.805/CID	.121	TR BC
Makita	RBC 25 B	1.49 CID	1.2 HP	7,000	.805/CID	.124	TR
Makita	RBC 252	1.49 CID	1.2 HP	7,000	.805/CID	.120	BC
Makita	RBE 250	1.49 CID	1.2 HP	7,000	.805/CID	.250	ED
Makita	RBC 310	1.86 CID	1.5 HP	7,000	.806/CID	.108	ED
Makita	RBC 311	1.86 CID	1.5 HP	7,000	.806/CID	.108	ED
Maruyama	BC 201	1.2 CID					TR
Maruyama	BC 320	1.94 CID					TR
Maruyama	BC 260 H	1.54 CID					BC
Maruyama	BC 320 H	1.94 CID					BC
Maruyama	BC 420 H	2.53 CID					BC
Maruyama	BC 500 H	3.06 CID					BC
Maruyama	HT 2300	1.38 CID					HT
Maruyama	HT 230	1.38 CID					HT
Maruyama	HT 230 L	1.38 CID					HT
Maruyama	HT 260	1.55 CID					HT
Maruyama	ED 261	1.55 CID					ED
McCulloch	GLE 2380	1.29 CID	.80 HP	8,000	.620/CID	.059	ED
McCulloch	2000	1.29 CID	.80 HP	8,000	.620/CID	.182	TR
McCulloch	2250	1.53 CID					TR
McCulloch	2310	1.29 CID	.80 HP	8,000	.620/CID	.100	TR BC
McCulloch	2030	1.29 CID	.80 HP	8,000	.620/CID	.076	TR
McCulloch	2560	1.53 CID					TR BC
McCulloch	2565	1.53 CID					TR BC
McCulloch	3000	1.83 CID					TR BC
McCulloch	2360	1.29 CID	.80 HP	8,000	.620/CID	.059	TR BC
McCulloch	3900	2.32 CID					TR BC
McCulloch	GLE 2580	1.53 CID					ED
McCulloch	GHT 24	1.29 CID	.80 HP	8,000	.620/CID	.065	HT
McCulloch	GHT 30	1.29 CID	.80 HP	8,000	.620/CID	.063	HT
McCulloch	PB 250	1.53 CID					BL

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Olympyk	OL 8260 LAV	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR BC
Olympyk	OL 826 TA	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR BC
Olympyk	OL 8260 DAV	1.58 CID	1.0 HP	7,000	.632/CID	.073	TR BC
Olympyk	OL 8260 BAV	1.58 CID	1.0 HP	7,000	.632/CID	.079	TR BC
Olympyk	OL 8350 LAV	2.13 CID	1.48 HP	7,500	.694/CID	.102	TR BC
Olympyk	OL 350 BAV	2.13 CID	1.48 HP	7,500	.694/CID	.091	TR BC
Olympyk	OL 8460 BAV	2.56 CID	1.8 HP	6,700	.703/CID	.101	TR BC
Olympyk	OL 8510 BAV	3.06 CID	2.1 HP	6,700	.686/CID	.117	TR BC
Poulon/Weed Eater	113	1.28CID					TR
Poulon/Weed Eater	114	1.95 CID					TR
Poulon/Weed Eater	115	1.28 CID					TR
Poulon/Weed Eater	165	1.28 CID					TR
Poulon/Weed Eater	185	1.95 CID					TR
Poulon/Weed Eater	200	2.45 CID	1.85 HP	7,000	.755/CID	.088	TR BC
Poulon/Weed Eater	442	2.45 CID	1.85 HP	7,000	.755/CID		BPB
Poulon/Weed Eater	452 MVB	1.95 CID					BL VU
Red Max	BT 2000	1.38 CID	1.2 HP	7,500	.869/CID	.109	TR
Red Max	BC 2001 DL	1.38 CID	1.2 HP	7,500	.869/CID	.111	TR BC
Red Max	BC 2600 DL	1.55 CID	1.4 HP	8,000	.903/CID	.122	TR BC
Red Max	BC 342 DL	2.05 CID	1.7 HP	7,000	.829/CID	.111	TR BC
Red Max	BC 442 DWM	2.53 CID	2.2 HP	7,000	.869/CID	.119	TR BC
Red Max	EB 431	2.53 CID	2.2 HP	7,000	.869/CID	.125	BPB
Red Max	EBA 430	2.53 CID	2.2 HP	7,000	.869/CID	.103	BPB
Red Max	EB 441	2.53 CID	2.2 HP	7,000	.869/CID	.116	BPB
Red Max	EBA 440	2.53 CID	2.2 HP	7,000	.869/CID	.097	BPB
Red Max	CHT 230 DL	1.38 CID	1.2 HP	7,500	.869/CID	.104	HT
Red Max	HB 2300	1.38 CID	1.2 HP	7,500	.869/CID	.151	BL
Red Max	CHT 2300	1.38 CID	1.2 HP	7,500	.869/CID	.112	HT
Red Max	HT 2300	1.38 CID	1.2 HP	7,500	.869/CID	.107	HT
Red Max	HT 2300 L	1.38 CID	1.2 HP	7,500	.869/CID	.092	HT
Red Max	AG 230	1.38 CID	1.2 HP	7,500	.869/CID	.107	AU
Red Max	AG 431	2.53 CID	2.2 HP	7,000	.869/CID	.110	AU
Red Max	ED 230	1.38 CID	1.2 HP	7,500	.869/CID	.115	DR
Red Max	SG 220 DL	1.38 CID	1.2 HP	7,500	.869/CID	.085	TR ED
Red Max	HE 2600	1.55 CID	1.4 HP	8,000	.903/CID	.105	ED
Robin America	NB 252	1.49 CID	1.0 HP	7,000	.671/CID	.116	TR BC
Robin America	NB 27	1.66 CID	1.2 HP	7,000	.723/CID	.092	TR BC
Robin America	NB 31	1.86 CID	1.5 HP	7,000	.806/CID	.115	TR BC
Robin America	NB 351	2.09 CID	1.7 HP	7,000	.813/CID	.108	TR BC
Robin America	NB 411	2.45 CID	2.0 HP	7,000	.816/CID	.124	TR BC
Robin America	NB 50	3.15 CID	2.5 HP	7,000	.793/CID	.131	TR BC
Ryobi	700 r	1.89 CID	1.0 HP	8,000	.529/CID	.105	TR
Ryobi	705 r	1.89 CID	1.0 HP	8,000	.529/CID	.111	TR
Ryobi	725 r	1.89 CID	1.0 HP	8,000	.529/CID	.095	TR Combo
Ryobi	790 r	1.89 CID	1.0 HP	8,000	.529/CID	.066	TR
Ryobi	780 r	1.89 CID	1.0 HP	8,000	.529/CID	.066	TR BC
Ryobi	775 r	1.89 CID	1.0 HP	8,000	.529/CID	.090	TR Combo
Ryobi	765 r	1.89 CID	1.0 HP	8,000	.529/CID	.090	TR
Ryobi	750 r	1.89 CID	1.0 HP	8,000	.529/CID	.083	TR
Ryobi	740 r	1.89 CID	1.0 HP	8,000	.529/CID	.083	TR BC
Ryobi	767 r	1.89 CID	1.0 HP	8,000	.529/CID	.090	TR
Shindaiwa	220	1.3 CID	.8 HP	6,800	.615/CID	.068	TR
Shindaiwa	210	1.3 CID	.8 HP	6,800	.615/CID	.068	TR

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Shindaiwa	T 27	1.7 CID	1.5 HP	8,500	.882/CID	.081	TR
Shindaiwa	T 250	1.5 CID	1.2 HP	7,000	.800/CID	.109	TR
Shindaiwa	T 25	1.5 CID	1.4 HP	8,000	.933/CID	.113	TR
Shindaiwa	T 230	1.4 CID	1.1 HP	7,500	.785/CID	.115	TR
Shindaiwa	F 230	1.4 CID	1.1 HP	7,500	.785/CID	.113	TR
Shindaiwa	T 20	1.3 CID	1.1 HP	7,500	.846/CID	.113	TR
Shindaiwa	LE 250	1.5 CID	1.2 HP	7,000	.800/CID	.097	ED
Shindaiwa	LE 230	1.4 CID	1.1 HP	7,500	.785/CID	.092	ED
Shindaiwa	RC 45	2.5 CID	2.3 HP	8,000	.920/CID	.128	BC
Shindaiwa	B 45	2.5 CID	2.3 HP	8,000	.920/CID	.128	BC
Shindaiwa	BP 35	2.1 CID	1.8 HP	7,500	.857/CID	.087	BC
Shindaiwa	C 35	2.1 CID	1.8 HP	7,500	.857/CID	.127	BC
Shindaiwa	C 27	1.7 CID	1.5 HP	8,000	.882/CID	.121	BC
Shindaiwa	C 250	1.5 CID	1.2 HP	7,000	.800/CID	.130	BC
Shindaiwa	C 230	1.4 CID	1.1 HP	7,500	.785/CID	.108	BC
Shindaiwa	HT 20	1.3 CID	1.1 HP	7,500	.846/CID	.092	HT
Shindaiwa	EB 240	2.4 CID	1.2 HP	8,000	.500/CID	.129	BL
Solo	414	3.29 CID	2.5 HP	7,000	.759/CID	.147	TR-BC
Solo	127	1.53 CID	1.33 HP	6,500	.869/CID	.092	TR
Solo	130	1.83 CID	1.96 HP	7,000	1.07/CID	.135	TR-BC
Solo	639	2.33 CID	2.66 HP	7,000	1.14/CID	.268	TR-BC
Solo	645	2.70 CID	3.08 HP	7,000	1.14/CID	.311	TR-BC
Solo	423	4.13 CID	3.64 HP	7,000	.881/CID	.143	TR
Stihl	FS 36	1.84 CID	.93 HP		.505/CID	.086	TR-BC
Stihl	FS 40	1.84 CID	.93 HP		.505/CID	.079	TR-BC
Stihl	FS 44 J	1.84 CID	.93 HP		.505/CID	.075	TR-BC
Stihl	FS 44 R	1.84 CID	.93 HP		.505/CID	.092	TR-BC
Stihl	FS 160	1.82 CID	.93 HP		.510/CID	.059	BC
Stihl	FS 106 AVE	2.10 CID	1.5 HP		.714/CID	.094	BC
Stihl	FR 106	2.10 CID	1.5 HP		.714/CID	.063	BC
Stihl	FS 180	2.15 CID	1.54 HP		.716/CID	.098	BC
Stihl	FS 280 K	2.38 CID					
Stihl	FS 360 AVEZ	3.15 CID					
Stihl	FS 88 AVRE	1.55 CID	1.2 HP		.774/CID	.092	TR-BC
Stihl	FS 88 AVE	1.55 CID	1.2 HP		.774/CID	.084	TR-BC
Stihl	FC 72	1.45 CID	.95 HP		.655/CID	.075	ED
Stihl	FC 44	1.84 CID	.93 HP		.505/CID	.069	ED
Stihl	FS 74 AVE	1.45 CID	.95 HP		.655/CID	.110	TR-BC
Stihl	FS 86 AVRE	1.45 CID	.95 HP		.655/CID	.075	TR-BC
Stihl	HS 72	1.45 CID	.95 HP		.655/CID	.081	HT
Stihl	HS 74	1.45 CID	.95 HP		.655/CID	.079	HT
Stihl	HS 76	1.45 CID	.95 HP		.655/CID	.086	HT
Stihl	BG 72	1.45 CID	.95 HP		.655/CID	.105	BL
Stihl	BR 400	3.44 CID	3.5 HP		1.017/CID	.189	BPB
Stihl	S 400	3.44 CID	3.5 HP		1.017/CID	.145	BPB
Stihl	BR 106	2.1 CID	1.5 HP		.523/CID	.063	BPB
Stihl	BR 320	2.73 CID	2.8 HP		1.03/CID	.151	BPB
Stihl	BR 320 L	2.73 CID	2.8 HP		1.03/CID	.141	BPB
Stihl	SR 320	2.73 CID	2.8 HP		1.03/CID	.117	BPB
Tanaka	TBC 4000	1.2 CID	1.0 HP	8,000	.833/CID	.091	TR
Tanaka	TBC 4500	1.2 CID	1.0 HP	8,000	.833/CID	.090	BC
Tanaka	TBG 220	1.3 CID	1.1 HP	8,500	.840/CID	.096	TR BC
Tanaka	TBG 250	1.4 CID	1.2 HP	8,000	.857/CID	.103	TR
Tanaka	TPE 250	1.4 CID	1.2 HP	8,000	.857/CID	.090	ED
Tanaka	TBC 265	1.56 CID	1.3 HP	9,000	.833/CID	.114	TR BC
Tanaka	TBC 300	1.8 CID	1.5 HP	8,500	.833/CID	.118	TR BC

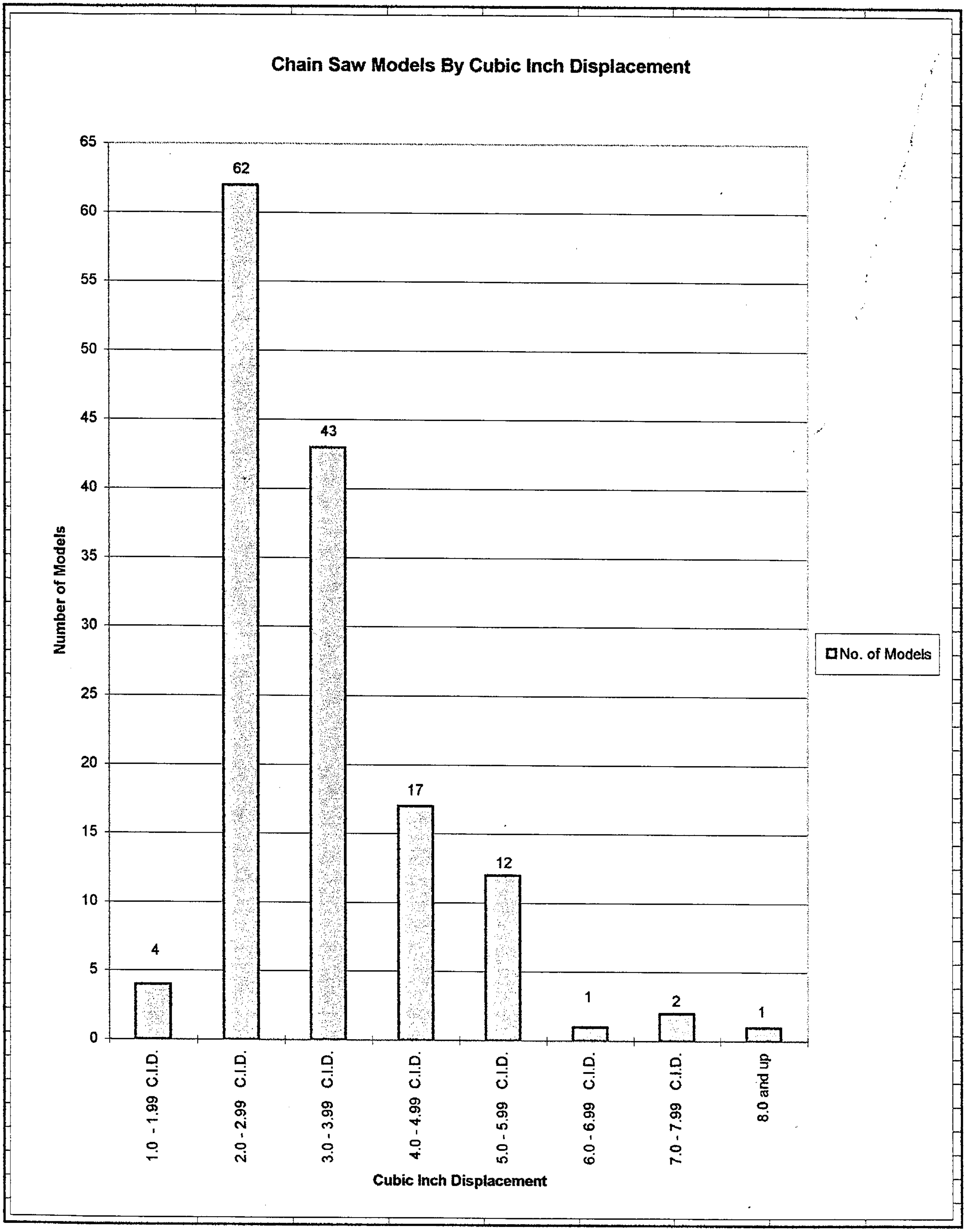
Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Tanaka	TBC 355	2.1 CID	1.8 HP	8,000	.857/CID	.066	TR BC
Tanaka	TBC 422 C	2.4 CID	2.1 HP	7,500	.958/CID	.116	TR BC
Tanaka	TBC 500	2.8 CID	2.5 HP	7,000	.892/CID	.125	TR BC
Tanaka	AST 5000	1.2 CID	1.0 HP	8,500	.830/CID	.076	TR BC
Tanaka	AST 7000 S	1.2 CID	1.0 HP	8,500	.830/CID	.076	TR BC
Tanaka	THT 210	1.3 CID	1.0 HP	8,000	.769/CID	.099	HT
Tanaka	THT 2120	1.3 CID	1.0 HP	8,000	.769/CID	.090	HT
Tanaka	THT 240	1.3 CID	1.0 HP	8,000	.769/CID	.890	HT
Tanaka	TCP 210	1.3 CID	1.0 HP	8,000	.769/CID	.890	PU
Tanaka	TCP 381	3.06 CID	2.1 HP	5,500	.677/CID	.100	PU
Tanaka	TEA 500	3.06 CID	2.1 HP	5,500	.677/CID	.056	AU
Tanaka	TLE 550	3.06 CID	2.1 HP	5,500	.677/CID	.024	ED
Tanaka	TED 210	1.3 CID	1.0 HP	8,000	.769/CID	.101	PU
Tanaka	TIA 340	1.86 CID	1.3 HP	8,000	.698/CID	.073	AU
Tanaka	THT 262	1.6 CID	1.3 HP	8,500	.812/CID	.131	HT
Tanaka	TED 262 L	1.6 CID	1.3 HP	8,500	.812/CID	.118	DR
Tanaka	TED 262 R	1.6 CID	1.3 HP	8,500	.812/CID	.118	DR
Tanaka	TED 262 DM	1.6 CID	1.3 HP	8,500	.812/CID	.095	DR
Tanaka	TBL 505	2.62 CID	2.1 HP	7,500	1.06/CID	.122	BPB
Tanaka	TBL 4600	2.6 CID	2.8 HP	7,500	1.08/CID	.129	BPB
TMC	KPW 2523	1.38 CID	.80 HP	7,000	.579/CID	.060	BC
TMC	KPW 2528	1.71 CID					BC
TMC	KPW 2525	1.47 CID	.80 HP	6,500	.544/CID	.066	BC
TMC	KPW 3410	2.03 CID	1.2 HP	6,500	.590/CID	.080	BC
TMC	KTBL 2300	1.38 CID	.80 HP	7,000	.579/CID	.080	BL
TMC	PHT 3550 A	1.38 CID	.80 HP	7,000	.579/CID	.070	HT
TMC	KTBL 5600	3.45 CID					BPB
Vandermolen	L 2035 G	1.24 CID	.70 HP	7,000	.564/CID	.068	TR
Vandermolen	L 2415 G	1.47 CID	.80 HP	6,500	.544/CID	.067	TR
Vandermolen	L 2815 G	1.71 CID					BC

HAND HELD POWER EQUIPMENT WITH DUPLICATE DISPLACEMENT DELETED

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Dolmar	MS-340	2.01 CID	2.24 HP		1.110/CID	.150	BC
Dolmar	MS-4000	2.37 CID	2.52 HP		1.060/CID	.140	BC
Dolmar	MS-4500	2.74 CID	3.22 HP		1.170/CID	.180	BC
Echo	GT 2000	1.29 CID	.80 HP	8,000	.620/CID	.086	TR
Echo	GT 2400	1.44 CID	1.0 HP	8,000	.694/CID	.095	TR
Efco	E 8260 LAV	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR-BC
Efco	E 8350 LAV	2.13 CID	1.48 HP	7,500	.694/CID	.102	TR-BC
Efco	E 8460 BAV	2.56 CID	1.8 HP	6,700	.703/CID	.101	TR-BC
Efco	E 8510 BAV	3.06 CID	2.1 HP	6,700	.686/CID	.117	TR-BC
Fradan	BB 50	2.50 CID					BPB
Fradan	ST 30	1.86 CID					ST
Green Mach.	2600	1.37 CID	1.0 HP	7,500	.720/CID	.100	ST BC
Green Mach.	2800	1.59 CID	1.3 HP	7,500	.810/CID	.100	ST BC
Green Mach.	4000 J	2.47 CID	2.0 HP	7,000	.800/CID	.110	ST BC
Green Mach.	1940	1.83 CID	1.13 HP	7,500	.601/CID	.080	ST BC
Green Mach.	4600 BP	2.45 CID	1.85 HP	7,000	.755/CID	.100	BL
Hoffco	PH 980	5.2 CID	4.1 HP	5,000	.788/CID	.130	AV
Hoffco	PH 1700 A	6.0 CID	3.8 HP	4,500	.683/CID	.090	AV
Hoffco	Li'l Hoe	2.0 CID	1.6 HP	6,000	.800/CID	.060	CU
Hoffco	GT 21	1.29 CID	.80 HP	8,000	.620/CID	.060	TR
Hoffco	JP 220 F	1.49 CID	1.2 HP	7,000	.805/CID	.100	TR BC
Hoffco	JP 390 C	1.86 CID	1.8 HP	7,000	.816/CID	.130	TR BC
Hoffco	JP 490	3.0 CID	1.6 HP	6,000	.800/CID	.090	TR BC
Hoffco	SE 301 F	1.35 CID	1.1 HP	7,000	.814/CID	.070	ED
Homelite	hx 16	.98 CID	.45 HP	6,000	.459/CID		HT
Homelite	Z 725 ee	1.52 CID	.85 HP	7,500	.559/CID	.078	TR-BC
Homelite	st 385	1.83 CID	1.13 HP	7,500	.617/CID	.086	TR-BC
Husqvarna	21 LCN	1.3 CID	.60 HP	7,500	.460/CID	.070	TR CL
Husqvarna	Mondo	1.3 CID	.70 HP	9,000	.538/CID	.076	TR CL
Husqvarna	32 L	2.0 CID	.90 HP	7,500	.450/CID	.072	TR CL
Husqvarna	122 L	1.4 CID	.70 HP	10,800	.500/CID	.073	TR CL
Husqvarna	225 L	1.5 CID	1.2 HP	11,000	.800/CID	.076	TR CL
Husqvarna	232 L	1.9 CID	1.5 HP	10,800	.789/CID	.117	TR CL
Husqvarna	235 R	2.2 CID	1.8 HP	11,000	.810/CID	.115	TR CL
Husqvarna	240 R	2.4 CID	2.4 HP	12,500	.818/CID	.062	TR CL
Husqvarna	245 R	2.7 CID	2.7 HP	12,500	1.000/CID	.147	TR CL
Husqvarna	250 RX	3.0 CID	3.3 HP	12,500	1.100/CID	.170	TR CL
Husqvarna	265 RX	4.0 CID	4.7 HP	11,000	1.175/CID	.200	TR CL
Husqvarna	18 H	1.1 CID					HT
Husqvarna	25 H	1.6 CID					HT
Husqvarna	250 PS	3.0 CID	2.4 HP	11,000	.800/CID	.147	PS
John Deere	T 30 c	1.83 CID	1.3 HP	7,500	.617/CID	.125	TR
John Deere	T 23 s	1.38 CID	1.0 HP	7,500	.720/CID	.080	TR
John Deere	T 26 sb	1.59 CID	1.3 HP	7,500	.810/CID	.100	TR
John Deere	T 40 sb	2.47 CID	2.0 HP	7,000	.800/CID	.100	TR
Jonsered	RS 51 PRO	3.1 CID	3.4 HP	9,300	1.096/CID	.175	TR-BC
Jonsered	RS 44	2.7 CID	2.7 HP	9,000	1.000/CID	.150	TR-BC
Jonsered	GR 50 PRO	2.97 CID	2.94 HP	9,000	.989/CID	.154	TR-BC
Jonsered	GR 41	2.45 CID	2.52 HP	9,000	1.028/CID	.132	TR-BC
Jonsered	GR 36	2.2 CID	1.7 HP	9,000	.772/CID	.140	TR-BC

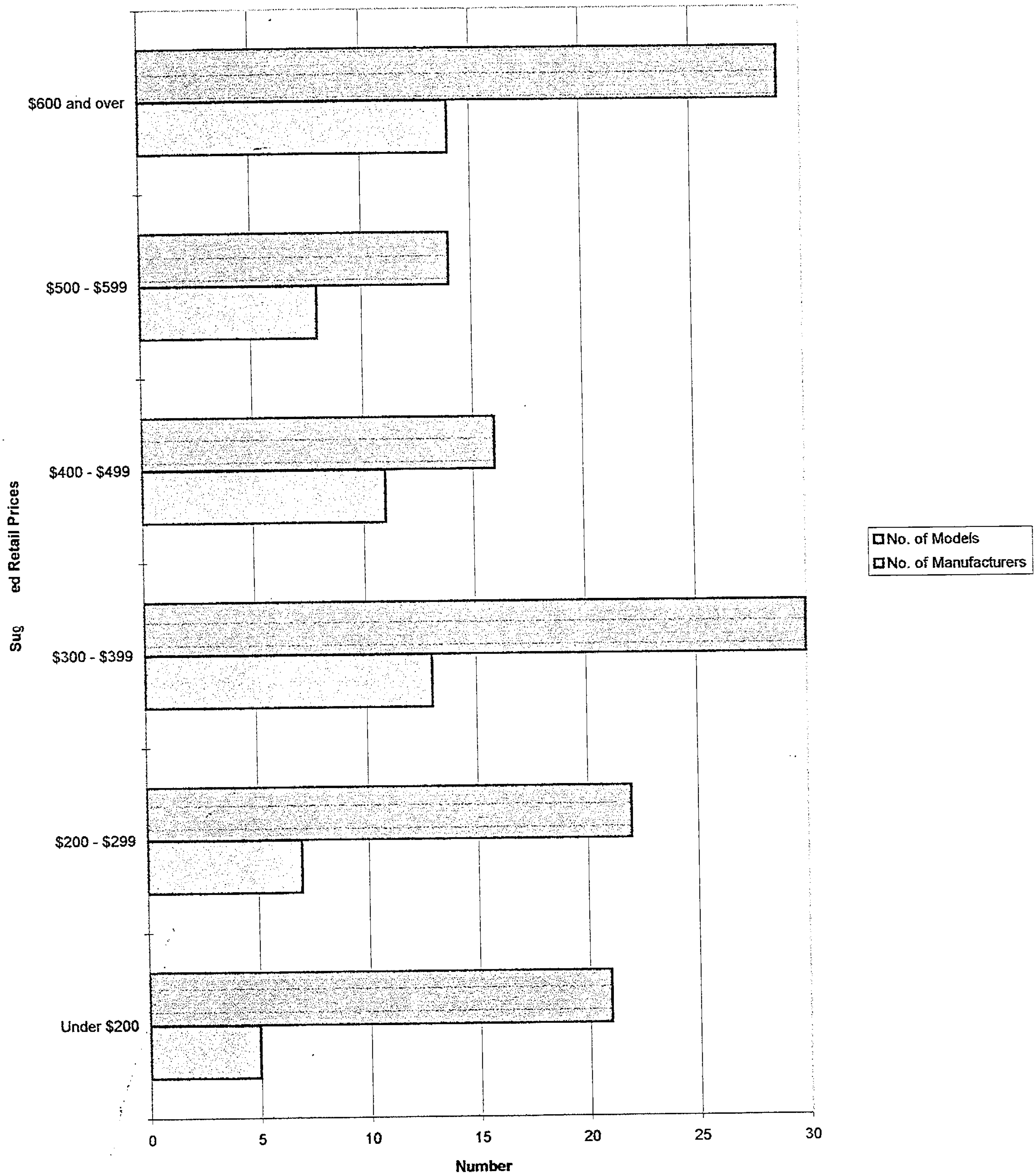
Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Jonsered	GR 32 D	1.9 CID	1.6 HP	9,000	.842/CID	.115	TR-BC
Jonsered	GR 26 D	1.6 CID	1.2 HP	9,000	.750/CID	.126	TR-BC
Jonsered	GT 24 L	1.29 CID	.98 HP	9,000	.759/CID	.092	TR-BC
Jonsered	HT 2	1.09 CID	.84 HP	6,500	.770/CID	.088	HT
Jonsered	BV 32	1.93 CID	.91 HP	6,500	.471/CID	.072	BL
Makita	RBL 250	1.9 CID	1.2 HP	7,000	.805/CID	.250	BL
Makita	RBC 221	1.32 CID	1.0 HP	7,000	.757/CID	.227	TR
Makita	RST 250	1.49 CID	1.2 HP	7,000	.805/CID	.127	TR BC
Makita	RBC 310	1.86 CID	1.5 HP	7,000	.806/CID	.108	ED
Maruyama	BC 201	1.2 CID					TR
Maruyama	BC 320	1.94 CID					TR
Maruyama	BC 260 H	1.54 CID					BC
Maruyama	BC 420 H	2.53 CID					BC
Maruyama	BC 500 H	3.06 CID					BC
Maruyama	HT 2300	1.38 CID					HT
McCulloch	GLE 2380	1.29 CID	.80 HP	8,000	.620/CID	.059	ED
McCulloch	2250	1.53 CID					TR
McCulloch	3000	1.83 CID					TR BC
McCulloch	3900	2.32 CID					TR BC
Olympyk	OL 8260 LAV	1.58 CID	1.0 HP	7,000	.632/CID	.090	TR BC
Olympyk	OL 8350 LAV	2.13 CID	1.48 HP	7,500	.694/CID	.102	TR BC
Olympyk	OL 8460 BAV	2.56 CID	1.8 HP	6,700	.703/CID	.101	TR BC
Olympyk	OL 8510 BAV	3.06 CID	2.1 HP	6,700	.686/CID	.117	TR BC
Poulon/W E	113	1.28CID					TR
Poulon/W E	114	1.95 CID					TR
Poulon/W E	200	2.45 CID	1.85 HP	7,000	.755/CID	.088	TR BC
Red Max	BT 2000	1.38 CID	1.2 HP	7,500	.869/CID	.109	TR
Red Max	BC 2600 DL	1.55 CID	1.4 HP	8,000	.903/CID	.122	TR BC
Red Max	BC 342 DL	2.05 CID	1.7 HP	7,000	.829/CID	.111	TR BC
Red Max	BC 442 DWM	2.53 CID	2.2 HP	7,000	.869/CID	.119	TR BC
Robin Amer.	NB 252	1.49 CID	1.0 HP	7,000	.671/CID	.116	TR BC
Robin Amer.	NB 27	1.66 CID	1.2 HP	7,000	.723/CID	.092	TR BC
Robin Amer.	NB 31	1.86 CID	1.5 HP	7,000	.806/CID	.115	TR BC
Robin Amer.	NB 351	2.09 CID	1.7 HP	7,000	.813/CID	.108	TR BC
Robin Amer.	NB 411	2.45 CID	2.0 HP	7,000	.816/CID	.124	TR BC
Robin Amer.	NB 50	3.15 CID	2.5 HP	7,000	.793/CID	.131	TR BC
Ryobi	700 r	1.89 CID	1.0 HP	8,000	.529/CID	.105	TR
Shindaiwa	220	1.3 CID	.8 HP	6,800	.615/CID	.068	TR
Shindaiwa	210	1.3 CID	.8 HP	6,800	.615/CID	.068	TR
Shindaiwa	T 27	1.7 CID	1.5 HP	8,500	.882/CID	.081	TR
Shindaiwa	T 250	1.5 CID	1.2 HP	7,000	.800/CID	.109	TR
Shindaiwa	T 25	1.5 CID	1.4 HP	8,000	.933/CID	.113	TR
Shindaiwa	T 230	1.4 CID	1.1 HP	7,500	.785/CID	.115	TR
Shindaiwa	RC 45	2.5 CID	2.3 HP	8,000	.920/CID	.128	BC
Shindaiwa	BP 35	2.1 CID	1.8 HP	7,500	.857/CID	.087	BC
Shindaiwa	EB 240	2.4 CID	1.2 HP	8,000	.500/CID	.129	BL
Solo	414	3.29 CID	2.5 HP	7,000	.759/CID	.147	TR-BC
Solo	127	1.53 CID	1.33 HP	6,500	.869/CID	.092	TR
Solo	130	1.83 CID	1.96 HP	7,000	1.07/CID	.135	TR-BC

Manufacturer	Model No.	CID	Max Output	RPM @ Max.	HP/CID	P/W Ratio	Products
Solo	639	2.33 CID	2.66 HP	7,000	1.14/CID	.268	TR-BC
Solo	645	2.70 CID	3.08 HP	7,000	1.14/CID	.311	TR-BC
Solo	423	4.13 CID	3.64 HP	7,000	.881/CID	.143	TR
Stihl	FS 36	1.84 CID	.93 HP		.505/CID	.086	TR-BC
Stihl	FS 160	1.82 CID	.93 HP		.510/CID	.059	BC
Stihl	FS 106 AVE	2.10 CID	1.5 HP		.714/CID	.094	BC
Stihl	FS 180	2.15 CID	1.54 HP		.716/CID	.098	BC
Stihl	FS 280 K	2.38 CID					
Stihl	FS 360 AVEZ	3.15 CID					
Stihl	FS 88 AVRE	1.55 CID	1.2 HP		.774/CID	.092	TR-BC
Stihl	FC 72	1.45 CID	.95 HP		.655/CID	.075	ED
Stihl	BR 400	3.44 CID	3.5 HP		1.017/CID	.189	BPB
Stihl	BR 106	2.1 CID	1.5 HP		.523/CID	.063	BPB
Stihl	BR 320	2.73 CID	2.8 HP		1.03/CID	.151	BPB
Tanaka	TBC 4000	1.2 CID	1.0 HP	8,000	.833/CID	.091	TR
Tanaka	TBG 220	1.3 CID	1.1 HP	8,500	.840/CID	.096	TR BC
Tanaka	TBG 250	1.4 CID	1.2 HP	8,000	.857/CID	.103	TR
Tanaka	TBC 265	1.56 CID	1.3 HP	9,000	.833/CID	.114	TR BC
Tanaka	TBC 300	1.8 CID	1.5 HP	8,500	.833/CID	.118	TR BC
Tanaka	TBC 355	2.1 CID	1.8 HP	8,000	.857/CID	.066	TR BC
Tanaka	TBC 422 C	2.4 CID	2.1 HP	7,500	.958/CID	.116	TR BC
Tanaka	TBC 500	2.8 CID	2.5 HP	7,000	.892/CID	.125	TR BC
Tanaka	TCP 381	3.06 CID	2.1 HP	5,500	.677/CID	.100	PU
Tanaka	TIA 340	1.86 CID	1.3 HP	8,000	.698/CID	.073	AU
Tanaka	THT 262	1.6 CID	1.3 HP	8,500	.812/CID	.131	HT
Tanaka	TBL 505	2.62 CID	2.1 HP	7,500	1.06/CID	.122	BPB
Tanaka	TBL 4600	2.6 CID	2.8 HP	7,500	1.08/CID	.129	BPB
TMC	KPW 2523	1.38 CID	.80 HP	7,000	.579/CID	.060	BC
TMC	KPW 2528	1.71 CID					BC
TMC	KPW 2525	1.47 CID	.80 HP	6,500	.544/CID	.066	BC
TMC	KPW 3410	2.03 CID	1.2 HP	6,500	.590/CID	.080	BC
TMC	KTBL 5600	3.45 CID					BPB
Vandermolen	L 2035 G	1.24 CID	.70 HP	7,000	.564/CID	.068	TR
Vandermolen	L 2415 G	1.47 CID	.80 HP	6,500	.544/CID	.067	TR
Vandermolen	L 2815 G	1.71 CID					BC



Chain Saw Models By Cubic Inch Displacement
Number of Models
65
60
55
50
45
40
35
30
25
20
15
10
5
0
62
43
17
12
4
1
2
1
No. of Models
1.0 - 1.99 C.I.D.
2.0 - 2.99 C.I.D.
3.0 - 3.99 C.I.D.
4.0 - 4.99 C.I.D.
5.0 - 5.99 C.I.D.
6.0 - 6.99 C.I.D.
7.0 - 7.99 C.I.D.
8.0 and up
Cubic Inch Displacement

Suggested Retail Prices - Chain Saws



CHAIN SAW MODELS IN ALPHABETICAL ORDER

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Dolmar	PS-340	2.01 CID	1.96 HP		.970/CID	.230	Chain Saw
Dolmar	PS-400	2.37 CID	2.38 HP		1.000/CID	.270	Chain Saw
Dolmar	109	2.62 CID	2.80 HP		1.060/CID	.250	Chain Saw
Dolmar	111	3.17 CID	3.36 HP		1.050/CID	.300	Chain Saw
Dolmar	110 i	2.62 CID	3.22 HP		1.220/CID	.290	Chain Saw
Dolmar	115 i	3.17 CID	3.78 HP		1.190/CID	.340	Chain Saw
Dolmar	PS 6000 i	3.66 CID	4.34 HP		1.180/CID	.320	Chain Saw
Dolmar	PS 6800 i	4.14 CID	5.18 HP		1.250/CID	.380	Chain Saw
Dolmar	PS 9000	5.49 CID	6.86 HP		1.150/CID	.390	Chain Saw
Echo	CS 4400	2.66 CID					Chain Saw
Echo	CS 5000	3.01 CID					Chain Saw
Echo	CS 6700	4.07 CID					Chain Saw
Echo	CS 8000	4.93 CID					Chain Saw
Echo	CS 3000	1.84 CID					Chain Saw
Echo	CS 3400	2.04 CID					Chain Saw
Echo	CS 3450	2.04 CID					Chain Saw
Green Machine	Model 20	2.0 CID	1.70 HP	9,000	.850/CID	.170	Chain Saw
Green Machine	Model 30	3.0 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
Homelite	180	1.8 CID	1.13 HP	7,500	.627/CID	.150	Chain Saw
Homelite	d 3350 b	2.0 CID	1.70 HP	9,000	.850/CID	.170	Chain Saw
Homelite	d 3850 b	2.3 CID	2.10 HP	9,000	.913/CID	.210	Chain Saw
Homelite	252	2.5 CID	2.3 HP	10,000	.920/CID	.219	Chain Saw
Homelite	300	3.0 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
Homelite	Old Blue	3.5 CID	3.33 HP	7,500	.951/CID	.239	Chain Saw
Homelite	8800	5.60 CID	3.46 HP	9,000	1.037/CID	.306	Chain Saw
Husqvarna	23	2.3 CID	2.1 HP	11,000	.913/CID	.238	Chain Saw
Husqvarna	36	2.2 CID	2.2 HP	13,000	1.00/CID	.222	Chain Saw
Husqvarna	40	2.4 CID	2.4 HP	12,500	1.00/CID	.222	Chain Saw
Husqvarna	41	2.4 CID	2.5 HP	13,000	1.041/CID	.252	Chain Saw
Husqvarna	42	2.6 CID	2.9 HP	14,000	1.115/CID	.276	Chain Saw
Husqvarna	45	2.7 CID	2.7 HP	12,500	1.00/CID	.250	Chain Saw
Husqvarna	51	3.1 CID	3.1 HP	12,500	1.00/CID	.267	Chain Saw
Husqvarna	55	3.2 CID	3.3 HP	12,500	1.03/CID	.284	Chain Saw
Husqvarna	61	3.8 CID	4.1 HP	12,500	1.078/CID	.303	Chain Saw
Husqvarna	242 XP	2.6 CID	3.1 HP	15,500	1.192/CID	.298	Chain Saw
Husqvarna	246	2.8 CID	3.3 HP	14,000	1.178/CID	.314	Chain Saw
Husqvarna	254 XP	3.3 CID	3.9 HP	13,800	1.181/CID	.327	Chain Saw
Husqvarna	257	3.5 CID	3.8 HP	13,000	1.085/CID	.308	Chain Saw
Husqvarna	262 XP	3.8 CID	3.5 HP	13,500	.921/CID	.281	Chain Saw
Husqvarna	268	4.1 CID	3.4 HP	12,500	.829/CID	.250	Chain Saw
Husqvarna	272 XP	4.4 CID	3.8 HP	13,500	.863/CID	.277	Chain Saw
Husqvarna	281 XP	5.0 CID	4.2 HP	12,500	.840/CID	.257	Chain Saw
Husqvarna	288 XP	5.4 CID	4.4 HP	12,500	.814/CID	.269	Chain Saw
Husqvarna	294 XP	5.7 CID	7.1 HP	12,500	1.244/CID	.417	Chain Saw
Husqvarna	3120 XP	7.3 CID	9.2 HP	10,750	1.260/CID	.401	Chain Saw
John Deere	300 CS	3.00 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
John Deere	350 CS	3.5 CID	3.33 HP	7,500	.951/CID	.239	Chain Saw
John Deere	550 CS	5.5 CID	5.6 HP	9,000	1.018/CID	.306	Chain Saw
Jonsered	2095 Turbo	5.71 CID	7.1 HP	13,000	1.243/CID	.408	Chain Saw
Jonsered	2083 Turbo	5.0 CID	5.9 HP	13,500	1.180/CID	.205	Chain Saw
Jonsered	670	4.07 CID	4.94 HP	13,500	1.203/CID	.352	Chain Saw
Jonsered	630	3.8 CID	4.4 HP	13,000	1.157/CID	.316	Chain Saw
Jonsered	625 II	3.8 CID	4.1 HP	12,500	1.078/CID	.301	Chain Saw

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Jonsered	2055 Turbo	3.25 CID	3.8 HP	14,500	1.169/CID	.339	Chain Saw
Jonsered	2050 Turbo	3.0 CID	3.3 HP	12,500	1.100/CID	.311	Chain Saw
Jonsered	2041 Turbo	2.45 CID	2.7 HP	12,500	1.102/CID	.254	Chain Saw
Jonsered	2040 Turbo	2.4 CID	2.6 HP	13,000	1.083/CID	.262	Chain Saw
Jonsered	2036 Turbo	2.2 CID	2.2 HP	13,000	1.000/CID	.222	Chain Saw
Jonsered (Cat)	2055 Turbo (C)	3.25 CID	3.8 HP	14,500	1.169/CID	.339	Chain Saw
Jonsered (Cat)	2054 Turbo (C)	3.25 CID	3.5 HP	13,000	1.076/CID	.312	Chain Saw
Makita	DCS 341	2.0 CID	1.9 HP	11,500	.950/CID	.220	Chain Saw
Makita	DCS 401	2.4 CID	2.3 HP	12,000	.958/CID	.262	Chain Saw
Makita	DCS 431	2.7 CID	2.8 HP	12,500	1.037/CID	.274	Chain Saw
Makita	DCS 520	3.2 CID	3.3 HP	12,500	1.031/CID	.317	Chain Saw
Makita	DCS 6800	4.1 CID	5.1 HP	12,500	1.243/CID	.369	Chain Saw
Makita	DCS 9000	5.4 CID	6.7 HP	11,800	1.240/CID	.385	Chain Saw
McCulloch	Titan 7	2.1 CID					Chain Saw
McCulloch	Titan 35	2.1 CID					Chain Saw
McCulloch	Titan 40	2.3 CID					Chain Saw
McCulloch	Timber Bear	3.5 CID					Chain Saw
McCulloch	Pro Mac 700	4.3 CID					Chain Saw
McCulloch	Pro Mac 3205	2.0 CID					Chain Saw
McCulloch	3212	2.0 CID					Chain Saw
McCulloch	Pro Mac 8200	5.0 CID					Chain Saw
Olympyk (Emak)	9350 F	2.13 CID	1.7 HP		.788/CID	.197	Chain Saw
Olympyk (Emak)	941	2.53 CID	2.3 HP		.909/CID	.216	Chain Saw
Olympyk (Emak)	951	3.05 CID	3.4 HP		1.140/CID	.317	Chain Saw
Olympyk (Emak)	264 F	3.59 CID	3.8 HP		1.05/CID	.255	Chain Saw
Olympyk (Emak)	970	4.27 CID	5.2 HP		1.21/CID	.363	Chain Saw
Olympyk (Emak)	980	4.92 CID	5.7 HP		1.158/CID	.393	Chain Saw
Olympyk (Emak)	999 F	6.16 CID	7.2 HP		1.168/CID	.325	Chain Saw
Poulon	3500	3.7 CID					Chain Saw
Poulon	3600	3.7 CID					Chain Saw
Poulon	3300	3.3 CID					Chain Saw
Poulon	3100	3.0 CID					Chain Saw
Poulon	3050	3.0 CID					Chain Saw
Poulon	2750	2.8 CID					Chain Saw
Poulon	2500	2.5 CID					Chain Saw
Poulon	2600	2.5 CID					Chain Saw
Poulon	2550	2.5 CID					Chain Saw
Poulon	2450	2.3 CID					Chain Saw
Poulon	2250	2.2 CID					Chain Saw
Poulon	2150	2.1 CID					Chain Saw
Poulon	2050	2.0 CID					Chain Saw
Red Max	G 310 TS	1.84 CID					Chain Saw
Red Max	G 561 AVS	3.25 CID					Chain Saw
Red Max	G 621 AVS	3.78 CID					Chain Saw
Shindaiwa	695	4.1 CID	4.8 HP	9,000	1.170/CID	.363	Chain Saw
Shindaiwa	575	3.5 CID	4.0 HP	9,000	1.142/CID	.305	Chain Saw
Shindaiwa	500	2.9 CID	3.1 HP	9,000	1.068/CID	.264	Chain Saw
Shindaiwa	451	2.7 CID	2.8 HP	8,500	1.037/CID	.239	Chain Saw
Shindaiwa	416	2.4 CID	2.6 HP	9,000	1.083/CID	.240	Chain Saw
Shindaiwa	350	2.2 CID	2.2 HP	8,500	1.000/CID	.203	Chain Saw
Shindaiwa	345	2.0 CID	2.0 HP	8,500	1.000/CID	.188	Chain Saw
Shindaiwa	300	1.8 CID	1.6 HP	8,500	.888/CID	.181	Chain Saw

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Solo	647	2.86 CID	3.2 HP	8,000	1.118/CID	.256	Chain Saw
Solo	662	3.78 CID	4.3 HP	8,000	1.137/CID	.311	Chain Saw
Solo	680	4.88 CID	6.9 HP	8,000	1.413/CID	.418	Chain Saw
Solo	690 D	5.49 CID	7.3 HP	8,000	1.329/CID	.437	Chain Saw
Solo	639	2.32 CID	2.6 HP	8,000	1.120/CID	.262	Chain Saw
Stihl	009 EQZ	2.23 CID	1.6 HP		.448/CID	.177	Chain Saw
Stihl	009 L	2.49 CID	2.1 HP		.843/CID	.233	Chain Saw
Stihl	011 AVTEQ	2.49 CID	2.1 HP		.843/CID	.216	Chain Saw
Stihl	017	1.84 CID	1.5 HP		.815/CID	.180	Chain Saw
Stihl	020 T	2.13 CID	2.1 HP		.985/CID	.272	Chain Saw
Stihl	021	2.14 CID	2.0 HP		.934/CID	.202	Chain Saw
Stihl	023	2.45 CID	2.6 HP		1.06/CID	.257	Chain Saw
Stihl	023 L	2.45 CID	1.5 HP		.612/CID	.148	Chain Saw
Stihl	023 C	2.45 CID	1.9 HP		.775/CID	.188	Chain Saw
Stihl	025	2.70 CID	3.0 HP		1.111/CID	.297	Chain Saw
Stihl	026	2.97 CID	3.5 HP		1.178/CID	.336	Chain Saw
Stihl	026 PRO	2.97 CID	3.5 HP		1.178/CID	.336	Chain Saw
Stihl	029	3.30 CID	3.7 HP		1.121/CID	.289	Chain Saw
Stihl	034 AVEQ	3.44 CID	4.1 HP		1.191/CID	.338	Chain Saw
Stihl	036 PRO	3.75 CID	4.6 HP		1.226/CID	.362	Chain Saw
Stihl	038 AVMEQ	4.40 CID	4.9 HP		1.113/CID	.333	Chain Saw
Stihl	039	3.91 CID	4.4 HP		1.125/CID	.333	Chain Saw
Stihl	044	4.31 CID	5.4 HP		1.252/CID	.406	Chain Saw
Stihl	044 (Htd)	4.37 CID	5.1 HP		1.167/CID	.340	Chain Saw
Stihl	046	4.66 CID	5.9 HP		1.266/CID	.412	Chain Saw
Stihl	046 MARTCTIC	4.31 CID	5.4 HP		1.252/CID	.406	Chain Saw
Stihl	064 AVEQ	5.17 CID	6.5 HP		1.257/CID	.427	Chain Saw
Stihl	064 AVREQ	5.17 CID	6.5 HP		1.257/CID	.427	Chain Saw
Stihl	066	5.58 CID	7.3 HP		1.308/CID	.450	Chain Saw
Stihl	066 Magnum	5.58 CID	7.3 HP		1.308/CID	.450	Chain Saw
Stihl	084 AVEQ	7.42 CID	8.5 HP		1.145/CID	.406	Chain Saw
Tanaka	120	3.8 CID	3.3 HP	8,500	.868/CID	.124	Chain Saw
Tanaka	ECS 320	2.0 CID	1.6 HP	7,000	.796/CID	.177	Chain Saw
Tanaka	ECS 330	2.0 CID	1.6 HP	7,000	.796/CID	.169	Chain Saw
Tanaka	ECS 3500	2.07 CID	1.8 HP	8,000	.869/CID	.163	Chain Saw
Tanaka	ECS 4000	2.43 CID	2.44 HP	8,000	.987/CID	.218	Chain Saw
Tanaka	ECS 655	3.85 CID	3.8 HP	8,500	.987/CID	.265	Chain Saw

CHAIN SAW MODELS WITH DUPLICATED DISPLACEMENTS ELIMINATED

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Dolmar	PS-340	2.01 CID	1.96 HP		.970/CID	.230	Chain Saw
Dolmar	PS-400	2.37 CID	2.38 HP		1.000/CID	.270	Chain Saw
Dolmar	109	2.62 CID	2.80 HP		1.060/CID	.250	Chain Saw
Dolmar	111	3.17 CID	3.36 HP		1.050/CID	.300	Chain Saw
Dolmar	PS 6000 i	3.66 CID	4.34 HP		1.180/CID	.320	Chain Saw
Dolmar	PS 6800 i	4.14 CID	5.18 HP		1.250/CID	.380	Chain Saw
Dolmar	PS 9000	5.49 CID	6.86 HP		1.150/CID	.390	Chain Saw
Echo	CS 4400	2.66 CID					Chain Saw
Echo	CS 5000	3.01 CID					Chain Saw
Echo	CS 6700	4.07 CID					Chain Saw
Echo	CS 8000	4.93 CID					Chain Saw
Echo	CS 3000	1.84 CID					Chain Saw
Echo	CS 3400	2.04 CID					Chain Saw
Green Machine	Model 20	2.0 CID	1.70 HP	9,000	.850/CID	.170	Chain Saw
Green Machine	Model 30	3.0 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
Homelite	180	1.8 CID	1.13 HP	7,500	.627/CID	.150	Chain Saw
Homelite	d 3350 b	2.0 CID	1.70 HP	9,000	.850/CID	.170	Chain Saw
Homelite	d 3850 b	2.3 CID	2.10 HP	9,000	.913/CID	.210	Chain Saw
Homelite	252	2.5 CID	2.3 HP	10,000	.920/CID	.219	Chain Saw
Homelite	300	3.0 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
Homelite	Old Blue	3.5 CID	3.33 HP	7,500	.951/CID	.239	Chain Saw
Homelite	8800	5.60 CID	3.46 HP	9,000	1.037/CID	.306	Chain Saw
Husqvarna	23	2.3 CID	2.1 HP	11,000	.913/CID	.238	Chain Saw
Husqvarna	36	2.2 CID	2.2 HP	13,000	1.00/CID	.222	Chain Saw
Husqvarna	40	2.4 CID	2.4 HP	12,500	1.00/CID	.222	Chain Saw
Husqvarna	42	2.6 CID	2.9 HP	14,000	1.115/CID	.276	Chain Saw
Husqvarna	45	2.7 CID	2.7 HP	12,500	1.00/CID	.250	Chain Saw
Husqvarna	51	3.1 CID	3.1 HP	12,500	1.00/CID	.267	Chain Saw
Husqvarna	55	3.2 CID	3.3 HP	12,500	1.03/CID	.284	Chain Saw
Husqvarna	61	3.8 CID	4.1 HP	12,500	1.078/CID	.303	Chain Saw
Husqvarna	242 XP	2.6 CID	3.1 HP	15,500	1.192/CID	.298	Chain Saw
Husqvarna	246	2.8 CID	3.3 HP	14,000	1.178/CID	.314	Chain Saw
Husqvarna	254 XP	3.3 CID	3.9 HP	13,800	1.181/CID	.327	Chain Saw
Husqvarna	257	3.5 CID	3.8 HP	13,000	1.085/CID	.308	Chain Saw
Husqvarna	262 XP	3.8 CID	3.5 HP	13,500	.921/CID	.281	Chain Saw
Husqvarna	268	4.1 CID	3.4 HP	12,500	.829/CID	.250	Chain Saw
Husqvarna	272 XP	4.4 CID	3.8 HP	13,500	.863/CID	.277	Chain Saw
Husqvarna	281 XP	5.0 CID	4.2 HP	12,500	.840/CID	.257	Chain Saw
Husqvarna	288 XP	5.4 CID	4.4 HP	12,500	.814/CID	.269	Chain Saw
Husqvarna	294 XP	5.7 CID	7.1 HP	12,500	1.244/CID	.417	Chain Saw
Husqvarna	3120 XP	7.3 CID	9.2 HP	10,750	1.260/CID	.401	Chain Saw
John Deere	300 CS	3.00 CID	2.94 HP	10,000	.980/CID	.249	Chain Saw
John Deere	350 CS	3.5 CID	3.33 HP	7,500	.951/CID	.239	Chain Saw
John Deere	550 CS	5.5 CID	5.6 HP	9,000	1.018/CID	.306	Chain Saw
Jonsered	2095 Turbo	5.71 CID	7.1 HP	13,000	1.243/CID	.408	Chain Saw
Jonsered	2083 Turbo	5.0 CID	5.9 HP	13,500	1.180/CID	.205	Chain Saw
Jonsered	670	4.07 CID	4.94 HP	13,500	1.203/CID	.352	Chain Saw
Jonsered	630	3.8 CID	4.4 HP	13,000	1.157/CID	.316	Chain Saw
Jonsered	2050 Turbo	3.0 CID	3.3 HP	12,500	1.100/CID	.311	Chain Saw
Jonsered	2041 Turbo	2.45 CID	2.7 HP	12,500	1.102/CID	.254	Chain Saw
Jonsered	2040 Turbo	2.4 CID	2.6 HP	13,000	1.083/CID	.262	Chain Saw
Jonsered	2036 Turbo	2.2 CID	2.2 HP	13,000	1.000/CID	.222	Chain Saw
Jonsered (Cat)	2055 Turbo (C)	3.25 CID	3.8 HP	14,500	1.169/CID	.339	Chain Saw

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Makita	DCS 341	2.0 CID	1.9 HP	11,500	.950/CID	.220	Chain Saw
Makita	DCS 401	2.4 CID	2.3 HP	12,000	.958/CID	.262	Chain Saw
Makita	DCS 431	2.7 CID	2.8 HP	12,500	1.037/CID	.274	Chain Saw
Makita	DCS 520	3.2 CID	3.3 HP	12,500	1.031/CID	.317	Chain Saw
Makita	DCS 6800	4.1 CID	5.1 HP	12,500	1.243/CID	.369	Chain Saw
Makita	DCS 9000	5.4 CID	6.7 HP	11,800	1.240/CID	.385	Chain Saw
McCulloch	Titan 7	2.1 CID					Chain Saw
McCulloch	Titan 40	2.3 CID					Chain Saw
McCulloch	Timber Bear	3.5 CID					Chain Saw
McCulloch	Pro Mac 700	4.3 CID					Chain Saw
McCulloch	Pro Mac 3205	2.0 CID					Chain Saw
McCulloch	Pro Mac 8200	5.0 CID					Chain Saw
Olympyk (Emak)	9350 F	2.13 CID	1.7 HP		.788/CID	.197	Chain Saw
Olympyk (Emak)	941	2.53 CID	2.3 HP		.909/CID	.216	Chain Saw
Olympyk (Emak)	951	3.05 CID	3.4 HP		1.140/CID	.317	Chain Saw
Olympyk (Emak)	264 F	3.59 CID	3.8 HP		1.05/CID	.255	Chain Saw
Olympyk (Emak)	970	4.27 CID	5.2 HP		1.21/CID	.363	Chain Saw
Olympyk (Emak)	980	4.92 CID	5.7 HP		1.158/CID	.393	Chain Saw
Olympyk (Emak)	999 F	6.16 CID	7.2 HP		1.168/CID	.325	Chain Saw
Poulon	3500	3.7 CID					Chain Saw
Poulon	3300	3.3 CID					Chain Saw
Poulon	3100	3.0 CID					Chain Saw
Poulon	2750	2.8 CID					Chain Saw
Poulon	2500	2.5 CID					Chain Saw
Poulon	2450	2.3 CID					Chain Saw
Poulon	2250	2.2 CID					Chain Saw
Poulon	2150	2.1 CID					Chain Saw
Poulon	2050	2.0 CID					Chain Saw
Red Max	G 310 TS	1.84 CID					Chain Saw
Red Max	G 561 AVS	3.25 CID					Chain Saw
Red Max	G 621 AVS	3.78 CID					Chain Saw
Shindaiwa	695	4.1 CID	4.8 HP	9,000	1.170/CID	.363	Chain Saw
Shindaiwa	575	3.5 CID	4.0 HP	9,000	1.142/CID	.305	Chain Saw
Shindaiwa	500	2.9 CID	3.1 HP	9,000	1.068/CID	.264	Chain Saw
Shindaiwa	451	2.7 CID	2.8 HP	8,500	1.037/CID	.239	Chain Saw
Shindaiwa	416	2.4 CID	2.6 HP	9,000	1.083/CID	.240	Chain Saw
Shindaiwa	350	2.2 CID	2.2 HP	8,500	1.000/CID	.203	Chain Saw
Shindaiwa	345	2.0 CID	2.0 HP	8,500	1.000/CID	.188	Chain Saw
Shindaiwa	300	1.8 CID	1.6 HP	8,500	.888/CID	.181	Chain Saw
Solo	647	2.86 CID	3.2 HP	8,000	1.118/CID	.256	Chain Saw
Solo	662	3.78 CID	4.3 HP	8,000	1.137/CID	.311	Chain Saw
Solo	680	4.88 CID	6.9 HP	8,000	1.413/CID	.418	Chain Saw
Solo	690 D	5.49 CID	7.3 HP	8,000	1.329/CID	.437	Chain Saw
Solo	639	2.32 CID	2.6 HP	8,000	1.120/CID	.262	Chain Saw
Stihl	009 EQZ	2.23 CID	1.6 HP		.448/CID	.177	Chain Saw
Stihl	009 L	2.49 CID	2.1 HP		.843/CID	.233	Chain Saw
Stihl	017	1.84 CID	1.5 HP		.815/CID	.180	Chain Saw
Stihl	020 T	2.13 CID	2.1 HP		.985/CID	.272	Chain Saw
Stihl	023	2.45 CID	2.6 HP		1.06/CID	.257	Chain Saw
Stihl	023 L	2.45 CID	1.5 HP		.612/CID	.148	Chain Saw
Stihl	023 C	2.45 CID	1.9 HP		.775/CID	.188	Chain Saw
Stihl	025	2.70 CID	3.0 HP		1.111/CID	.297	Chain Saw
Stihl	026	2.97 CID	3.5 HP		1.178/CID	.336	Chain Saw

Manufacturer	Model	CID	Max. Output	RPM at Max.	HP/CID	P/W	Appl.
Stihl	029	3.30 CID	3.7 HP		1.121/CID	.289	Chain Saw
Stihl	034 AVEQ	3.44 CID	4.1 HP		1.191/CID	.338	Chain Saw
Stihl	036 PRO	3.75 CID	4.6 HP		1.226/CID	.362	Chain Saw
Stihl	038 AVMEQ	4.40 CID	4.9 HP		1.113/CID	.333	Chain Saw
Stihl	039	3.91 CID	4.4 HP		1.125/CID	.333	Chain Saw
Stihl	044	4.31 CID	5.4 HP		1.252/CID	.406	Chain Saw
Stihl	044 (Htd)	4.37 CID	5.1 HP		1.167/CID	.340	Chain Saw
Stihl	046	4.66 CID	5.9 HP		1.266/CID	.412	Chain Saw
Stihl	064 AVEQ	5.17 CID	6.5 HP		1.257/CID	.427	Chain Saw
Stihl	066	5.58 CID	7.3 HP		1.308/CID	.450	Chain Saw
Stihl	084 AVEQ	7.42 CID	8.5 HP		1.145/CID	.406	Chain Saw
Tanaka	120	3.8 CID	3.3 HP	8,500	.868/CID	.124	Chain Saw
Tanaka	ECS 320	2.0 CID	1.6 HP	7,000	.796/CID	.177	Chain Saw
Tanaka	ECS 3500	2.07 CID	1.8 HP	8,000	.869/CID	.163	Chain Saw
Tanaka	ECS 4000	2.43 CID	2.44 HP	8,000	.987/CID	.218	Chain Saw
Tanaka	ECS 655	3.85 CID	3.8 HP	8,500	.987/CID	.265	Chain Saw

OEM ENGINES SORTED BY DISPLACEMENT

Manufacturer	Model No.	CID	Max. Output	RPM at Max.	HP/CID	P to W Ratio	Appli-cation	Other Notes
uji Robin	ECO1 ER	.97 CID	.60 HP	7,000	.619/CID	0.143	OEM	
itsobishi	TM 20	1.22 CID	.70 HP	7,500	.570/CID	0.130	OEM	
Fuji Robin	ECO2 ER	1.24 CID	.99 HP	7,000	.798/CID	0.225	OEM	
Kawasaki	TG 20 D	1.24 CID	.70 HP	7,000	.564/CID	0.138	OEM	
Kioritz	SB4 V	1.29 CID	.80 HP	8,000	.620/CID	0.182	OEM	
U.S. Engines	21	1.29 CID	1.0 HP	7,000	.775/CID	0.190	OEM	
Electrolux	21 L	1.29 CID	1.03 HP	8,000	.798/CID	0.160	OEM	
McCulloch	SI 410	1.29 CID	.80 HP	8,000	.620/CID	0.182	OEM	
Fuji Robin	ECO22 GR	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	
Fuji Robin	ECO22 GA	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	Brush Cutter
Fuji Robin	ECO22 GR	1.32 CID	1.0 HP	7,000	.757/CID	0.217	OEM	Pump
Fuji Robin	ECO22 GRV	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	Vertical
Fuji Robin	ECO2 EHR	1.35 CID	1.1 HP	7,000	.814/CID	0.250	OEM	
Mitsobishi	TM 21	1.37 CID	1.0 HP	7,500	.720/CID	0.180	OEM	
Kawasaki	TE 22 D	1.38 CID	.80 HP	7,000	.579/CID	0.145	OEM	
Komatsu Zenoah	G 23	1.38 CID	1.2 HP	7,500	.875/CID	0.187	OEM	
Komatsu Zenoah	G 23 LH	1.38 CID	1.2 HP	7,500	.875/CID	0.261	OEM	
Kioritz	CT2400	1.44 CID	1.0 HP	8,000	.694/CID	0.227	OEM	
Kawasaki	TG24D	1.47 CID	.80 HP	6,500	.544/CID	0.140	OEM	
Fuji Robin	ECO25 GR	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	
Fuji Robin	ECO25 GA	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	Brush Cutter
Fuji Robin	ECO25 GR	1.49 CID	1.2 HP	7,000	.757/CID	0.217	OEM	Pump
Fuji Robin	ECO25 GRV	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	Vertical
U.S. Engines	25	1.50 CID	1.44 HP	8,000	.960/CID	0.261	OEM	
Homelite	725	1.52 CID	.85 HP	7,500	.559/CID	0.088	OEM	
McCulloch	2250	1.53 CID						
Komatsu Zenoah	108/G2	1.55 CID	1.4 HP	8,000	.903/CID	0.304	OEM	
Mitsobishi	TM 26	1.59 CID	1.3 HP	7,500	.810/CID	0.220	OEM	
ectrolux	26	1.6 CID	1.2 HP	9,000	.750/CID	0.181	OEM	
EMAK	TS 330	1.83 CID	1.2 HP	7,200	.655/CID	0.088	OEM	
Homelite	40	1.83 CID	1.13 HP	7,500	.617/CID	0.220	OEM	
Electrolux	31	1.9 CID	1.6 HP	9,000	.842/CID	0.173	OEM	
Mitsobishi	TM 33	1.98 CID	1.7 HP	7,500	.850/CID	0.260	OEM	
Tecumseh	TC200	2.0 CID	1.6 HP	6,000	.80/CID	0.228	OEM	
Kawasaki	TG33D	2.03 CID	1.2 HP	6,500	.591/CID	0.181	OEM	
Komatsu Zenoah	G-2K	2.05 CID	1.7 HP	7,000	.829/CID	0.250	OEM	
Fuji Robin	ECO3 ER	2.10 CID	1.8 HP	7,000	.857/CID	0.240	OEM	
U.S. Engines	35	2.12 CID	2.0 HP	7,500	.952/CID	0.363	OEM	
Electrolux	40	2.2 CID	1.7 HP	9,000	.772/CID	0.184	OEM	
Homelite	HBC 40	2.44 CID	2.2 HP	7,000	.901/CID	0.550	OEM	
Fuji Robin	ECO4 ER	2.45 CID	2.0 HP	7,000	.816/CID	0.250	OEM	
Fuji Robin	ECO4 ERV	2.45 CID	2.0 HP	7,200	.816/CID	0.233	OEM	
Kawasaki	TD40D6	2.45 CID	1.85 HP	6,000	.755/CID	0.199	OEM	
Electrolux	41	2.45 CID	2.52 HP	9,000	1.028/CID	0.229	OEM	
Mitsobishi	TM 40	2.47 CID	2.0 HP	7,000	.800/CID	0.250	OEM	
U.S. Engines	41	2.5 CID	2.9 HP	8,000	1.16/CID	0.517	OEM	
Komatsu Zenoah	G-4K	2.53 CID	2.2 HP	7,000	.869/CID	0.271	OEM	
Electrolux	44	2.7 CID	2.7 HP	9,000	1.000/CID	0.247	OEM	
Kawasaki	TD 48D	2.97 CID	1.85 HP	6,000	.625/CID	0.199	OEM	
Electrolux	50	2.97 CID	2.94 HP	9,000	.989/CID	0.245	OEM	
Tecumseh	TC300	3.0 CID	2.4 HP	6,000	.80/CID	0.340	OEM	
Electrolux	51	3.1 CID	3.4 HP	9,300	1.096/CID	0.274	OEM	
EMAK	265 TTA	3.59 CID	3.8 HP		1.050/CID	0.146	OEM	
Fuji Robin	ECO6 D	3.71 CID	2.5 HP	5,000	.673/CID	0.149	OEM	
EMAK	1000 TTA	3.82 CID	7.2 HP		1.830/CID	0.226	OEM	
ji Robin	ECO8 D	4.78 CID	3.3 HP	5,500	.690/CID	0.214	OEM	
Fuji Robin	ECO8 D	4.79 CID	3.3 HP	5,500	.689/CID	0.214		
Tecumseh	AH480	4.8 CID	3.25 HP	6,500	.677/CID	0.382	OEM	
EMAK	285 TTA	4.94 CID	5.5 HP		1.113/CID	0.180	OEM	

Manufacturer	Model No.	CID	Max. Output	RPM at Max.	HP/CID	P to W Ratio	Appli-cation	Other Notes
umseh	AV520	5.2 CID	4.1 HP	5,000	.788/CID	0.309	OEM	
umseh	AH520	5.2 CID	2.1 HP	3,000	.404/CID	0.182	OEM	
Tecumseh	AV520	5.2 CID	3.0 HP	4,500	.579/CID	0.227	OEM	
U.S. Motor Power	580	5.8 CID	4.2 HP	6,000	.724/CID	0.289	OEM	
Fuji Robin	EC10 V	5.97 CID	4.0 HP	5,000	.670/CID	0.122	OEM	
Fuji Robin	EC10 D	5.98 CID	4.0 HP	5,000	.668/CID	0.133	OEM	
Fuji Robin	EC10 V	5.99 CID	4.0 HP	5,000	.667/CID	0.123	OEM	Vertical
Fuji Robin	EC10 D	5.99 CID	4.0 HP	5,000	.668/CID	0.294	OEM	
Tecumseh	AV600	6.0 CID	5.0 HP	5,500	.833/CID	0.377	OEM	
Tecumseh	AV600	6.0 CID	3.8 HP	4,500	.633/CID	0.316	OEM	
ILO	L 99	6.1 CID	4.75 HP	5,500	.778/CID		OEM	
U.S. Motor Power	700	7.0 CID	5.0 HP	5,500	.714/CID	0.344	OEM	
Fuji Robin	EC13 V	7.49 CID	4.2 HP	4,000	.560/CID	0.170	OEM	Vertical
Tecumseh	AH817	8.1 CID	5.5 HP	6,000	.687/CID	0.355	OEM	
Tecumseh	AH817	8.16 CID	5.5 HP	6,000	.673/CID	0.355	OEM	
U.S. Motor Power	820	8.2 CID	8.0 HP	8,000	.975/CID	0.516	OEM	
Fuji Robin	EC17 D	10.68 CID	6.5 HP	5,000	.608/CID	0.159	OEM	
Fuji Robin	EC17 V	10.68 CID	6.5 HP	5,000	.608/CID	0.148	OEM	Vertical

OEM ENGINES SORTED BY HORSEPOWER PER CUBIC INCH DISPLACEMENT

Manufacturer	Model No.	Displacement	Max. Output	RPM at Max.	HP/CID	P to W Ratio	Application	Other Notes
:cumseh	AH520	5.2 CID	2.1 HP	3,000	.404/CID	0.182	OEM	
Kawasaki	TG24D	1.47 CID	.80 HP	6,500	.544/CID	0.140	OEM	
Homelite	725	1.52 CID	.85 HP	7,500	.559/CID	0.088	OEM	
Fuji Robin	EC13 V	7.49 CID	4.2 HP	4,000	.560/CID	0.170	OEM	Vertical
Kawasaki	TG20D	1.24 CID	.70 HP	7,000	.564/CID	0.138	OEM	
Mitsobishi	TM 20	1.22 CID	.70 HP	7,500	.570/CID	0.130	OEM	
Tecumseh	AV520	5.2 CID	3.0 HP	4,500	.579/CID	0.227	OEM	
Kawasaki	TE22D	1.38 CID	.80 HP	7,000	.579/CID	0.145	OEM	
Kawasaki	TG33D	2.03 CID	1.2 HP	6,500	.591/CID	0.181	OEM	
Fuji Robin	EC17 D	10.68 CID	6.5 HP	5,000	.608/CID	0.159	OEM	
Fuji Robin	EC17 V	10.68 CID	6.5 HP	5,000	.608/CID	0.148	OEM	Vertical
Homelite	40	1.83 CID	1.13 HP	7,500	.617/CID	0.220	OEM	
Fuji Robin	ECO1 ER	.97 CID	.60 HP	7,000	.619/CID	0.143	OEM	
McCulloch	SI 410	1.29CID	.80 HP	8,000	.620/CID	0.182	OEM	
Kioritz	SB4 V	1.29 CID	.80 HP	8,000	.620/CID	0.182	OEM	
Kawasaki	TD 48D	2.97 CID	1.85 HP	6,000	.625/CID	0.199	OEM	
Tecumseh	AV600	6.0 CID	3.8 HP	4,500	.633/CID	0.316	OEM	
EMAK	TS 330	1.83 CID	1.2 HP	7,200	.655/CID	0.088	OEM	
Fuji Robin	EC10 V	5.99 CID	4.0 HP	5,000	.667/CID	0.123	OEM	Vertical
Fuji Robin	EC10 D	5.98 CID	4.0 HP	5,000	.668/CID	0.133	OEM	
Fuji Robin	EC10 D	5.99 CID	4.0 HP	5,000	.668/CID	0.294	OEM	
Fuji Robin	EC10 V	5.97 CID	4.0 HP	5,000	.670/CID	0.122	OEM	
..ji Robin	ECO6 D	3.71 CID	2.5 HP	5,000	.673/CID	0.149	OEM	
.cumseh	AH817	8.16 CID	5.5 HP	6,000	.673/CID	0.355	OEM	
Tecumseh	AH480	4.8 CID	3.25 HP	6,500	.677/CID	0.382	OEM	
Tecumseh	AH817	8.1 CID	5.5 HP	6,000	.687/CID	0.355	OEM	
Fuji Robin	ECO8 D	4.79 CID	3.3 HP	5,500	.689/CID	0.214		
Fuji Robin	ECO8 D	4.78 CID	3.3 HP	5,500	.690/CID	0.214	OEM	
Kioritz	CT2400	1.44 CID	1.0 HP	8,000	.694/CID	0.227	OEM	
U.S. Motor Power	700	7.0 CID	5.0 HP	5,500	.714/CID	0.344	OEM	
Mitsobishi	TM 21	1.37 CID	1.0 HP	7,500	.720/CID	0.180	OEM	
U.S. Motor Power	580	5.8 CID	4.2 HP	6,000	.724/CID	0.289	OEM	
Electrolux	26	1.6 CID	1.2 HP	9,000	.750/CID	0.181	OEM	
Kawasaki	TD40D	2.45 CID	1.85 HP	6,000	.755/CID	0.199	OEM	
Fuji Robin	ECO22 GR	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	
Fuji Robin	ECO22 GA	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	Brush Cutter
Fuji Robin	ECO22 GR	1.32 CID	1.0 HP	7,000	.757/CID	0.217	OEM	Pump
Fuji Robin	ECO22 GRV	1.32 CID	1.0 HP	7,000	.757/CID	0.227	OEM	Vertical
Fuji Robin	ECO25 GR	1.49 CID	1.2 HP	7,000	.757/CID	0.217	OEM	Pump
Electrolux	40	2.2 CID	1.7 HP	9,000	.772/CID	0.184	OEM	
U.S. Engines	21	1.29 CID	1.0 HP	7,000	.775/CID	0.190	OEM	
ILO	L 99	6.1 CID	4.75 HP	5,500	.778/CID		OEM	
Tecumseh	AV520	5.2 CID	4.1 HP	5,000	.788/CID	0.309	OEM	
Electrolux	21 L	1.29 CID	1.03 HP	8,000	.798/CID	0.160	OEM	
Fuji Robin	ECO2 ER	1.24 CID	.99 HP	7,000	.798/CID	0.225	OEM	
umseh	TC200	2.0 CID	1.6 HP	6,000	.80/CID	0.228	OEM	
Tecumseh	TC300	3.0 CID	2.4 HP	6,000	.80/CID	0.340	OEM	
Mitsobishi	TM 40	2.47 CID	2.0 HP	7,000	.800/CID	0.250	OEM	

Manufacturer	Model No.	Displacement	Max. Output	RPM at Max.	HP/CID	P to W Ratio	Application	Other Notes
Fuji Robin	ECO25 GR	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	
Fuji Robin	ECO25 GA	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	Brush Cutter
Fuji Robin	ECO25 GRV	1.49 CID	1.2 HP	7,000	.805/CID	0.250	OEM	Vertical
Mitsobishi	TM 26	1.59 CID	1.3 HP	7,500	.810/CID	0.220	OEM	
Fuji Robin	ECO2 EHR	1.35 CID	1.1 HP	7,000	.814/CID	0.250	OEM	
Fuji Robin	ECO4 ER	2.45 CID	2.0 HP	7,000	.816/CID	0.250	OEM	
Fuji Robin	ECO4 ERV	2.45 CID	2.0 HP	7,200	.816/CID	0.233	OEM	
Komatsu Zenoah	G-2K	2.05 CID	1.7 HP	7,000	.829/CID	0.250	OEM	
Tecumseh	AV600	6.0 CID	5.0 HP	5,500	.833/CID	0.377	OEM	
Electrolux	31	1.9 CID	1.6 HP	9,000	.842/CID	0.173	OEM	
Mitsobishi	TM 33	1.98 CID	1.7 HP	7,500	.850/CID	0.260	OEM	
Fuji Robin	ECO3 ER	2.10 CID	1.8 HP	7,000	.857/CID	0.240	OEM	
Komatsu Zenoah	G-4K	2.53 CID	2.2 HP	7,000	.869/CID	0.271	OEM	
Komatsu Zenoah	G 23	1.38 CID	1.2 HP	7,500	.875/CID	0.187	OEM	
Komatsu Zenoah	G 23 LH	1.38 CID	1.2 HP	7,500	.875/CID	0.261	OEM	
Homelite	HBC 40	2.44 CID	2.2 HP	7,000	.901/CID	0.550	OEM	
Komatsu Zenoah	108/G2	1.55 CID	1.4 HP	8,000	.903/CID	0.304	OEM	
U.S. Engines	35	2.12 CID	2.0 HP	7,500	.952/CID	0.363	OEM	
U.S. Engines	25	1.50 CID	1.44 HP	8,000	.960/CID	0.261	OEM	
U.S. Motor Power	820	8.2 CID	8.0 HP	8,000	.975/CID	0.516	OEM	
Electrolux	50	2.97 CID	2.94 HP	9,000	.989/CID	0.245	OEM	
Electrolux	44	2.7 CID	2.7 HP	9,000	1.000/CID	0.247	OEM	
Electrolux	41	2.45 CID	2.52 HP	9,000	1.028/CID	0.229	OEM	
EMAK	265 TTA	3.59 CID	3.8 HP		1.050/CID	0.146	OEM	
Electrolux	51	3.1 CID	3.4 HP	9,300	1.096/CID	0.274	OEM	
EMAK	285 TTA	4.94 CID	5.5 HP		1.113/CID	0.180	OEM	
U.S. Engines	41	2.5 CID	2.9 HP	8,000	1.16/CID	0.517	OEM	
EMAK	1000 TTA	3.82 CID	7.2 HP		1.830/CID	0.226	OEM	

D. COST IMPACTS OF INCREASES

The following formulas can be used as a guide to the effect of any added increases in the MLB cost of an engine.

MLB cost times 1.30% equals total cost at OEM sales level.

Estimated Cost:

Material, Labor & Burden	$30.00
Shrinkage Allowance @ 1/2 of 1%	.15
Inventory Cost	$30.15
G & A (Excluding Selling) 9%	$ 2.71
Selling (3%)	.90
Selling Cost	$33.76
Profit 11%	$ 3.71
Subtotal	$37.47
Discount & Sales Allowance @ 1%	.37
Warranty @ 1/2 of 1%	.18
Tooling	$ 1.00
Total	$39.02

Suggested Retail:

For 2-step Distribution (Cost x 1.66%)	$64.77
For 1-step Distribution (Cost x 1.50%)	$58.53
For Mass Merchandiser Contract Price Estimated @ 1.15%	$44.87

Note: For the Southern California Market and other states in the Sun Belt, costs may be lower, at least seasonably. Since these areas offer year round sales potential, most grass related power equipment will carry anticipation discounts to allow manufacturers to levelize production in off season.

E. SERVICE CONSIDERATION IN ENGINE DESIGN

While the increases manufacturing cost will negatively impact the retail price of power equipment, it is important to bear in mind that, over time, serviceability will also play an important part in field acceptance.

Two things impact serviceability:

1. Replacement part cost and

2. Service time requirements

Service parts costs are basically not negotiable, but must be considered in an analysis of an engine design for serviceability.

Parts costs are fundamentally dictated by industry practice.

Almost all small engine service parts used in the United States rely for distribution on the Engine Service Association (ESA) practices. There are approximately 57 Central Warehouse Distributors nationwide that control this distribution system.

The discount structure on parts is as follows:

Central Warehouse Distributor	List less 65%
Service Distributor	List less 55%
Stocking Service Dealer	List less 40%
Non-Stocking Dealer	List less 25%

To operate economically within this structure, a product manufacturer must price service parts approximately as follows:

Parts with Material, Labor and Burden:

Cost	Retail Price
.01 - .49	Ten times MLB cost
.50 - .99	Seven times MLB cost
1.00 and more	Five times MLB cost

Under this schedule, a parts manufacturer, using the longest discount (65%) and the lowest multiple on cost (5 times) will have a gross margin on part sales of 75%.

Service Time

Nationally, the Servicing Dealer shop labor rate averages $38.00/hour.

For service shops, as well as consumers, this makes it important to analyze every new engine design for service cost impact.

The service shop owner/manager is concerned that he will damage his relationship with his customers if his costs are too high. In many cases, a dealer will refuse to handle certain products if he is concerned about high service costs. Also, a dealer who sells equipment to commercial customers who do their own servicing. will use the low service design as a selling point.

On low end products, many servicing dealers make it a practice to refuse to service the item if they expect the service time to be more than one hour.

In any case, it is good practice for an engine designer to have a qualified person specifically review the final design for serviceability.

Some of the basic steps should include making all features as consistent as possible in type to reduce the tools required.

Also, special attention for easy access, should apply to maintenance service items like spark plugs, air filter elements and spark arrestor screens.

REPLACEMENT UNIT SALES

In the "Industry Overview" section of the California Air Resources Board (CARB), regulations approved December 14, 1990; Booz, Allen & Hamilton, Exhibits 1-10, included a number of charts showing historical unit sales for some of the high volume Utility and Lawn & Garden Products.

For evaluation, S. J. Benton & Associates, has updated the figures to reflect more current market conditions. These updated charts, following this section, indicate that most of the products (except for chain saws) have reached what appears to be a plateau.

That would indicate that future markets for these products will represent mostly replacement buyers rather than first time buyers. First time buyers, for most products, shop for price. On the other hand, a high percentage of the replacement buyers are generally more discriminating and will look for better products, more convenience features, longer life, etc. This will also include an increasing number of buyers willing to consider environmental impact.

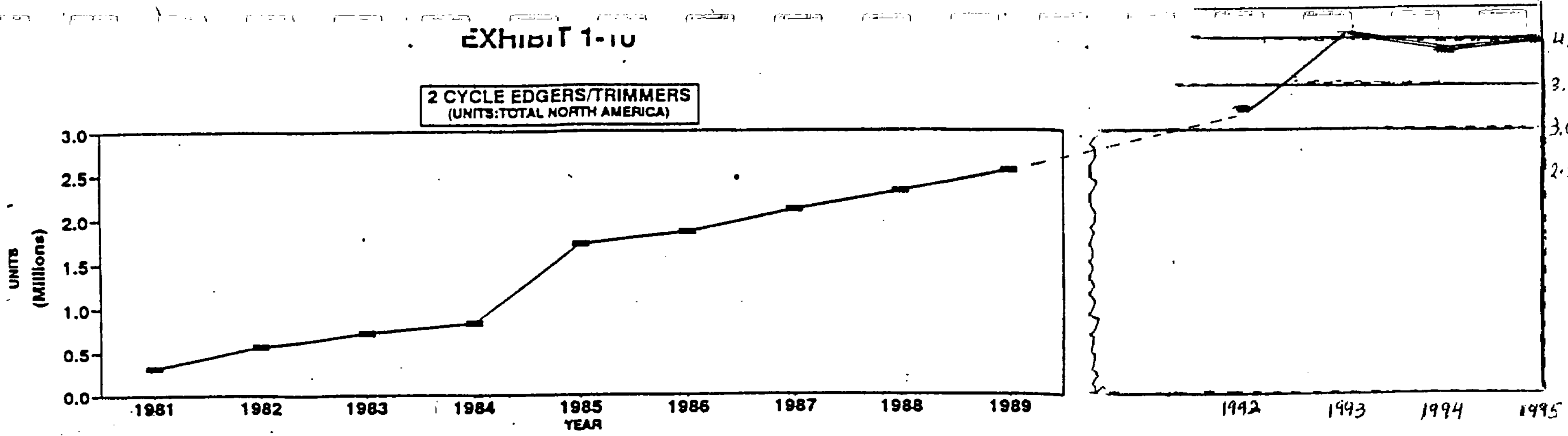
Price conscious buyers will tend to shift to more electric powered units. Mass Merchandisers will tend to encourage this trend as a means of reducing servicing needs.

Also included is a projection on the trimmer market made by a national market research firm in about 1987. This appears to be quite on target with projected replacement buyers.

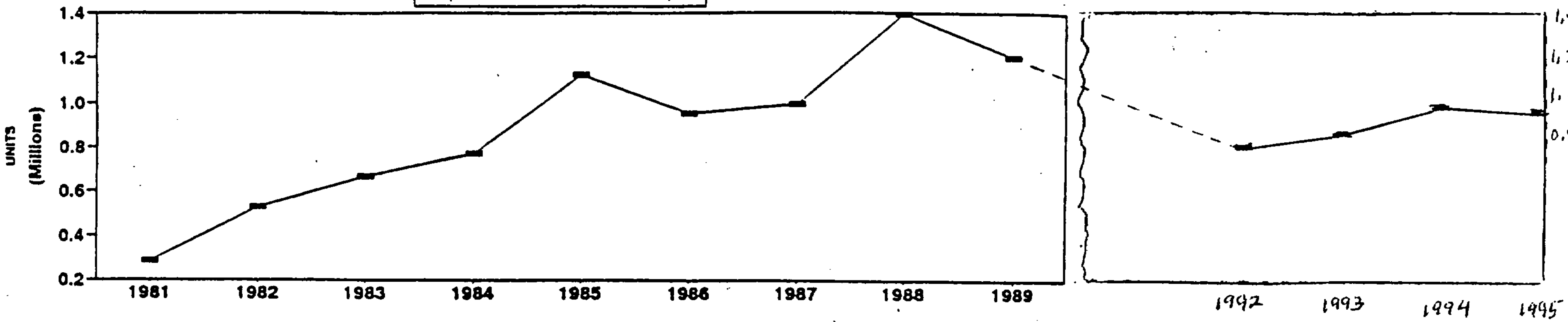
Chain saws will probably be an exception to the plateau pattern for the present. While present chain saw sales continue to show growth, they, like walk behind mowers, are not into a replacement unit pattern. With the introduction of light weight home owner type saws in 1967, the market went from what had been a quite stable volume of about 300,000 units per year to a ten fold increase of over 3,000,000 units per year by the mid 1970's. This reflected a combination of the more consumer friendly lightweight saws and the fuel energy crisis that stimulated the use of wood burning stoves, fireplaces, etc.

Without this stimulation, the market suffered an almost 50% drop in unit sales. Current growth is a more normal market pattern and the acceptance of the chain saw as a standard consumer product. Growth is also being stimulated by the increasing cost of firewood for lifestyle fireplaces plus the increasing costs of limber and inexpensive, consumer friendly, lumber making equipment.

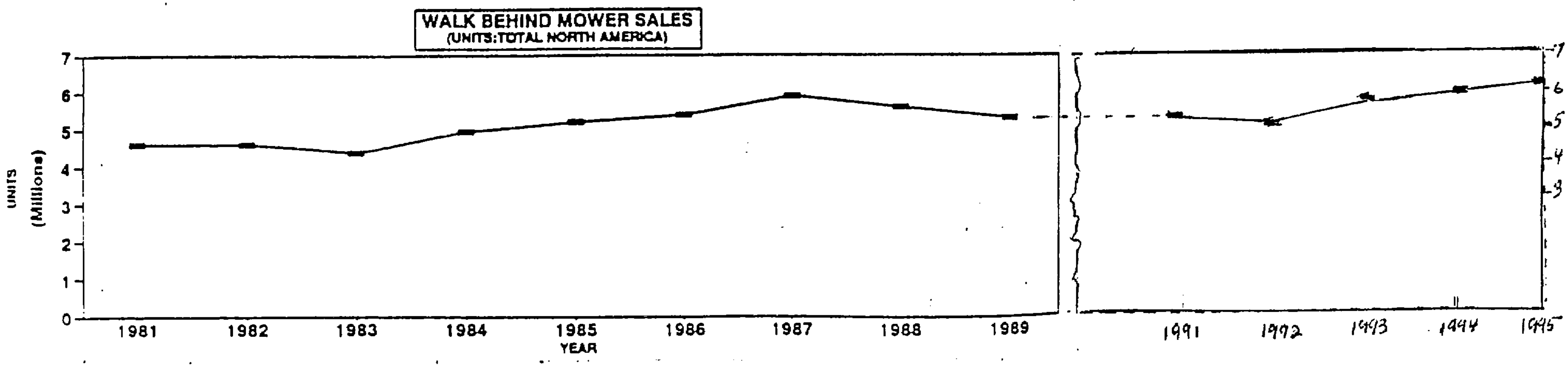
EXHIBIT 1-10



2 CYCLE EDGERS/TRIMMERS
(UNITS:TOTAL NORTH AMERICA)
UNITS
(Millions)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1981
1982
1983
1984
1985
1986
1987
1988
1989
YEAR
1992
1993
1994
1995
3.0
2.5



2 CYCLE BLOWERS/VACUUMS
(UNITS:TOTAL NORTH AMERICA)
UNITS
(Millions)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1981
1982
1983
1984
1985
1986
1987
1988
1989
1992
1993
1994
1995
1.4
1.2
1.0
0.8


WALK BEHIND MOWER SALES
(UNITS:TOTAL NORTH AMERICA)
UNITS
(Millions)
0
1
2
3
4
5
6
7
1981
1982
1983
1984
1985
1986
1987
1988
1989
YEAR

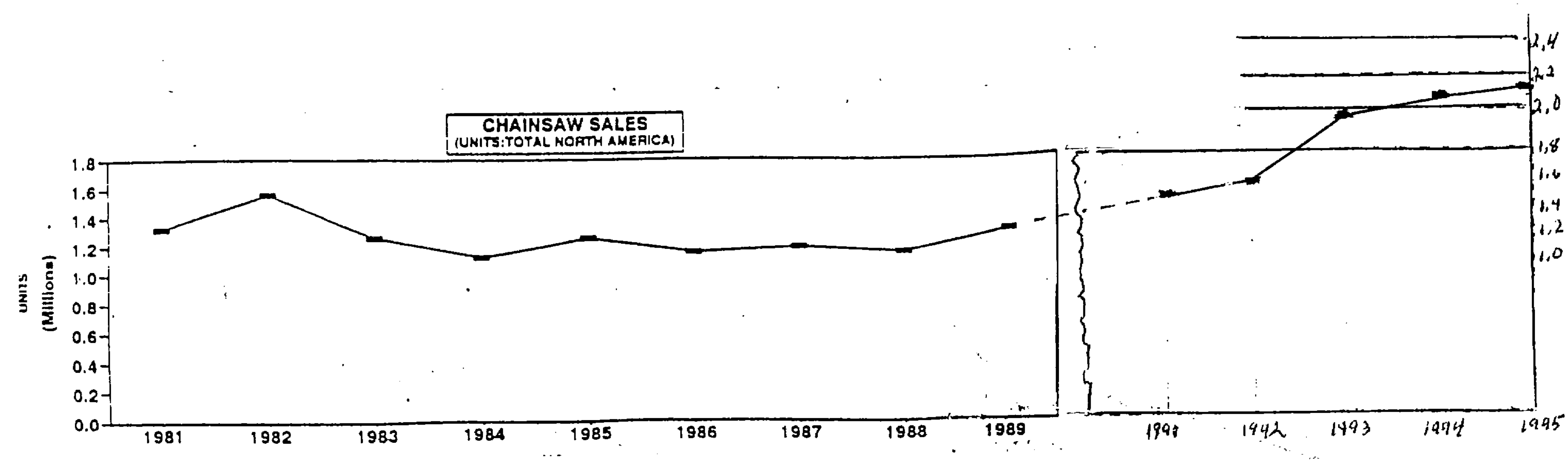
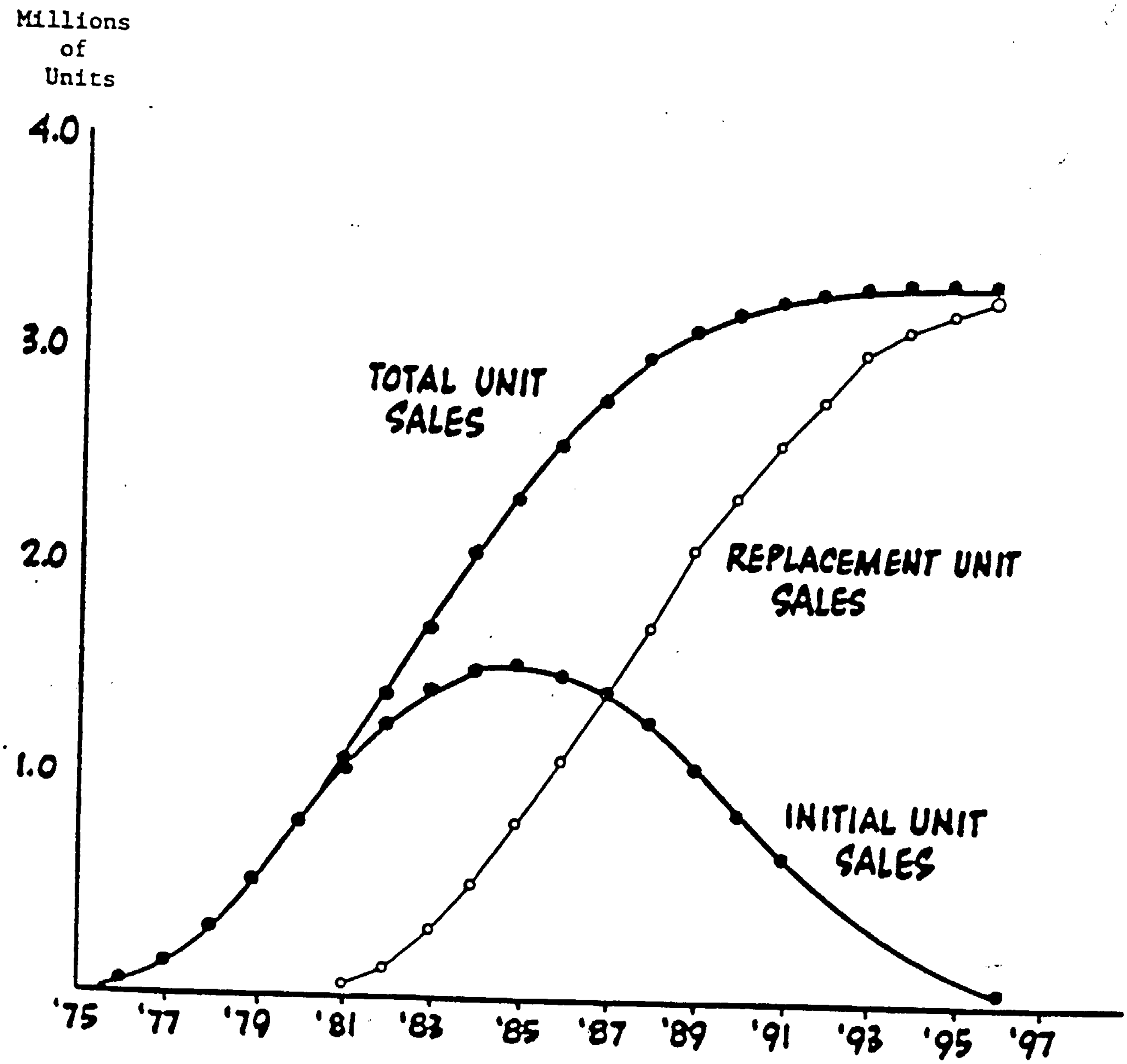

CHAINSAW SALES
(UNITS:TOTAL NORTH AMERICA)
UNITS
(Millions)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
1981
1982
1983
1984
1985
1986
1987
1988
1989

EXHIBIT A

HISTORICAL* AND FORECAST GAS TRIMMER SALES, 1975-1996

INITIAL, REPLACEMENT, AND TOTAL SALES

(in millions of units)



* Historical sales restated to conform to growth formula. This minor revision removes meaningless irregularities in later years.

Appendix B - Test Results

CATS Results Summary

Flow Bench Tests

The injector closing pressure is at about 1250 psi.
The injection spray quality is good.
The accumulator check valve has a slight leak.

Motored Engine Tests

Initially only very low pressure was developed by the pump, much lower than predicted.
The cause for this appeared to be leakage. Leakage occurred in all of the following areas.

1. Leakage Around The Pump Plunger

The needle roller bearing selected to be used as the fuel pump plunger was slightly barrel shaped, so the end did not seal well with the cylinder. This dimensional problem was resolved by fabricating a custom plunger with the correct dimensions and tolerances. This leakage around the plunger was compounded by the presence of a "spill port" at the bottom of the cylinder bore for initiating mechanical injection. Even with a straight plunger there was still leakage past the plunger and out the spill port when the port is supposed to be closed.

2. O-Ring Damage

In the prototype pump installation design, o-rings are used to seal the high pressure fuel sections of the pump assembly. During installation o-ring damage occurred by passing these o-rings over intersecting passages in the engine block. A design change was developed which can be used in the future to avoid this problem. Currently the o-ring clearance has been increased and careful installation with grease seems to work.

3. Leaky Check Valves

Originally custom fabricated check valves were used for the inlet check valve, priming check valve and accumulator check valve. The seal of these custom check valves was not as good as desired. A commercially available product line of small check valves was discovered. The pump design was modified to allow the use of these commercial check valves for the inlet and priming check valves.

4. Fuel Delivery Tube Fitting

The design of the hydraulic fitting which attaches the fuel delivery tube to the pump outlet includes a section with a relatively large area exposed to the pump pressure compared to the cross-sectional area of the inner passage of the tube. This excessive area results in a large separating force. This in turn causes flexing at this fitting. The flexing changes the control volume of the pump, thus decreasing the pump efficiency. This flexing also eventually fatigues the fitting to the point of failure. The design of the pump will eventually be changed so there is not a large area for the pressure to push on. For the immediate operation of the engine an aluminum bracket was installed to retain the fuel delivery tube.

From strain gage traces the following data was gathered.

1. System delay times were measured

The peak pressure in the accumulator occurs at about the same time as in the control volume.
The fill delay was measured at .8 ms.
The vent delay was measured at .8 ms
The injection delay was measured at 1.25 ms

2. The control pressure leaks down to pump pressure. The leak is worse at low rpm. The accumulator check valve holds peak pressure pretty well, but leaks down between injection events.

The vent line has a bubble in it for every time the solenoid vents. This makes it unsuitable to tee this line in to the inlet of the high-pressure pump. Whenever the high-pressure pump ingests a bubble, pressure is lost for several cycles.

Performance and Emissions Optimization

The first operation of the engine on injection occurred on August 23, 1997. The engine was run with one set of injection timings, both the fill and injection timings were set for maximum fuel delivery. The engine was started with and without mechanical injection. The throttle was adjusted to find the best A/F ratio. The throttle only changed the airflow, and did nothing to the quantity of fuel injected.

After preliminary operation, the following problems were identified and design changes were made.

1. Insufficient Quantity Of Fuel Available For Each Injection

In order to increase the maximum quantity of fuel that could be delivered, the spill port was plugged. It should be noted that with no spill port the pump is capable of building pressure cycle by cycle, if it is not vented by the solenoid. The pump could theoretically build up a pressure of 48,144 psi if nothing were to vent the pressure between pumping cycles. Currently the only thing limiting this maximum pressure besides mechanical failure is the solenoid, which lifts of its seat at about 5000 psi.

Now the change in pressure during the pumping cycle is larger when the solenoid is deactivated. This change in performance increases from 500 to 1000 rpm, but stays the same from 1000 to 2000 rpm. The cause may be due to fuel vaporizing across the supply check valve, or as the control volume leaks back into the pump chamber through the spill port passage. The peak pressure with the solenoid active is about 1500 psi. This pressure is relatively constant from 500 rpm to 4000 rpm. No improvement was seen when the vent pressure was increased, up to 120 psi.

A larger bore plunger and pump assembly was fabricated as well as injectors with larger and smaller accumulators in order to be able to install a system with the required fuel flow capabilities.

2. Fuel Delivery Tube Bracket

The first fuel delivery tube bracket failed. A new design was fabricated that necessitated modifying the engine cylinder cooling fins. With this bracket installed, the injector flows increased substantially due to the reduced flexing.

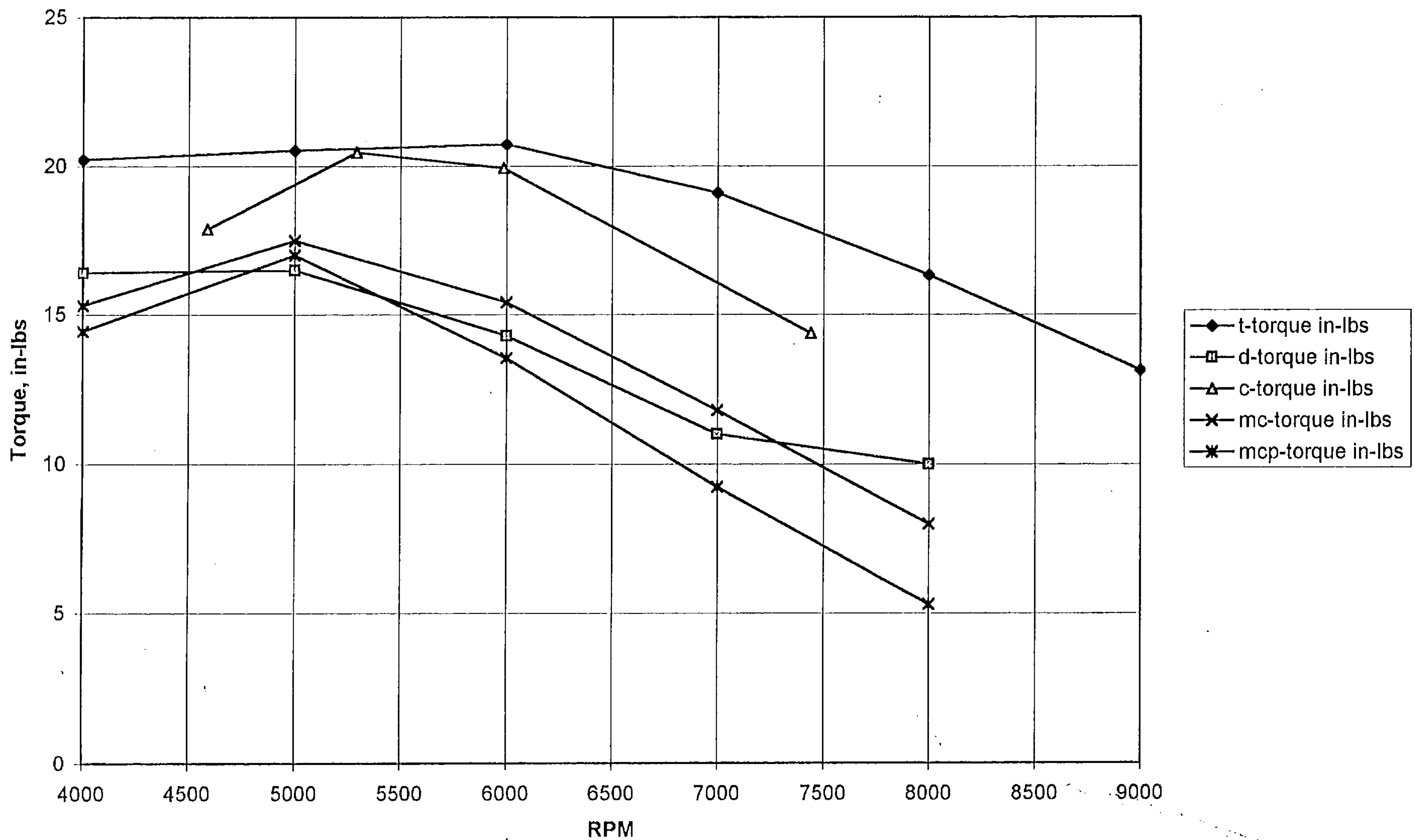
3. Heat Induced Vapor Lock

The engine would die after sustained periods of operation, and then failed to develop any pressure when cranked with the solenoid functioning. The pump would develop pressure when the injector was fired mechanically, but would stop building pressure as soon as the solenoid was put back in operation.
The cause for this loss of pressure is believed to be fuel percolating in hot fuel lines. When the vapor is ingested into the pump, pressure can no longer be built. When the system was operated mechanically the high pressure side of the system never had its pressure drop down to atmospheric pressure, so the boiling point of the fuel would be higher, and therefor a higher temperature would be needed to form vapor.

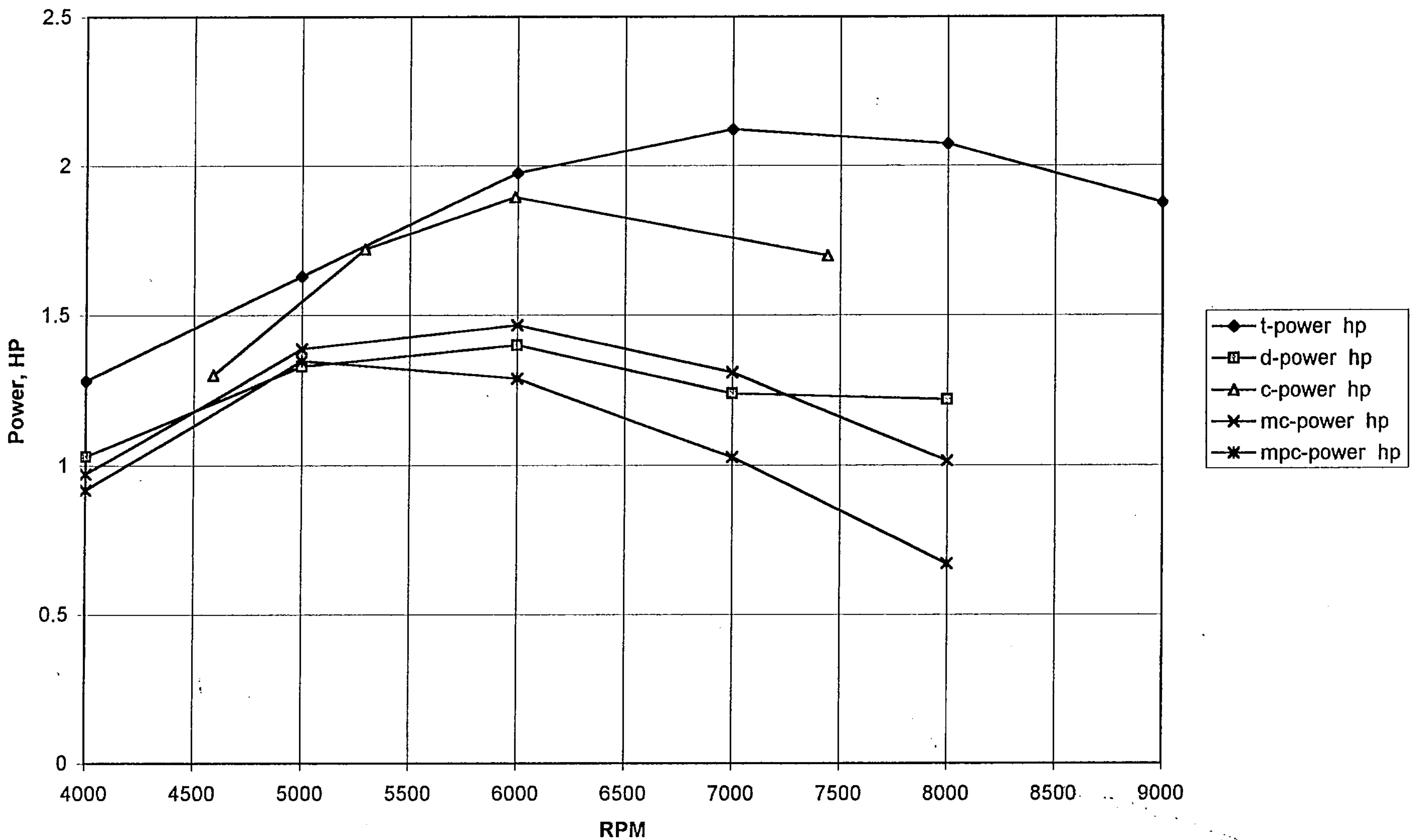
This problem appears to be have been solved by installing an 80 psi pressure relief valve at the solenoid vent. Once this was done, no more hot start problems were experienced, or loss of pressure due to prolonged operation. The 80 psi relief valve has caused a problem in priming the pump. After disassembly the pump can not prime itself unless the relief valve is first removed.

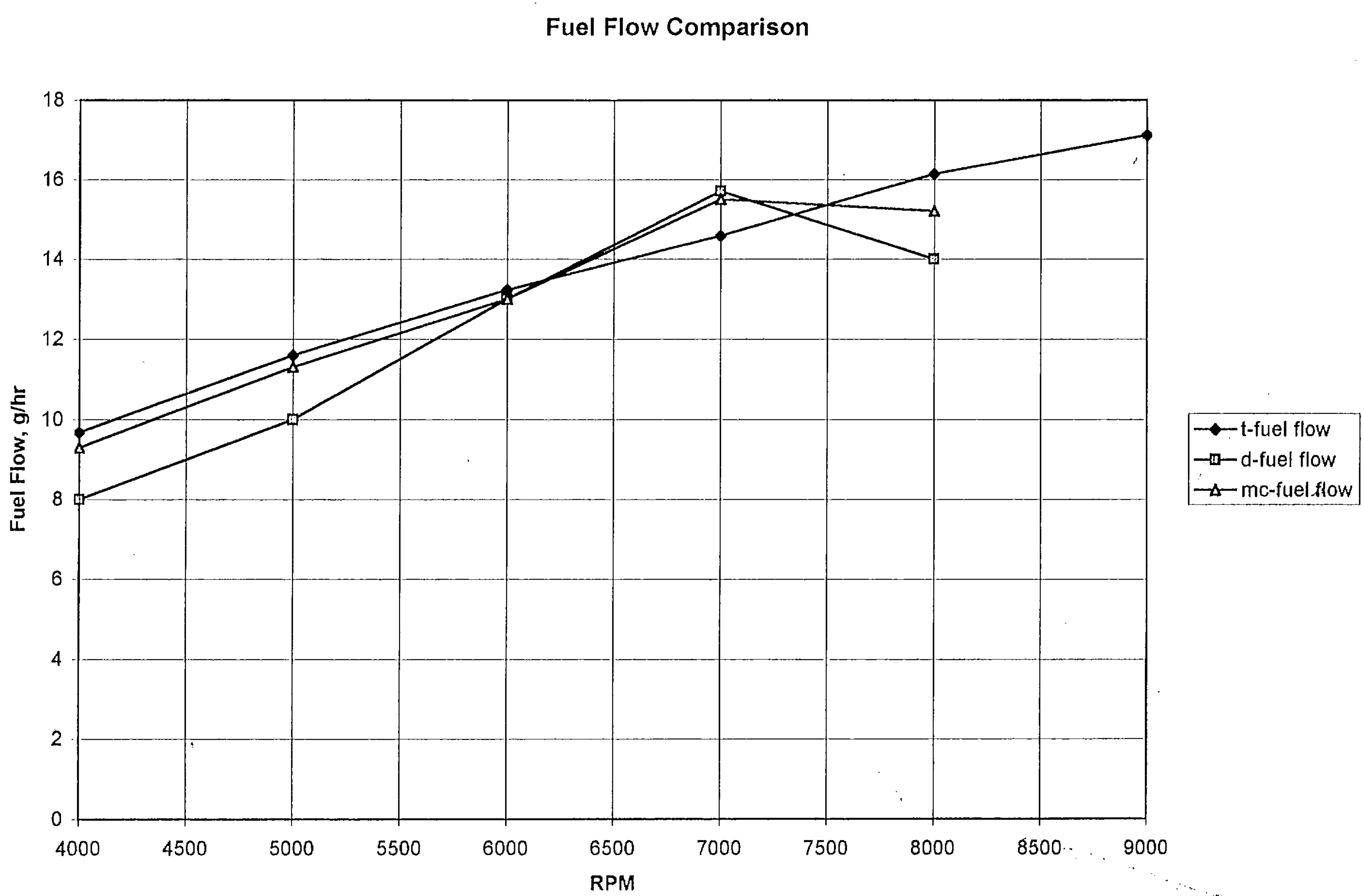
	tanaka claimed carb			DFI			Stock engine measure		mod engine on Carb no pump			mod engine on Carb with pump injecting external to engine					
RPM	t-torque	t-power	t-fuel flow	d-torque	d-power	d-fuel flow	c-torque	c-power	mc-torque	mc-power	mc-fuel flo	mcp-torqu	mpc-power				
RPM	in-lbs	hp	g/hr	in-lbs	hp	g/hr	in-lbs	hp	in-lbs	hp		in-lbs	hp				
3000																	
4000	20.21512	1.283011	9.675473	16.4	1.03	8			15.3	0.971059	9.3	14.44	0.916476				
5000	20.52614	1.628438	11.59816	16.5	1.33	10			17.5	1.38836	11.3	17	1.348693				
6000	20.73347	1.973864	13.23142	14.28	1.4	13			15.4	1.466108	13	13.54	1.289033				
7000	19.10441	2.121904	14.57937	11	1.24	15.7			11.8	1.310612	15.5	9.24	1.026276				
8000	16.3276	2.072557	16.1506	10	1.22	14			8	1.015486	15.2	5.3	0.67276				
9000	13.1312	1.875171	17.12641														
4589							17.88	1.301									
5292							20.46	1.718									
5987							19.94	1.894									
7441							14.38	1.697									

Torque Comparison



Power comparison





Fuel Flow Comparison
Fuel Flow, g/hr
18
16
14
12
10
8
6
4
2
0
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
RPM
t-fuel flow
d-fuel flow
mc-fuel flow

4. Fuel Impingement and Deflection on the Piston Crown

The center of the piston crown is washed clean by the fuel injected. There is an outer ring of carbon build up on the edges of the piston. From tests in the open air, observing the fuel plume striking a piston top, it is believed that the fuel spray is striking the center of the piston, and then deflecting radially outward. This would potentially allow the fuel to shoot out the exhaust port or collect in the ring land crevices.

To solve this problem a bowled piston dome is being look into, as well as ways to decrease the fuel spray penetration.

5. Fuel Leakage Around the New Supply Check Valve

The design, incorporating the new supply check valve, had a press in fitting containing the check valve. After a few hours of operation this fitting developed a leak. After several attempts to salvage this design, a new thread-in fitting containing the check valve was incorporated

6. Fuel Leakage Out the Fuel Delivery Tube Fitting at the Pump

After several hours of operation fuel began to leak out the top of the pump. It was found that the o-ring on the fuel delivery tube had extruded out of its groove. The o-ring has been replaced with a harder durometer viton material. So far the o-ring has not extruded again.

7. Excessive Wear on the Cam Ring

After minimal operation time the brass cam ring showed considerable wear (.010-.020").
The pump cavity and cam ring, were modified for a better fit. An oiling hole was added to the crankcase to drip oil onto the top of the cam ring, and two oiling holes were put in the cam ring to allow the oil down to the cam. After this modification no obvious wear has been evident on the cam ring.

A preliminary fuel injection calibration has been completed. Excellent starting and good run quality was achieved. A big temperature effect was noticed on the required fill timings. Good temperature compensation needs to be developed. Numerous strip chart recordings have been taken of engine temperatures. It has now been confirmed that the crankcase air temperature readings were taken to close to the case wall, so they are more representative of the wall temperature than the air temperature. The crankcase temperatures generally follow the injector surface temperature, though not exactly, and with much smaller temperature swings. So far, the change of fuel flow with temperature cannot be accurately measured. This is at least partially due to our fuel flow meter, which is meant for much higher flows, doesn't have a good averaging routine. The fuel flow readings fluctuate considerably.

A wide open throttle power sweep was taken, on fuel injection. This was repeated with the same engine, only with the high-pressure pump disconnected, and the engine operated with the carburetor. This same test was performed with the same engine, only this time the high-pressure pump was connected and injecting fuel outside the engine. This was done to measure the power required by the pump. The torque, power and fuel consumption data from these tests is compared to the published Tanaka data, and to baseline data taken at BKM of an unmodified engine. This data is shown in the following tables and graphs.

The injector tube still has a tendency to develop leaks periodically, and cannot seem to be run outside the engine with out developing cracks.

There was a failure of the pump inlet check valve. This check valve is a Lee press in valve. It backed its way out approximately ½ in the inlet fitting, increasing the control volume considerably, and thus lowering the system's available peak pressure. This check valve was replaced with a new one. The valve has stayed in place so far.

The inlet fitting has shown a tendency to pinch the o-ring. This design will have to be changed if a new system is built.

The power loss from the published Tanaka data to the DFI engine is a real problem. So a new Tanaka engine was tested for torque and fuel flow here at BKM. This engine was run out of the box, with no modifications to anything, including the jet settings. This engine then had parts changed on it incrementally until it was a DFI engine. This was done to identify the source of the power loss. In addition a modified, bowled piston was testing in the carbureted engine for durability and the effect on power.

The incremental changes went as follows:

1. Factory Stock
2. External oil pump added, no longer premixed gas, Sample probe in the exhaust, fuel delivered at 6 psi.
3. Bowled Piston
4. Stock Piston, modified cylinder
5. Modified Crankcase

Each engine configuration was run at idle, and WOT from 4000 rpm to 8000 rpm in 1000 rpm increments. Torque, fuel flow, and %CO was taken at each point, with the exception of The Factory Stock, where only torque could be taken.

The primary source of the power loss seems to be from the different cylinder. There is a very large difference in the transfer ports of the two cylinders. Although both have the same timing, the DFI cylinder supplied by Tanaka has much less flow area than the current factory engine. The new engine has approximately a 50% increase in flow area.

Changed: Accumulator Volume
Closing Pressure
Injector Location
Ignition system and timings
Bowled piston

By correctly balancing the system volumes and closing pressures I appeared to be able to make the system much more tolerant to changes in fuel temperature, enough so that no temperature compensation or cold start routine was needed for dyno room operation.

Upon engine disassembly patterns could be seen on the piston dome. These patterns suggest that the fuel spray is definitely hitting the piston, but also is being deflected by the transfer air. The fuel appears to not be hitting the center of the piston, but to be centered on the edge of the piston farthest from the exhaust port. It is believed that fuel is wetting the cylinder wall, and being collected in the ring lands.

To try and eliminate this problem the injector location was moved closer to the exhaust port. This only had a moderate effect.

The cam ring was replaced once due to wear. The pump cavity was completely dry of oil, and had considerable dust from wear of the ring. It is believed that the plunger may have had enough fuel leaking by it to wash all of the oil out of the pump chamber. A new tighter fitting plunger was made, and careful oiling of the pump chamber will be done until the engine oiling is rerouted directly to the pump chamber.

The next theory tried was to go away from a 30-degree spray cone angle, and try something narrower.

Osca flow bench study

One injector nozzle was modified to deliver a different spray configuration. The end of the pintle needle was machined off to provide as narrow a spray angle a conveniently possible.

The resulting spray was a nice pencil stream spray. On the flow bench the behavior of the spray was studied when hitting various shaped objects, stock pistons, bowled pistons, flat top and concave topped cylinders of various diameters, at various distances. From this study a "target" was designed and built to screw onto the top of the stock piston. This "target" was then incrementally trimmed to see the effect on engine performance.

ECU problems

When the engine was last assembled for DFI several problems were discovered. The injector tube leaked. The inlet fitting o-ring failed. The pump seemed to have developed a vapor lock problem again, though not as severe as before the 80 psi pop-off valve was installed. The engine performed worse at WOT than before. It seemed to be unable to inject enough fuel. Upon closer inspection it was discovered that the fill timing, as observed on an oscilloscope, was not behaving properly. The timing was not what was commanded, and did not change smoothly. There was a band of timing that could not be delivered around TDC. At higher fuel flow timings the actual timing was stuck around 0 DBTDC until a timing of about 80 DBTDC was commanded, which is later than peak fuel flow timing as seen in the motoring system. A thermister was mounted on the crankcase and the output was monitored on a strip chart. Considerable amplitude noise spikes were seen. A filtering system will be needed. The fuel flow meter readings are very sporadic at idle when running DFI.

The ECU problems are being solved before further running of the engine is done.

A comparison of the previously obtained DFI WOT torque and fuel flows and the Carburetted WOT torque and fuel flows on the new engine with the same modified cylinder are shown in the following tables.

Motec ECU

To alleviate the ECU problems a Motec ECU was purchased and will be used for all further development.

A new crank position sensor and timing gear now replaces the north pole south pole sensing system. The new gear is a 36 minus 2-tooth gear. The timing now is very steady and accurate, with almost undetectable dither, while before it was in the neighborhood of plus or minus 5 degrees, with a shift occurring with rpm. It is not known if the problem stemmed from the Eagle ECU or from using only 3 magnets for crank position sensing. Further software development on the Eagle would be needed to run it with the new timing gear.

Crankcase failure

After a few days of running with the Motec, the crankcase began to leak fuel. The cause for this was that the o-ring sealing surface for the inlet check valve fitting had blown out into a no longer used drilling. This was not the first time this had happened, so a new improved crankcase was built.

New Engine Design

Several new designs were incorporated in the new engine. For better cooling of the high pressure fuel pump is separate from the engine crankcase, just bolting on to it. This eliminates all of the high pressure o-ring seals that were problematic in the previous design. The injector tube fitting is now a thread in fitting with minimal surface area exposed to high pressure.

To facilitate new injector locations, and combustion chamber geometries, the stock cylinder head was machined off, and a billet head was designed to bolt onto the top of the modified cylinder.

To provide a boost pump for the system, and to improve the airflow to the engine and new throttle body was designed. This throttle body will result in the same tuning length as with the carburetor. (The current throttle body is considerable longer) A pulse pump will be incorporated into the base of the throttle body. The throttle body will be made of plastic, so no separate insulator piece will be needed to shield the pulse pump from the heat of the engine.

Although the new throttle body has not yet been fabricated the rest of the new engine was tested. First baseline tests were run with the stock carburetor. This was done with a stock piston, and then with a target screwed into the top of the piston.

DFI testing was done with various target geometries, 11mm flat, dished, 7mm flat, dished, 3 mm flat, and with a bowled piston with no target.

Hot wire ignition test run with a 7mm bowled target.

Hot Wire Preliminary Test Report

The engine was run first with the HEI automotive ignition, and an NGK DPR6EA-9 spark plug at 5000 rpm WOT. Then the Hot Wire was used with a Beru spark plug. The Beru plug was used because it was a non-resistor plug. Then the Hot Wire was run with the NGK resistor plug. With the timings approximately optimized the torque seemed to remain pretty constant around 20 in-lbs. The following table shows the quickly optimized timings.

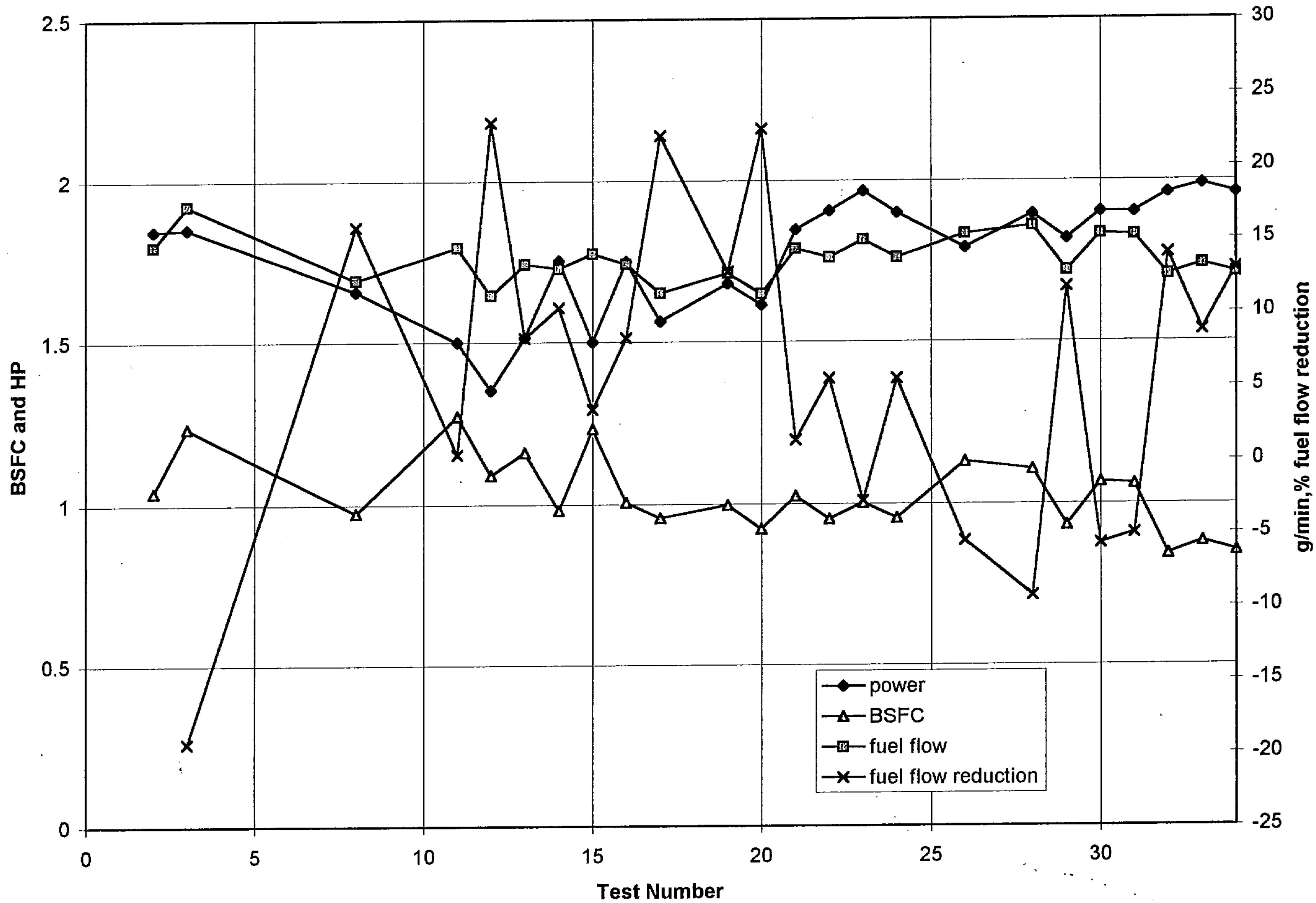
	Automotive ignition with NGK resistor plug	Hot Wire with Beru plug	Hot Wire with NGK resistor plug
Fill Timing	-20	-35	-30
Injection Timing	260	240	240
Ignition Timing	30	30	30
Peak spark amperage	26ma	60amps	2.8amps

Initial fuel flow readings did not show any marked decrease, but this will have to be verified with long averaging times for the fuel flow meter. Also the test should be re-run with the engine hooked up to an HC meter to verify that the later injection times decrease the emissions.

So the summary of the preliminary results were that running the Hot Wire allowed the engine to be run with later injection and fill timings, without losing power.

A Hot Wire was left with me for further testing. I was also given a higher energy coil, and left several of the non-resistor Beru plugs. Nology was loaned a stock Tanaka coil, and flywheel cover and flywheel to perform ignition tests. They also expressed an interest in returning again and taking the time to put together a complete, tuned ignition system for the Tanaka. This may be done after I have completed the rest of my engine and fuel system tests.

peak power																								
WOT																								
fully warmed up																								
																	new engine	new engine	new engine	new engine	new engine	new engine	new engine	
ecu			Eagle	Eagle	Eagle	Eagle	Eagle	Eagle	Eagle	Eagle	Eagle	Eagle	Motec	Motec	Motec	Motec	Motec	motec	motec	motec	motec	motec	motec	
fuel system	Carb	Carb	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	DFI	carb	DFI	DFI	DFI	DFI	DFI	DFI	DFI
head	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	1st new	1st new	1st new	1st new	1st new	1st new	1st new	2nd new
sparkplug location	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	stock	exhaust	exhaust	exhaust	exhaust	exhaust	exhaust	exhaust	exhaust
ignition system	stock	stock	stock	stock	auto	stock	auto	stock	auto	stock	auto	stock	stock	stock	auto	stock	stock	stock	stock	stock	stock	stock	stock	stock
piston	stock	bowled	stock	stock	stock	stock	stock	stock	stock	bowled	bowled	stock	stock	stock	stock	bowled	stock	11mm targ	11mm targ	11mm dish	7mm large	7mm dishe	3mm large	bowled
injector location			1	1	1	1	1	1	1	1	1	2	2	2	2	2	central	central	central	central	central	central	central	central
pump bore			4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4	4	4	4	4	4	4	4
accum volume			302	360	360	500	500	500	500	500	500	500	500	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil	360 pencil
closing pressure			1200	1200	1200	1200	1200	500	500	700	700	700	700	700	700	700	700	700	700	700	700	700	700	700
test#	2	3	8	11	12	13	14	15	16	17	19	20	21	22	23	24	26	28	29	30	31	32	33	34
power	1.845	1.850406	1.6565	1.5	1.353	1.514	1.752	1.5	1.749	1.563	1.68	1.613	1.846	1.904	1.966	1.898	1.79	1.894	1.817	1.901	1.9	1.96	1.987	1.96
fuel flow	14.5	17.3	12.2	14.44	11.16	13.3	13	14	13.3	11.3	12.65	11.23	14.3	13.7	14.9	13.7	15.3	15.845	12.8	15.33	15.23	12.47	13.23	12.62
BSFC	1.039578	1.236701	0.974213	1.27339	1.091068	1.162014	0.98151	1.234589	1.005883	0.956324	0.996017	0.920939	1.024684	0.951786	1.002509	0.954794	1.130639	1.106618	0.931838	1.066708	1.060307	0.841581	0.88074	0.851704
fuel flow reduction		-19.3103	15.86207	0.413793	23.03448	8.275862	10.34483	3.448276	8.275862	22.06897	12.75862	22.55172	1.37931	5.517241	-2.75862	5.517241	-5.51724	-9.27586	11.72414	-5.72414	-5.03448	14	8.758621	12.96552


BSFC and HP
g/min,% fuel flow reduction
Test Number
power
BSFC
fuel flow
fuel flow reduction
2.5
2
1.5
1
0.5
0
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
5
10
15
20
25
30

Test Summary																																		
Test #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
fuel system																																		
Carb	X	X	X	X	X	X																			X	X	X							
DFI																																		
Injector Cone angle																																		
30 degrees							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X													
pencil stream																						X	X	X				X	X	X	X	X	X	X
Injector Volume																																		
208							X	X																										
302																																		
360									X	X	X	X										X	X	X				X	X	X	X	X	X	X
500													X	X	X	X	X	X	X	X	X													
Injector Closing Pressure																																		
500															X	X																		
700																	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X
1200							X	X	X	X	X	X	X	X																				
Ignition System																																		
stock IDI	X	X	X	X	X	X	X	X	X		X		X		X		X			X	X	X		X	X	X	X	X	X	X	X	X	X	X
Automotive IDI optimized timings										X		X		X		X			X				X											
Automotive IDI stock timings																		X																
Hot Wire																																		
Piston																																		
stock																																		
no target	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X		X	X								
11mm flat target																											X	X	X					
11 mm dished target																														X				
7mm flat target																															X			
7mm dished target																																X		
3 mm flat target																																	X	
Bowled			X														X	X	X					X										X
Combustion Chamber																																		
Stock, offset																																		
Injector location																																		
none	X	X	X																															
1st				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
2nd																				X	X	X	X	X										
central hemispherical																																		
Injector location																																		
central																									X	X	X	X	X	X	X	X	X	X
offset, intake side																																		
central connical																																		
Cylinder																																		
Small Transfer ports				X	X	X	X																											
Large Transfer ports	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oil System																																		
32:1 premix	X																																	
Oil Injection, equivalent to 56:1 on Carb at WOT		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

1				
new stock tanaka engine				
32:1 premix				
factory carb				
cold idle	2800			
warm idle	3300			
hot idle	3700			
speed	torque	power	torque	power
rpm	in-lbs	hp	in-lbs	hp
4000	18.34	1.164001	18.06	1.14623
5000	20.52	1.627951	19.86	1.57559
6000	20.08	1.911653	19.26	1.833587
7000	17.86	1.983689	17.8	1.977025
8000	14.54	1.845646	14.68	1.863417

2									
new stock tanaka									
oil injection from now on			56 to 1	versus base carburetted fuel flow at WOT					
old muffler with exhaust sample probe									
fuel flow readings									
factory carb									
	speed	co	ff						
cold idle	3000	2.6	3						
warm idle	2800	3.2	3.3						
hot idle	3000	3.6	3.2						
speed	torque	power	co	ff	torque	power	co	ff	
rpm									
4000	19.2	1.218583	3.52	10.2	18.5	1.174156	3.53	10.5	1.182903
5000	20.4	1.618431	4.53	12.4	20.14	1.597804	4.64	12.5	1.034837
6000	19.48	1.854532	5.3	14.5	19.38	1.845011	5.37	14.5	1.039572
7000	16.22	1.801536	6.75	17	16.26	1.805979	6.73	17	1.24515
8000	11.04	1.401371	8.26	19.6	10.96	1.391216	8.24	19.7	1.873084

3									
factory carb									
bowled piston									
oil pump									
new cylinder, big ports, no inj port									
new crankcase									
new crank									
	speed	co	ff						
cold idle	2900	2.76	3.2						
warm idle	2700	3.25	3.5						
hot idle	2800	3.74	3.5						
speed	torque	power	co	ff	torque	power	co	ff	
rpm									
4000	18.2	1.155116	3.78	11.2	17.18	1.090378	3.86	11	
5000	19.5	1.54703	4.68	13.3	19.22	1.524816	4.7	12.8	
6000	18.8	1.789794	5.55	15.5	18.62	1.772658	5.62	15.2	
7000	16.76	1.861513	6.92	17.2	16.66	1.850406	6.86	17.3	
8000	12.5	1.586697	8.35	19.4	12.2	1.548616	8.32	19.5	

4								
modified cylinder, small ports								
normal piston								
new crank								
new crankcase								
oil pump								
factory carb								
	speed	co	ff					
cold idle	2000	2.47	3.2					
warm idle	2100	3.18	3.2					
hot idle	2100	3	3.4					
speed	torque	power	co	ff	torque	power	co	ff
rpm								
4000	15.42	0.978675	3.8	11.3	15.02	0.953288	3.83	10.7
5000	17.86	1.416921	4.06	13.3	17.6	1.396293	4.04	13.1
6000	15.5	1.475628	5.15	15.4	15.62	1.487053	5.16	15.2
7000	11.6	1.288398	6.38	16.9	11.66	1.295062	6.35	16.8
8000	5.3	0.67276	6.76	19.5	5.18	0.657527	6.65	19

5									
stock fly wheel, no alternator									
modified crankshaft									
modified crankcase, no high pressure fuel pump									
oil pump									
modified cylinder, small ports									
normal piston									
factory carb									
	speed	co	ff						
cold idle	1900	2.5	3.2						
warm idle	2300	3	3.5						
hot idle	2100	2.94	3.2						
speed	torque	power	co	ff	torque	power	co	ff	
rpm									
4000	16.26	1.031988	2.9	10.3	15.46	0.981214	3.07	9.8	
5000	18.22	1.445481	4.04	13	18	1.428027	4.1	12.8	
6000	14.82	1.410891	5.4	15.1	15.16	1.44326	5.4	15.1	
7000	9.1	1.010726	7.25	17.44	9.26	1.028497	7.17	17.3	
8000	5.26	0.667682	6.63	18	4.7	0.596598	6.37	18.2	

6								
same as above run the next day with no exhaust sample probe								
stock fly wheel, no alternator								
modified crankshaft								
modified crankcase, no high pressure fuel pump								
oil pump								
modified cylinder, small ports								
normal piston								
factory carb								
	speed	co	ff					
cold idle	1800		3					
warm idle	1900		3					
hot idle	1700		3.2					
speed	torque	power	co	ff	torque	power	co	ff
rpm								
4000	18.14	1.151307		11.2	17.36	1.101802		9.8
5000	17.42	1.382013		13.7	17.38	1.37884		12.8
6000	15.1	1.437548		15.2	14.74	1.403275		15.1
7000	8.4	0.932978		18.1	8.5	0.944085		17.3
8000	3.5	0.444275		18.3	3.4	0.431582		18.2

7				
DFI				
modified crankshaft				
new half of crankcase				
oil pump				
modified cylinder, small ports				
normal piston				
	speed	co	ff	
cold idle				
warm idle				
hot idle				
speed	torque	power	co	ff
rpm				
4000	16.4	1.040873		8
5000	16.5	1.309025		10
6000	14.28	1.359482		13
7000	11	1.221757		15.7
8000	10	1.269358		14

8										
modified crankshaft										
new half of crankcase										
oil pump										
modified cylinder, big ports										
normal piston										
DFI (no alternator)										
	2 stroke			4 stroke			6 stroke			
	speed	co	ff	speed	co	ff	speed	co	ff	
cold idle										
warm idle	2500	2.5	2.8	2500	2.7	3	2400	1.5	1.7	
hot idle										
speed	torque	power	co	ff						
rpm										
4000	17.44	1.10688	3.3	9						
5000	18.6	1.475628	3.74	11.4						
6000	17.4	1.656512	3.62	12.2						
7000	12.6	1.399467	3.52	13.5						
8000	-									

9		
DFI		
big ports		
new plunger		
360 accumulator		
stock ignition		
speed	torque	power
2000	14.38	0.455
3000	14.46	0.689
4000	17.26	1.094
5000	18.76	1.486
6000	17.54	1.67
7000	12.88	1.435

10		
DFI		
big ports		
new plunger		
360 accumulator		
inductive ignition timing set to optimum to the nearest 5 degrees, though some software glitch variation still exists, 6.0 ms dwell		
speed	torque	power
2000	14.52	0.464
3000	15.1	0.7
4000	18	1.14
5000	19.78	1.58
6000	19.92	1.9
7000	15.1	1.7

11							
DFI							
big ports							
360mm3 accum							
stock ignition							
stock piston							
idle							
skips	tp	rpm	ff				
0	9.9	2250	1.98				
1	9.9	2250	1.5	1.75	1.9	1.93	2.05
any more skipps failed to achive sustained running							
WOT	several minutes at each point to get a good average fuel flow reading						
rpm	torque	power	ff				
2000	14.2	0.459	3.13	3.59			
3000	13.5	0.655	6.29	5.19	6.24		
4000	15.04	0.945	8.51	8.46			
5000	16.28	1.289	11.21	11.64	11.61		
6000	15.76	1.5	13.33	14.96	14.44		

12						
DFI						
big ports						
360mm3 accum						
inductive ignition 6ms dwell set to previous optimum ignition						
stock piston						
idle						
skips	tp	rpm	ff			
0	9.8	2600	3.52	2.51	2.3	2.1
1	9.8	2600	2.4	2.25	2.33	3.13
any more skips failed to sustain running						
WOT						
rpm	torque	power	ff			
2000	14.3	0.43	3.12	3.18		
3000	14.36	0.699	6.31	5.99	6.7	
4000	16.8	1.054	8.67	8.65		
5000	17.28	1.353	11.16			
6000	engine appeared to vapor lock the pump					

13				
500mm3 accum				
stock ignition				
could not sustain 2 or more skips at idle				
wot				
rpm	power	torque	ff	
2000	0.423	13.66	3.16	3.05
3000	0.633	13.66	5.28	5.31
4000	0.956	14.92	8.49	8.32
5000	1.3	16.36	11.64	12.65
6000	1.514	16.04	13.49	13.22

14									
IDI, same fuel, old ignition timing(previously optimized)									
WOT									
rpm	power	torque	ff						
2000	0.383	12.62	2.1	2.3					
3000	0.656	13.96	6.95	6.99	5.34	5.87			
4000	1.065	16.72	7.79	8.31	8.13				
5000	1.443	18.16	10.28	10.74	10.73				
6000	1.752	18.18	13.38	12.22					

15						
500mm3						
accumulator; with 500 psi closing pressure(previously is was close to 1200 psi)						
stock ignition						
idle						
skip#	TP	RPM	FF			
0	13	2700	3.45	3.41		
0	10	2200	2.49	2.89	2.9	
1	13	2900	3.44	3.37		
2	13	2700	2.8	2.59	3.03	3.02
3	13	2800	2.34	2.21		
4	22.6	4100	3.21	3.03		
WOT						
rpm	power	torque	ff			
2000	0.48	15.06				
2000	0.45	14	3.72	3.84		
3000	0.648	13.3	5.93	5.89		
4000	1.007	15.8	9.62	10.81	9.53	
5000	1.333	16.7	11.86	11.8		
6000	1.5	15.9	12.28	14	14.03	
7000						

16					
automotive ignition					
set to best timing					
idle					
skip#	TP	RPM	FF		
0	10	2700	3.36	3.52	
1	10	2600	2.54	2.86	2.73
2	10	2800	2.81	2.99	
3	11.5	2900	3.2	3.42	
4	15	3050	2.44	died	
WOT					
rpm	power	torque	ff		
2000	0.44	13.72	3.51	3.85	
3000	0.697	14.56	5.51	6.37	5.94
4000	1.045	16.76	7.49	9.94	9.85
5000	1.432	17.86	12.46	12.31	
6000	1.749	18.18	13	13.6	
7000					

17						
Changed to bowled piston and added .02" shims to spring for a Pc of about 700						
stock ign						
idle						
skip#	TP	RPM	FF			
0	10	2500	2.01	1.89		
1	10	2550	2.74	3.03		
2	10	2550	2.62	2.35	2.35	2.29
3	10	dies				
WOT						
rpm	power	torque	ff			
2000	0.446	14.02	3.43	3.36		
3000	0.676	14.2	6.2	5.6	5.44	
4000	1.067	16.6	9.1	8.67		
5000	1.386	17.4	10.81	10.94		
6000	1.563	16.26	10.61	11.85	11.31	
7000	looses injections from ecu					

18						
automotive ignition						
timing set to 28 degree commanded, same as stock						
idle						
skip#	TP	RPM	FF			
0	10					
1	10					
2	10					
3	10	dies				
WOT						
rpm	ignt meas	power	torque	ff		
2000	28+-1	0.43	13.66	2.97	2.9	
3000	29+-2	0.667	14.18	6.66	5.57	5.55
4000	29+-2	1.054	16.68	8.62	8.63	
5000	25+-3	1.357	17.28	11.1	10.94	
6000	22+-4	1.41	15.08	11.96	11.93	
6000	33	1.8				

19									
automotive ignition with optimized timing									
idle									
skip#	TP	RPM	FF						
0	10	2500	1.76	1.83					
1	10	2600	2.56	2.47					
2	10	2400	2.5	1.72	1.54	1.61			
3	10	dies							
WOT									
rpm	ign com.	ignt meas	power	torque	ff				
2000	30	30	0.472	14.66	3.76	3.58			
3000	35	34-37	0.724	15.36	5.4	5.43			
4000	35	34-36	1.093	17.28	8.88	8.93	occasional timing shifts		
5000	40	36-38	1.472	18.5	11.42	11.49			
6000	50	42-46	1.68	17.7	12.63	12.68			

20										
stock piston										
new cylinder, modified stock for 2nd injector location, closer to the exhaust port, but still at a 15 degree angle										
500mm3 accum										
700 psi closing pressure.										
stock ignition										
idle										
skip#	TP	RPM	FF							
0	12.6	2450	1.98	2.58	3.07	3.21	2.81	2.85	3.22	
1	12.7	2800	2.17	1.99	2.39	3.28				
2	12.7	dies								
3	12.7	dies								
WOT										
rpm	ign com.	ignt meas	power	torque	ff					
2000										
3000										
4000			1.12	17.54	7.82	7.71	occasional timing shifts			
5000			1.468	18.64	10.47	10.14	10.5			
6000			1.613	16.92	11.75	11.23	11.13			

21									
Motec ECU									
stock piston									
2nd inj location									
500 mm3 accum									
700 psi closing									
stock ignition									
new timing wheel									
idle									
tp	rpm	ff			ft	ijt			
5	2500	2.16	2.14		-20	100			
wot									
rpm	ft	it	power	torque	ff				
3000	0	200	0.776	16.12	5.93	5.95			
4000	-10	230	0.998	15.56	8.31	8.56			
5000	-10	240	1.44	17.92	11.06	11.37			
			1.514	19	10.9	11.23	11.34		
6000	-15	240	1.558	16.76	12.03	11.73	11.48		
7000	-15	260	1.846	16.6	14.27	14.47			
8000			1.3						

22				
Motec ECU				
stock piston				
2nd inj location				
360 mm3 accum				
700 psi closing				
pencil stream spray				
stock ignition				
idle				
rpm	ff	amps		
2500	2.77	1.2		
	3.05			
	2.92			
WOT				
rpm	hp	in-lbs	g/min	amps
4000	0.992	15.66	7.61	1.8
			7.56	
5000	1.446	18.14	11.04	1.8
			11.02	
6000	1.727	18.3	12.77	1.8
			12.11	
			12.13	
7000	1.904	17.14	12.13	2.22
			13.72	
			13.77	

23				
Motec ECU				
stock piston				
2nd inj location				
360 mm3 accum				
700 psi closing				
pencil stream spray				
automotie ignition				
idle				
rpm	g/min	amps		
2600	2.79	2		
	2.56			
wot				
rpm	hp	in-lbs	g/min	amps
4000	0.995	15.64	7.77	2.8
5000	1.49	18.64	10.2	3.1
			7.63	
			10.74	
			11.12	
6000	1.787	18.74	13.11	3.6
			12.41	
7000	1.966	17.64	14.91	4.5
			14.86	

24			
Motec ECU			
bowled piston			
2nd inj location			
360 mm3 accum			
700 psi closing			
pencil stream spray			
stock ignition			
idle			
rpm	g/min		
2500	2.25		
	2.66		
	2.73		
wot	2.65		
rpm	hp	in-lbs	g/min
4000	1.09	17.16	6.86
			7.01
			7.07
5000	1.43	17.92	9.27
			6.48
			9.09
			9.67
6000	1.706	17.9	12.95
			12.07
			12.04
7000	1.898	16.96	13.97
			13.63

25				
carb				
stock piston				
central inj location,spark plug on exhaust side, with thermocouple				
360 mm3 accum				
700 psi closing				
pencil stream spray				
stock ignition				
first new head design				
rpm	torque	power	head temp	
rpm	in lbs	hp	F	
4000	16.12	1.02	335	
	18.3	1.45	390	
	18.3	1.74	420	
	15.16	1.66	400	
				ff
2500	0	0	94	1.41
				1.23
				1.32

26								
carb								
stock piston								
central inj location,spark plug on exhaust side, no thermocouple								
360 mm3 accum								
700 psi closing								
pencil stream spray								
stock ignition								
first new head design								
rpm	torque	power	ff				ave ff	bsfc
rpm	in lbs	hp	g/min					
4	17	1.075	10.66	10.64			10.65	1.31047
5	19.64	1.556	13.88	13.03			13.455	1.14383
6	18.74	1.79	15.21	15.35			15.28	1.12916
7	14	1.55	17.68	18.46	20.26		18.8	1.6044

27		
carb		
stock piston with full length target		11mm hieght
central inj location,spark plug on exhaust side, no thermocouple		
360 mm3 accum		
700 psi closing		
pencil stream spray		
stock ignition		
first new head design		
rpm	torque	power
rpm	in lbs	hp
4	16.38	1.045
5	17.36	1.402
6	15.8	1.527
7	12.58	1.402

28									
motec dfi									
stock piston with full length target			11mm hieght						
central inj location,spark plug on exhaust side, no thermocouple									
360 mm3 accum									
700 psi closing									
pencil stream spray									
stock ignition									
first new head design									
rpm									
rpm	ft	it	power	torque	ff			ave ff	bsfc
4	-20	260	1.15	18	8.91	8.65		8.78	1.009909
4	-30	80	0.93	14.64	7.07	7.14		7.105	1.010571
5	-25	250	1.531	19.36	10.27	10.3		10.285	0.888617
5	-30	50	1.208	15.34	10.01	10.9		10.455	1.144834
6	-25	260	1.802	18.82	11.7	11.83		11.765	0.86362
7	-15	270	1.894	17	13.84	15.91	15.78	15.845	1.106618

29										
motec dfi										
stock piston with full length target			11mm hieght							
central inj location,spark plug on intake side, no thermocouple										
360 mm3 accum										
700 psi closing										
pencil stream spray										
stock ignition										
first new head design										
rpm	ft	it	power	torque	ff				ave ff	bsfc
4	-20	260	1.102	17.34	10.86	10.12	9.92	10.1	10.25	1.230348
5	-25	250	1.515	19.18	11.24	10.89	10.96		11.03	0.963049
6	-25	260	1.817	19.1	12.28	13.41	12.76		12.81667	0.933052
7	-15	270	1.808	16.18	15.91				15.91	1.164012

30									
motec dfi									
stock piston with full length target			11mm hieght		dished with a .25 ball nose end mill				
central inj location,spark plug on intake side, no thermocouple									
360 mm3 accum									
700 psi closing									
pencil stream spray									
stock ignition									
first new head design									
rpm	ft	it	power	torque	ff			ave ff	bsfc
4	-20	260	1.188	18.62	8.78	8.81		8.795	0.979276
5	-25	250	1.585	19.86	9.97	10.02		9.995	0.83414
6	-25	260	1.805	18.92	12.23	12.22		12.225	0.895895
7	-15	275	1.901	17.04	15.32	15.34		15.33	1.066708

31										
motec dfi										
stock piston with medium length target				7mm hieght						
central inj location,spark plug on intake side, no thermocouple										
360 mm3 accum										
700 psi closing										
pencil stream spray										
stock ignition										
first new head design										
idle	rpm	TP	FT	IT	FF					
	2350	6.5	-45	150	1.63	1.74	1.79			
rpm	ft	it	power	torque	ff			ave ff	bsfc	
4	-20	255	1.215	19.18	8.45	8.6	8.7	8.583333	0.93447	
5	-20	260	1.633	20.6	11.07	10.98	11.07	11.04	0.89427	
6	-25	260	1.839	19.36	12.43	12.36		12.395	0.89156	
7	-15	270	1.9	17.04	15.23			15.23	1.060308	

32									
motec dfi									
stock piston with medium length target				7mm hieght		dished w .25" ball nosed end mill			
central inj location,spark plug on intake side, no thermocouple									
360 mm3 accum									
700 psi closing									
pencil stream spray									
stock ignition									
first new head design									
rpm	ft	it	power	torque	ff			ave ff	bsfc
4000	-20	260	1.216	19.04	8.58	9.08		8.83	0.960534
5000	-20	260	1.634	20.52	11.36	11.22		11.29	0.913961
6000	-25	260	1.88	19.8	13.54	12.26	12.49	12.76333	0.898032
7000	-20	270	1.96	17.52	12.32	12.62		12.47	0.841581

33											
motec dfi											
stock piston with short length target				3mm hieght		flat					
central inj location,spark plug on intake side, no thermocouple											
360 mm3 accum											
700 psi closing											
pencil stream spray											
stock ignition											
first new head design											
rpm	ft	it	power	torque	ff				ave ff	bsfc	
4000	-25	250	1.164	18.48	8.19	7.67	7.38	7.42	7.665	0.871053	
5000	-20	260	1.612	20.3	10.83	10.87			10.85	0.890329	
6000	-20	270	1.88	19.72	13.21	13.22			13.215	0.929811	
7	-20	270	1.987	17.92	13.11	13.28	13.29		13.22667	0.880518	

34									
motec dfi									
bowled piston, no target									
central inj location,spark plug on intake side, no thermocouple									
360 mm3 accum									
700 psi closing									
pencil stream spray									
stock ignition									
first new head design									
rpm	ft	it	power	torque	ff			ave ff	bsfc
4000	-25	250	1.173	18.42	7.44	7.37		7.405	0.83505
5000	-20	260	1.573	19.82	10.82	10.92	10.99	10.91	0.917448
6000	-20	270	1.89	19.74	13.26	13.23	13.18	13.22333	0.925475
7000	-20	280	1.96	17.56	12.49	12.63	12.74	12.62	0.851704

35										
motec dfi										
bowled piston, no target										
central inj location,spark plug on intake side, no thermocouple										
500mm3 accumulator										
700 psi closing										
30 degree spray										
stock ignition										
first new head design										
idle	rpm	tp	ft	it	ff					
	2500	7	-40	110	1.86	1.92				
rpm	ft	it	power	torque	ff			ave ff	bsfc	
4000	-20	250	1.148	18.1	9.02	8.39	8.45	8.62	0.993233	
5000	-20	260	1.575	19.84	11.08	11.43	11.47	11.32667	0.951277	
6000	-20	270	1.907	20.08	13.42	13.74		13.58	0.941965	
7000	-10	290	2.021	18.1	15.4	15.88		15.64	1.023661	

36												
motec dfi												
bowled piston, no target												
central inj location,spark plug on intake side, no thermocouple												
208mm3 accumulator												
700 psi closing												
pencil stream spray												
stock ignition												
first new head design												
idle	rpm	tp	ft	it	ff							
	2500	7	-35	180	1.45	1.8						
rpm	ft	it	power	torque	ff						ave ff	bsfc
4000	-5	250	1.18	18.66	6.48	6.53					6.505	0.729207
5000	-5	260	1.58	19.96	8.89	8.65	8.98	9.59	9.75	9.74	9.693333	0.811525
6000	5	270	1.885	19.76	12.41	12.62					12.515	0.878224
7000	10	280	2.016	18.04	11.54	14.61	14.33	14.64			14.52667	0.95315

Appendix C – Walbro Letter

[redacted]

Walbro
Engine Management
New Product Development

4144 Doerr Road
Cass City, Michigan 48726-9309
Telephone (517) 872-2131
FAX (517) 872-1838

March 23, 1998

Bill Johnson
BKM, Inc.
5141 Santa Fe Street
San Diego, CA 92104

Dear Bill:

I have received your letter of March 5, 1998. Thank you.

Walbro remains excited about your new fuel injection system for small two-stroke engines, and eagerly await performance and emission test results. As BKM continues development with its customers, please keep us informed of the results and continued customer interest.

As discussed, Walbro is committed to being the preferred global supplier of engine management components and systems for small gasoline engines. Currently, Walbro produces more than 10,000,000 carburetors and 5,000,000 ignitions annually for this market, and enjoys rapid growth in components and sub-systems for EFI/DI on motorcycles, snowmobiles, personal water craft and outboard motors. To support this, Walbro has technology centers in Asia, Europe and North America, with manufacturing sites in Japan, China, Singapore, Mexico, Michigan, Indiana and Italy.

With the above brief background, Walbro expresses its interest in being the supplier of components and/or complete systems now in development at BKM. If chosen, Walbro would consider each future customers business case individually, as well as the market collectively, to assure most favorable pricing. Of course, the design of the "common product" (platform) will have a great deal to do with volume manufacturing and favorable pricing. Further, Walbro would be interested in becoming the future "Tier I" supplier, assuming continued engineering and development responsibility. This will require a great deal of joint effort between BKM and Walbro to assure know-how is transferred while customers are supported.

In summary, Walbro will continue to expand into new technologies, views BKM's new technology as a "high potential winner" and may wish to be a supplier of components and/or systems, contingent upon a successful business case.

Thank you for the opportunity to review your project, we look forward to a mutually profitable relationship.

Sincerely,

Ron Roche

Ron Roche, Director
Advanced Technology