A Gear Selection Aid For Agricultural Tractors

by

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PREFACE

This thesis describes the design, construction and testing of a device designed to assist the operators of agricultural tractors to minimize fuel usage during field operations. This project was conceived by Dr. Mark Schrock. His work in promoting gear-up and throttle-down while working for the Agricultural Extension Service provided much of the insight necessary during development of both hardware and software. His assistance and encouragement as both an advisor and friend has made the project much easier.

I would like to give a special thanks to International Harvester for providing the tractor and their technical assistance for this project.

I would also like to acknowledge and thank my major advisor, Dr. J. Garth Thompson for his assistance during this project. He was very helpful with the technical aspect of implementation. His assistance in the implementation of the electronic hardware saved countless hours of delay during equipment development.

I would also like to acknowledge and thank Mike Schwarz and the Agricultural Engineering Department for allowing the use of computer equipment and software Mike had developed for previous projects as well as providing ideas for the software for this project.

And finally, a special thanks to my family. Without their support I would not have been able to finish this project.

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Chapter 1

CONCEPT DEVELOPMENT

Project Justification

Rising fuel costs have prompted farmers to explore ways of optimizing fuel efficiency in operating their equipment. Diesel fuel prices, for example, increased 588% from 1972 to 1981. This increased cost has made the farmer aware of energy-saving modifications and practices in operating farm equipment.

Gear Up and Throttle Down

Many methods of reducing fuel consumption already have been implemented with varying degrees of success. Gear up and throttle down effectively reduces fuel consumption during light field operations with agricultural tractors, Hauck[1] (1979).

The basic concept of gear up and throttle down is to operate the tractor at the most fuel-efficient engine speed and gear ratio while maintaining the desired ground speed. This practice was promoted during the mid to late '70s by Kansas State University Extension Agricultural Engineering Department. Although this practice cannot be implemented in all agricultural field operations, it can be beneficial when the tractor is being operated at less than full load. The savings afforded by gear up and throttle down are due to the reduced engine friction, hydraulic pumping, and fan losses.

Estimated Savings

Chancellor[2] (1981) estimated a potential fuel savings of 10% and an increased rate of work of 17% by operating a tractor at its most efficient torque-speed combination during a field operation. The estimation was based on a hypothetical transmission, selecting from 32 possible gear ranges for light loading during a single field operation. The simulation provided for sampling and changing gears at 10-second intervals. The increased rate of work indicated that the tractor also changed field speed in the optimization.

Stevens[3] (1981) evaluated the fuel savings resulting from operating a John Deere 4640 tractor at 1700 rpm instead of full throttle. The study was based on draft data from 10 relatively low-power requirement field operations. The savings ranged from 13 to 36%, depending on the extent of loading and field variation.

Operator Concerns

The main concern in implementing gear up and throttle down is engine damage. Diesel engines and turbochargers can be damaged by prolonged excessive loading at low engine speeds. This overloading at low rpm often is referred to as "lugging." Lugging for short periods will not damage engines, but lugging for extended periods may damage pistons, bearings, and turbo chargers.

Limitations of Application

Gear up and throttle down also is limited to field operations where implements are not driven by the power take-off (pto). The pto speed is directly proportional to the engine speed, and most pto-driven equipment must be operated at an engine speed of 2100 rpm. Another limitation is the reduction in reserve power, or ability to recover from short intervals of overloading. At lower engine speeds the torque rise is reduced, thus limiting the ability of the engine to recover during field operations with highly variable loading, such as chiseling or plowing.

The use of gear up and throttle down is believed to be limited. Much of the hesitancy is due to insufficient information provided by the tractor instrumentation and the operator's lack of familiarity with the procedure. Feedback from the tractor to the operator could greatly enhance the use of gear up and throttle down. In most situations, the operator cannot estimate the loading of the engine or the potential fuel savings from using gear up and throttle down. The operator may be reluctant to use the practice because he thinks it may damage the tractor. Depending on the load, this damage may be either real or imaginary, but to the operator, it is a real concern. During most light field operations, the operator can be assured he will not damage the tractor by gear up and throttle down. As the loading is increased, however, the possibility of overloading is increased, and the operator becomes hesitant to implement gear up and throttle down.

Operator Interface

If the operator had information indicating the tractor could be operated in a more optimum range without damaging it, the operator's reluctance would be decreased. A gear selection aid could provide this link between the operator and the tractor. If the operator knew the optimum operating range, engine speed, and estimated fuel savings, he would have all the necessary information as well as the incentive to use gear up and throttle down.

Incentive for Development

Several recent developments have decreased the cost and enhanced the feasibility of developing equipment to implement a gear selection aid for the gear up and throttle down concept. The analysis necessary for evaluating the engine load, ground speed, engine speed, fuel consumption, and potential fuel savings is complex. Although it may have been possible to implement this concept by using TTL or CMOS devices, the microprocessor greatly increased the flexibility of the implementation.

The price, size, and calculating power of microprocessors have changed drastically in recent years. Single board microcomputers with 4000 bytes of RAM and 2000 bytes of ROM can be purchased for less than $300. The physical dimensions of these units are about the size of a sheet of notebook paper and less than an inch thick. These units can be programmed to do all calculations necessary for the optimization routines.

Electronic sensors capable of direct connection to the microcomputer also have enhanced the implementation. Automotive and agricultural equipment now use digital electronics that are less expensive, more accurate, more reliable, and more rugged than the older analog technology.

The reserve torque capacity of tractor engines also has increased with the newer engine designs. Many of the early turbocharged diesel tractor engines had a relatively sharp torque drop with reduced engine speed. When the engine was loaded and the rpm decreased, the torque also decreased rapidly, thus causing the engine to lug or stall. This made operating the engine at speeds less than 1800 rpm possible only during light loading. The more recent tractor engines have relatively high torque rises, which helps to minimize the possibility of overloading or lugging the engines.

The drawbar pull, or draft, for most field operations increases with ground speed. Thus, if the ground speed is decreased, the draft decreases. If the engine torque remains constant or increases, the tractor can maintain short periods of overload without having to shift down. After the field conditions have changed and the draft has decreased, the tractor will be able to resume its previous ground speed. If the draft is increased for an extended period of time, the operator should select a lower gear ratio.

Implementation Criteria

Equipment to encourage the use of gear up and throttle down must meet several criteria. The device must be accurate enough to achieve the desired results, reliable within the constraints of the design criteria, and easily understood by the operator. Because the device is transferring information rather than providing direct implementation, the device also must have credibility with the operator.

In this project all the tractor's original instrumentation was left operational. This allowed the operator to use the instrumentation to set engine rpm and check such items as ground speed and exhaust gas temperature. The operator was advised to monitor all safety indicators, such as the exhaust gas temperature warning indicator, and to stop operations if any sign of engine overloading or damage occurred. Because the device recommended operations within the constraints of the tractor safety indicators, the operator was provided with the confidence to implement the suggestions. If the operator had any concern about the tractor's ability to operate at the recommended ranges, the operator was able to check the instrumentation to verify the tractor's performance.

Project Objective

The objective of this project was to build and evaluate a gear selection aid to assist the operator in minimizing fuel consumption during field operations. To evaluate the performance of the gear selection aid, the tractor and operator's performance were monitored both before and after the device was made operational. Engine speed, ground speed, and rack position were recorded and stored so the operator's performance as well as the performance of the gear selection aid could be evaluated. The number of times the gear selection aid recommended gear changes and how often the operator responded to those recommendations was also recorded. Thus, the success of implementation could be determined. The data also provided information to optimize the different variables used in the optimization routines.

Thesis Objective

The objective of this thesis is to explain how a gear selection aid with data collection was designed, constructed, installed, and tested on an International Harvester 3588 agricultural tractor. Because the data analysis will be the topic of another thesis, there will be only minimal discussion of the data collected during testing.

Chapter 2

METHODOLOGY

Fuel Optimization Alternatives

Several methods of implementing fuel optimization routines for agricultural tractors are possible. The choices range from simply educating the operators about the economic advantages of gear up and throttle down to a device having complete control of the tractor. Attempts at educating operators have met with limited success. Complete control of tractor engine speed and gear selection would be quite expensive and may not be accepted by the tractor owners.

The exact savings of the different methods are almost impossible to calculate. If the operator is given sufficient information, presen-ted in an understandable format; a large portion of the potential savings may be realized. This project was based on the idea of providing the necessary information to the operator and leaving the implementation to the operator's discretion. Because the key to implementing the optimization routine was the interfacing between the tractor and the optimization device, it was important to find a tractor that could be modified and instrumented with the appropriate sensors, data manipulation equipment, and a display.

Equipment for Implementation

The International Harvester Company loaned the Agricultural Engineering Department at Kansas State University a Model 3588, 4-wheel drive tractor to use on this project, (Fig. 2a). This tractor has two important features which simplified the implementation of the instrumentation for this project. The tractor has electronic instrumentation and an American Bosch fuel-injection system.

The tractor's electronic instrumentation incorporated magnetic pick-ups for engine speed and wheel speed. By sensing the outputs of these pick-ups rather than developing new engine and wheel speed sensors, the development time of the project was reduced. The American Bosch fuel injection system was also an important factor in simplifying the instrumentation for this project. Rather than using a mechanical load transducer and a fuel meter to measure load and fuel consumption, the engine speed and rack position were used to estimate the fuel consumption and engine load using mathematical models.

Optimization Procedure

To determine the recommended gear ratio/engine speed, the engine speed and position of the fuel metering rod (rack) were used to calculate an estimate of the present load and fuel consumption. Assuming the same ground speed and engine load, the program then computed the fuel consumption for successively higher gear ratios and correspondingly reduced engine speeds until the program estimated an engine overload or an engine underspeed condition. The estimated fuel consumption at each gear ratio was compared with the present fuel consumption estimations to determine potential fuel savings.

If the estimated minimum fuel usage resulted in a predicted savings of greater than .5 gallons per hour (gph), the display was enabled. The estimated present fuel flow, predicted fuel savings, recommended gear ratio, and recommended engine speed were displayed to the operator. Specific details of the development and use of the model are given in Chapters 4, 5, and 6. After developing, testing, and verifying the opimization models, it was important to develop a method of presenting the information to the operator in a manner that would be acceptable and meet the design constraints.

Design Criteria

The main design criteria were that the device be reliable, accurate, easy to understand, and above all, be credible with the operators. The reliability and accuracy of the device were verified during several stages of testing. This included several hundred hours of testing during the performance mapping and other laboratory tests and approximately 100 hours of field operations by the research staff. After the unit was built, it was tested in the lab using a signal generator to simulate ground speed and a dynomometer to simulate field loading. By using the simulated loading, the range limits could be tested, and the accuracy of the calculations could be verified. The next step was to determine if the display presented the information to the operator in a way that made it easy to implement the recommendations.

Because the operator often is doing several tasks during tractor operations, the device also must be easy to understand. To accomplish this, a light on the display panel alerted the driver when new information was displayed. The present fuel consumption, recommended gear ratio and engine speed, and the potential fuel savings were displayed to the operator. The operator then had the information necessary to make the gear change, but the actual implementation was still at the operator's discretion.

Field Operation

Because the device was designed to assist the operator only during field operations, it was important that the device be activated only during the field operations. If the display were allowed to operate during activities other than field work, the display would give erroneous recommendations, and the operator would soon learn to ignore the display. Ground speed and time were used as an indication of when the tractor was operating in field conditions.

Most field operations require a ground speed of from four to nine miles per hour and are operated within this range for extended periods of time. Other operating modes such as moving the tractor to and from the field and connecting to implements are either outside this range of speed or are for short periods of time. The program required the tractor to be operating between four and nine m.p.h. for at least one minute before the display could be activated. Because the tractor was to be operated under lightly loaded conditions where wheel slippage is minimal, the wheel speed and ground speed are approximately the same. Wheel speed is easier to detect so it was used as an indicator of when the tractor was operating in field conditions.

It was also important to monitor the peak field loading conditions to eliminate possible overloading. If the engine was operated for more than eight consecutive seconds with an average rack position of greater than 90% of full rack, the calculations for savings were not performed for that minute. This minimized the possibility of selecting a gear range that could cause overloading of the engine. This overloading would result in the operator having to shift down from the previously recommended gear range and could reduce the credibility of the device.

Operator Interface

When the operating parameters are within the program limits and an output is displayed, the operator can choose to implement or ignore the recommendations. The display will stay on for one minute regardless of whether the recommended changes are made. The display is then disabled for the next minute. This one minute delay occurs any time the display has been on. At the end of the minute, the calculations are performed to determine if a recommendation should be made. If the operator did not make any changes and the field conditions have not changed, the calculations should result in the same recommendations to the operator.

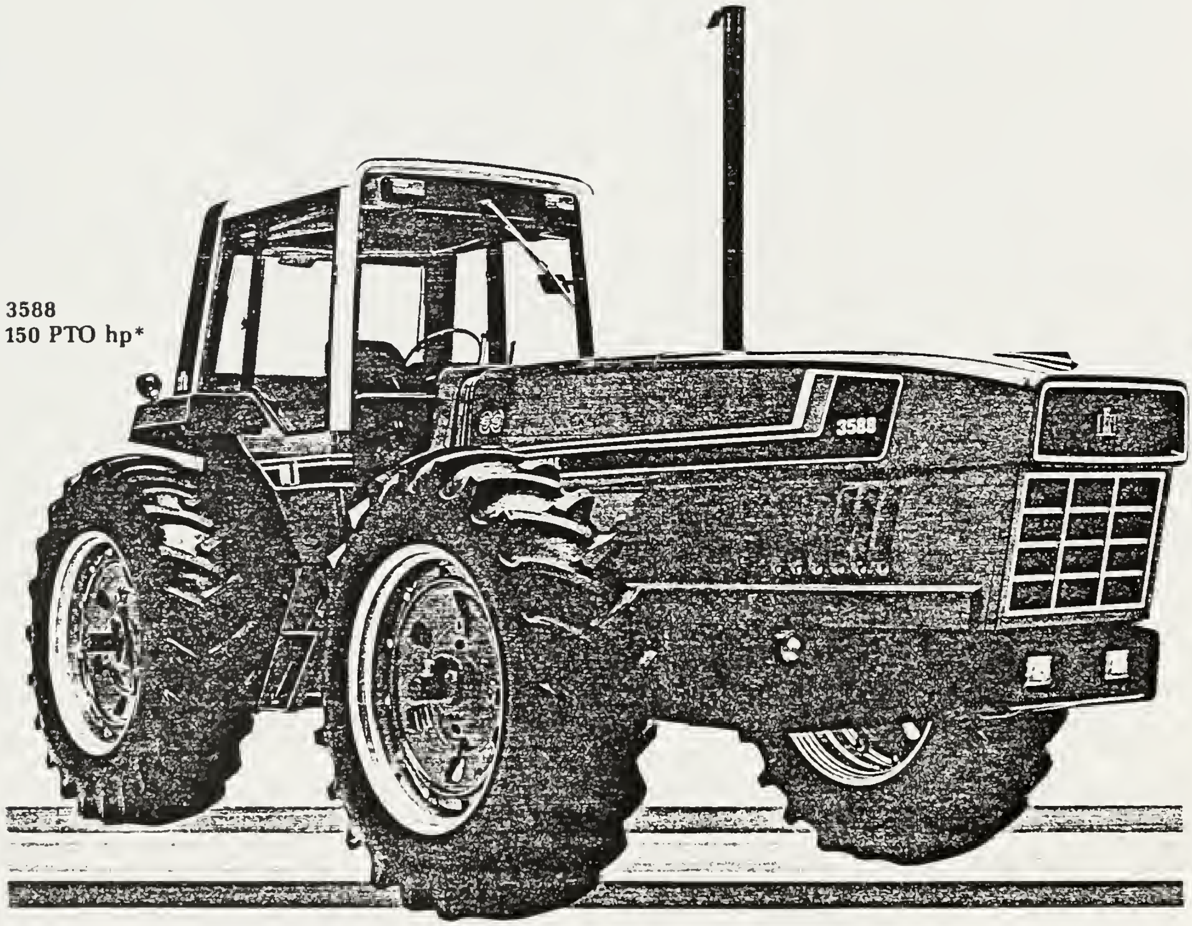
If the operator makes the recommended changes, the display will still remain on for the entire minute. This gives the operator enough time to check that the new gear range and engine speed are correct. The display then will be disabled for the next minute. After the recommended change has been made, the optimization routines will occur every minute but the display will stay off unless the field conditions change. The reason the display stays off is that the routine has been optimized for that specific field loading pattern.

This display format was designed to help operators that are leery of the recommended changes. If the operator thinks the gear ratio displayed is too high and engine speed too low, he can choose a gear ratio between the present gear and the displayed gear. If the selec-ted gear ratio and engine speed do not result in performance within

optimum gear ratio and engine speed after a one minute interval. If the field conditions have not changed, this recommendation will be the same as the previous one.

Data Collection

To determine how often the display was enabled and if the operators implemented the recommended changes, a data collection system was added. The data recorded were time, average rack value, pulse counts from the engine and transmission pick-ups, and the recommended gear ratio and engine speed. The previous 30 minutes of data were stored on cassette tapes at 15-minute intervals for later analysis. By storing 30 minutes of data each 15 minutes, the data were duplicated to provide a backup in case of tape reading problems. The analysis was performed using the DEC PDP11/34 computer in the Agricultural Engineering Department.



International Harvester Model 3588 Tractor
Fig. 2a

Chapter 3

HARDWARE DEVELOPMENT

Selecting the Computer

Several types of computers could have been used for on-board computing and data collection for this project. The inexpensive single-board, eight-bit microcomputers, such as the SYM-1, and the medium cost eight-bit micros with disc drives, such as the Apple II, were considered in detail.

The Apple II had been used by the Agricultural Engineering Department for machine language program development, but had not been tested in the field environment. The main advantage of the Apple II was the availability of floppy disc drives. The disc drives would allow for more data storage but were unproven for unattended operation in a harsh environment. Because the speed and quantity of storage necessary could be met with cassette tapes and because cassette tapes are more rugged, it was determined that cassette tape storage should be used for this project.

The SYM-1 had been used in environments with large temperature swings, but had not been used in environments with the vibration encountered in the field operation. To minimize vibration and temperature swings, the computer and associated periphials were mounted in the cab of the tractor. The operator cab of the tractor is mounted on isolation dampers and is air conditioned and heated for the operator's comfort. By mounting most of the equipment inside the cab, the equipment was in a relatively stable environment during the operation. The cab reached temperatures higher than 100°F when not being used, but during the field operations the cab was air conditioned.

After evaluating previously developed data collection software and hardware, it was decided to minimize the hardware costs and size and to reduce programming time by using a SYM-1 microcomputer with cassette tape storage (Fig. 3a). The SYM-1, built by the Synertec Corporation, is an inexpensive single-board computer that has been used successfully for data logging and control applications within the agricultural and mechanical engineering departments. Some of the in-house software, such as data collection and real time clock subroutines, could be used with minimal changes, thus reducing the development time.

Real Time Clock

The previously developed real time clock with its own back-up battery and hardware that provided the day of the year, and time of day in hours, minutes, and seconds was important to the project. A MSM5832RS clock chip and associated circuitry had been developed and tested on the SYM-1 microcomputer, Schwarz[4] (1984). The clock was interfaced to the SYM-1 using external port A. The clock provided the timing needed for determining when to collect data, calculate potential savings, and store data on tape. Interfacing the computer to the magnetic pickups for engine and wheel speed was accomplished by using operational amplifiers.

Interfacing Tractor Instrumentation

To avoid disabling or loading of the tractor's existing instrumentation, capacitor coupling to the magnetic pickups was used, (Figure 3b). For each pickup a capacitor was connected to each lead. The other end of the capacitors was connected to the inputs of the appropriate operational amplifier. Balancing resistors were used as shown to keep the inputs of the operational amplifier at approximately six volts. The outputs of the amplifiers were connected to pulse-counting inputs of port PB6 on the SYM-1.

Sensing Rack Position

Sensing of rack position was not available on the tractor's standard instrumentation, therefore a method of sensing the fuel metering rod, commonly referred to as the "rack", was developed. The rack position was determined by sensing the rotational position of a shaft. The shaft was accessible by removing a cover from the fuel pump. Because the shaft did not extend outside the fuel injector housing, it was necessary to extend the fuel metering shaft to allow attachment of a position sensor.

Several methods of measuring the rotation of the shaft were considered. The first consideration was the use of a potentiometer and a regulated power supply to provide an analog signal. Limitations associated with potentiometers are their non-linearity and drift when subject to temperature variations. The analog signals are also more susceptible to noise problems than digital signals and the analog signal would have to be converted to a digital signal before interfacing to the SYM-1. To eliminate the analog signals and minimize electrical interference problems a digital rotary position encoder was used for this project.

To determine the required resolution of the encoder, it was necessary to determine the amount of rotation of the fuel metering shaft. To accomplish this, the position of the shaft was marked with the throttle set to the minimum position. The tractor was loaded to maximum horsepower using a dynamometer, and maximum shaft rotation was marked. The difference between the minimum and maximum position was approximately 60°. Encoders were available in either eight or 10-bit resolution for 360° of rotation. Eight-bit units have an accuracy of approximately 1.41 degrees of rotation per bit. The 10-bit unit has an accuracy of .35 degrees per bit. To achieve the accuracy required by the mathematical model the 10 bit unit was selected.

After reviewing specifications of several encoders, it was determined that the Litton Model 76-NB10-2-S-1, 10 bit, absolute rotary encoder (Appendix A) would have suitable resolution and would withstand the vibration and temperature environments. The encoder was ordered with gray code conversion to natural binary. The gray code eliminates the possibility of getting incorrect readings during state changes of the encoder.

Installing Encoder

Mounting the encoder required modification of the fuel pump cover. A machined aluminum plate was used to attach the encoder to the fuel injector pump housing. The shaft of the metering rod was extended and a zero-backlash flexible coupling was used to connect the encoder to the shaft. Because the encoder was located on the engine, it was exposed to high vibration levels and large temperature variations. After attaching the encoder to the fuel injector pump, it was determined that the heat transfer to the encoder was causing the encoder temperature to exceed the specifications given for the encoder. To accomplish some thermal isolation, an asbestos gasket was installed between the adapter plate and the encoder. With this modification, the encoder case temperature was limited to a maximum of 160°F during full load dynamometer testing. This temperature was within the specifications of the encoder. The electrical interface connection to the SYM-1 was port PA0, bits 0 through 7. The power supply for the encoder was provided by the SYM-1.

Power Supplies

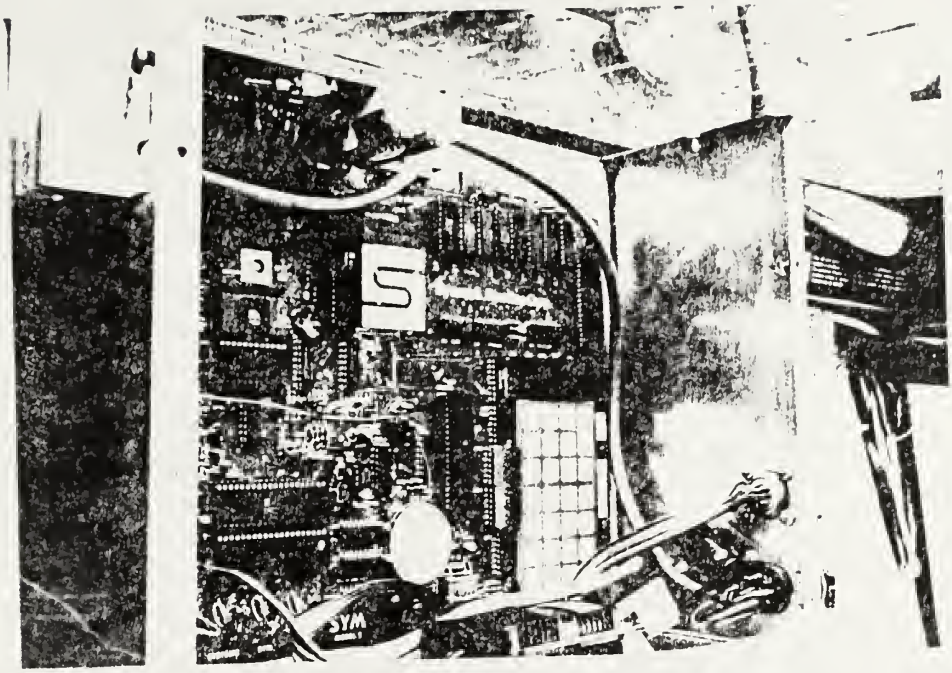
The power for the instrumentation package was provided by the tractor battery through voltage convertors and regulators. The SYM-1, the digital encoder, and the display unit, required five volts dc. This was provided by a Lambda Model LAS1405 dc-to-dc converter. The six volts dc required by the recorder was provided by a Radio Shack 12 volt dc to 6 volt dc converter.

Display Unit

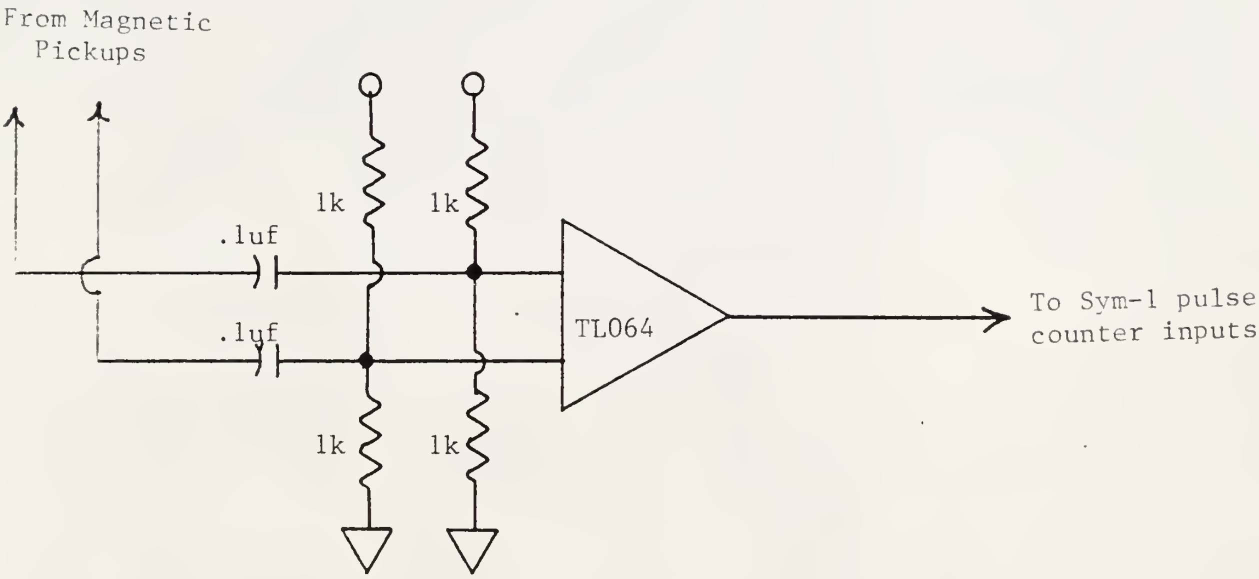
The display unit was designed to provide the operator with the recommended gear selection and engine speed. The tractor had a dual range differential, a four-range manual transmission, and a hydraulically activated dual range torque amplifier. This provided 16 possible gear ratios. The original concept was to display the gear number, one through 16. This would have been quite confusing unless the operator was familiar with the gear ratios for this particular tractor and would have required the operator to determine mentally the three control settings required to obtain the recommended gear ratio.

To simplify the display and provide more concise instructions to the operator, the gear selection display was designed using a combination of light-emitting diodes (LEDs) (Fig. 3c). The recommended gear ratio was displayed by lighting one of two LEDs for the T/A, one of four LEDs for the transmission gear, and one of two LEDs for the range of the differential. Because the engine speed will vary by a few hundred rpm in typical field operations, the recommended engine speed was rounded to the nearest hundred and displayed using two seven-segment displays to indicate hundreds and thousands of rpm.

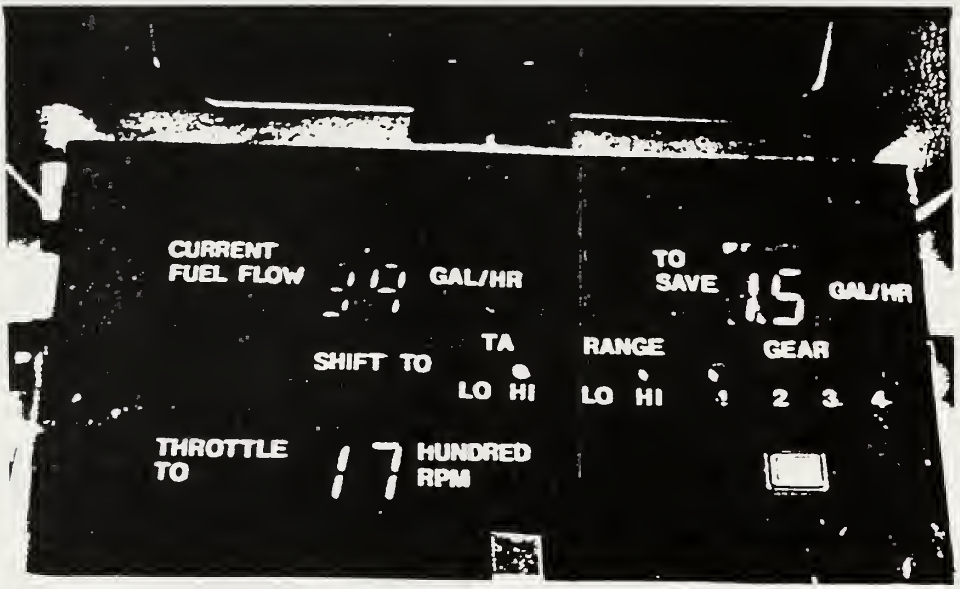
Estimated fuel consumption and estimated fuel savings were calculated to the nearest tenth of a gallon per hour (gph). The maximum anticipated fuel consumption was less than 10 gph, so the estimated fuel consumption and estimated fuel savings were displayed using two seven-segment displays for each value.



SYM-1 Computer by Synertec Corporation
Fig. 3a



Magnetic Pick-up Interface
Fig. 3b



Display Unit for Optimization Device
Fig 3c

Chapter 4

ENGINE PERFORMANCE MAPPING

Performance Map Criteria

Mapping the engine performance was critical for developing the models used during this project. The tractor used for this project was furnished by International Harvester Corporation. The International Harvester Company provided recommended limits for operating of the engine safely: a minimum engine speed of 1200 rpm for full load and a maximum exhaust gas temperature (EGT) of 1400 ^{o}F for any loading. During the mapping, the engine was operated at speeds as low as 1500 rpm with wide open throttle, and the EGT remained below the 1400^{o} F limit.

A performance map for the engine was provided with the tractor; however, this performance map was not sufficient for this project because it did not include fan, hydraulic, and other drive train losses. The modeling also required a value for the rack position corresponding to each point of the engine performance map. This position was not provided with the original engine map. Other measurements necessary for the engine mapping were engine speed, engine load, and fuel flow. The engine speed and rack position measurement were implemented as described in chapter 3. Measuring the fuel flow was necessary for mapping the engine, but a mathematical model was used during the field testing.

Fuel Measurement

The fuel flow was calculated by measuring fuel weight at the beginning and end of each test and dividing by time. The diesel fuel from the diesel injection pump is not completely consumed by the tractor engine. Some of the fuel is passed through the injector and returned to the fuel tank. This "return" fuel is necessary to prevent the injector from overheating. The quantity of return is highly variable and dependent on engine speed and load. To measure only the consumed fuel, two three-way valves were added to the fuel lines (Fig. 4a). One valve selected the supply, either tractor tank or weigh scale, and the other valve selected the return path, either tractor tank or weigh scale.

During warm-up and between tests, both the supply and return were set to position A. During each test, the supply and return were set to position B. Because the return was going back to the weigh scale, the change in quantity of fuel in the weigh scale represented the actual fuel consumed by the engine. The weigh scale was filled by pumping fuel from the tractor tank to the weigh scale. This was accomplished by setting the supply valve to position A, opening the fill valve, and turning on the auxiliary fill pump. During most of the testing, this allowed the weigh scale to be filled while the engine temperature was stablizing between tests. After filling the weigh scale, the fill pump was turned off and the fill valve was closed.

Fuel Temperature

Before the performance mapping could begin, it was necessary to investigate the effect of fuel temperature on engine performance. [5]Wu and McAulay indicate an inverse relationship between fuel temperature and horsepower output for a diesel powered engine. To determine if the supply fuel temperature effected the engine performance, the temperature of the fuel supply was subject to temperature variations much larger than could be experienced during actual field operations.

The fuel supply line was disconnected from the inlet of the fuel filter. A finned tube heat exchanger was connected between the fuel line and the fuel filter. Thermocouples were placed on the surface of the fuel line at five locations; the supply tank, before the heat exchanger, after the heat exchanger, at the inlet to the injector pump, and the outlet of the injector pump.

The tractor engine was operated at various speeds and loads while the temperatures, engine speed, fuel flow, and horsepower output were recorded. The heat exchanger then was submerged in an ice bath to cool the fuel supply. The engine speeds and loading were repeated, and the temperatures, engine speed, fuel flow, and horsepower output were recorded.

The temperatures recorded at the inlet of the injector pump and the outlet of the injector pump were approximately the same regardless of supply fuel temperature, engine speed, or engine loading. This stable fuel temperature was attributed to the large heat transfer surfaces provided by the fuel filters, fuel lines, the injector pump, and the relatively slow flow rates.

Further analysis of fuel consumption for the entire range of engine loads and fuel supply temperatures indicated no significant change in engine performance due to changes in fuel supply temperatures. Therefore, the fuel supply temperature was disregarded in the performance testing and modeling. The heat exchanger then was removed from the fuel supply line before the final engine mapping was performed.

Data Collection

During the performance mapping, engine speed, fuel weight, rack position, dynamometer torque, and time of day were recorded. Engine speed, rack position, and time were recorded and stored on cassette tape by the SYM-1. The fuel weight was measured by suspending a two-gallon tank from an Ametek model BA-25-LB strain gage transducer (Appendix B). The strain gage was powered and sensed by a Calex model 166 voltage to frequency converter (Appendix C). The output, which was proportional to weight, was connected to port PB6 pin A of the SYM-1.

A program was written for the SYM-1 to count the pulse inputs from the engine speed and fuel weight during each two-second interval, and to store these values in memory. At the end of each two-minute test, these stored values and the time were recorded automatically on cassette tape.

Dynamometer torque and exhaust gas temperature were recorded manually at 15-second intervals during each test. The torque was read from the digital display on the Model NEB 400 A&W dynamometer. The exhaust gas temperature was read from the tractor instrumentation.

Testing Range

The engine loading was for the range of 50% to full load for engine speeds of 1500 rpm to wide open throttle. The tractor was operated at wide open throttle, and the load was increased until an engine speed of 1500 rpm was maintained. Data then were recorded for this condition. The load was decreased until an engine speed of 1700 was maintained at wide open throttle. This process was repeated at 200 rpm steps until approximately 50% of the full load, 75 horsepower, was reached.

During the next series of test points, the engine load was reduced approximately 10 horsepower for each of the engine speeds previously determined until a minimum of 75 horsepower was recorded. This was accomplished by having the tractor operator set the engine rpm while the dynamometer was set to the appropriate load. After this set of data was collected, the loads were reduced another 10 horsepower for each of the engine speeds until 75 horsepower was recorded.

Testing Procedure

The test procedure for collecting each data point on the performance mapping follows.

1. The tractor is started and idled with the pto off and the fuel selectors in position A.

2. The fuel fill valve is opened, and the fill pump is turned on until the weigh scale is full. The fill pump is turned off, and the fill valve is closed.

3. When the engine water and oil temperatures indicate the engine is warm, the pto is engaged with no load on the dynamometer. Then the dynamometer load and engine speed were set.

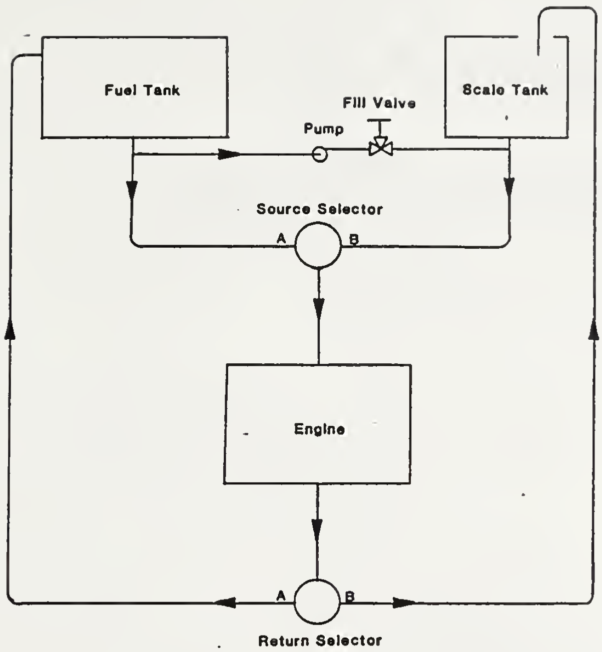
4. The engine exhaust temperature is monitored until it stabilizes.

5. The fuel selectors are switched to position B.

6. The SYM-1 data collection is started, and the operator records the exhaust gas temperatures and pto torque and horsepower every 15 seconds.

7. At the end of the two minutes, the dynamometer load is reduced while reducing the engine speed. The pto is disengaged, and the engine is set to idle.

8. Steps two through six are repeated for each of the test points.



Fuel Flow Switching Valves
Fig. 4a

Chapter 5

DEVELOPMENT OF THE MATHEMATICAL MODELS

After collecting data for the performance map, different models were evaluated by the statistics department at KSU. It was determined that a linear regression model did not fit the parameters with the desired accuracy. The regression procedure in the Statistical Analysis System (Helwig, 1979) was tested. This procedure provided models with accuracy well within the project guidelines, so it was used to develop the mathematical models for engine loading, fuel consumption, and rack position.

To simplify the model, the average rpm and encoder readings were subtracted from the data values before entering the value into the equation. For the original data these values were 1921.51 and 128.054, respectively.

Horsepower Calculation:

Average horsepower is predicted by using the rack position and the engine rpm in the following equation.

Equation 1

```
hphat = 2.070851+(.023899*rpm)+(1.681623*rack)
        -(.00003113075*rpm*rpm)+(.001008684*rpm*rack)
```

where:

```
        hphat = ptohp predicted from the model
        rpm = (engine rpm)-1921.51
        rack = (encoder reading)-128.054
```

The "F" statistic of this model is 2804.53 and the "R squared" value is 0.9968 for the range of engine speeds and loads used during the dynamometer tests. Both the "F" statistic and the "R squared" values indicate a good fit to the original dynamometer data.

Fuel Flow Calculation:

Average fuel flow is predicted by using the rack position and the engine rpm in the following equation:

Equation 2

```
ffhat = 45.331760+(.016695*rpm)+(.539934*rack)
        -(.0000055161*rpm*rpm)+(.00199687*rack*rpm)
        +(.0002517891*rpm*rack)
```

where:

```
ffhat = predicted fuel flow in lbs/hr
rpm = (engine rpm)-1921.51
rack = (encoder reading)-128.054
```

The "F" statistic of this model is 2637.99 and the "R squared" value is 0.9973 for the range of engine speeds and loads used during the dynamometer tests. Both the "F" statistic and the "R squared" values indicate a good fit to the original dynamometer data.

Rack Position Calculation:

Average rack position is predicted by using the engine rpm and the predicted horsepower from the first equation as follows:

Equation 3

```
rackhat = -1.310154-(.015853*rpm)+(.615521*hp)
          +(.00002779667*rpm*rpm)-(.000372483*rpm*hp)
```

where:

```
rackhat = predicted encoder reading - 128.054
rpm = (engine rpm)-1921.51
hp = (engine hp)-104.53
```

The "F" statistic of this model is 2129.37 and the "R squared" value is 0.9958 for the range of engine speeds and loads used during the dynamometer tests. The "F" statistic and the "R squared" values both indicate a good fit to the original dynamometer data.

The rpm and the rack data were "normalized" as discussed before, 128.054 must be added to the rackhat to obtain a predicted encoder reading.

Chapter 6

COMPUTER PROGRAM

Machine Language Assembler

The computer programs used for the SYM-1 computer were developed on an Apple II computer using a machine language assembler. The programs were transferred to an EPROM which was used on the SYM-1. The SYM-1 computer has the capacity for two EPROM chips, one of which can be used to boot the system. Because the SYM-1 must be initialized each time the tractor is started, the circuit board was modified to boot from the EPROM program when the power is turned on or the computer is reset. Reset was provided by either manual reset or by an external automatic reset circuit.

Automatic Reset

The automatic reset was implemented to initiate a reset if the computer program gets lost. To accomplish the reset an external 4047 multivibrator circuit was added. The 4047 was operated in the astable mode and a time constant per cycle of 30 seconds was implemented. When operated in this mode, retriggering causes the time period to start over. Every second the SYM-1 main program retriggers the 4047, which prevents the output from changing states. The output was connected to a logic gate on the hardware reset. The only time the one second interruption would not occur was when the program saves data to cassette tape. Saving data to tape required approximately 10 seconds, therefore the time constant on the 4047 was set to 30 seconds to allow saves to tape without resetting the program.

Data Storage

Data read from the instruments was in fixed point binary form. To perform the calculations and store and display the results, several other forms were required.

The data saved on tape and the values used in the model equations are average values of several data samples. The calculations to obtain the averages and the calculations of the model equations were performed in floating point form to insure adequate precision in the results. A set of floating point subroutines were used which had been developed and tested on the SYM1 by Mike Schwarz of the Agricultural Engineering Department. Data was converted from binary form to floating point form for the calculations and converted back to binary form for storage on the cassette tape. Values to be displayed including fuel flow, fuel savings and engine rpm were converted to BCD for use by the display output routines.

The data was recorded on cassette tape using a Radio Shack Model TRS81 audio tape recorder controlled by the microcomputer. When the tractor key switch was on, data was saved on the tape every 15 minutes. The computer copied the data for the previous 30 minutes during each save to tape. This provides duplicate copies of each set of data.

There are no means of sustaining the power to the recorder after the key switch is off, thus if the key is turned off at 10 minutes after the data was saved on tape, the last ten minutes data would not be saved. The maximum amount of data that could be lost is 15 minutes. If the tractor is operating properly, it should be allowed to idle for several minutes after heavy field operations. Therefore, in the last five to 10 minutes, the tractor should not be used in field operations.

Determining Field Operations

The optimization routines were designed for operating in actual field conditions, therefore the specific times of operation, types of field operation, etc. were unknown. To determine when the tractor was operating in field conditions and to account for the variability of the load, the optimization routine used a combination of 1-second, 4-second, and 1-minute averages. The 1-second and 4-second values of rack, engine speed, and transmission speed were used to determine load peaking and to count operation changes that could give false averages. These peak loads and changes were counted by "flags".

Out-of-Range Indication

Each flag uses one byte of memory. Bit seven is used to indicate the event is happening and bits 0 to 6 were used to count the number of times the event occured during each minute. For example, if the operator stopped for 30 seconds during one minute, the averages for engine speed, ground speed, and rack used in the calculations, would not be a good indication of the actual working conditions. To detect this change in operation, the program monitors the ratio of engine speed and ground speed. When this ratio changes, bit seven of the gear change flag is set. The bit stays set until the ratio of engine speed to ground speed is not zero and is the same for at least two seconds. Then bit seven is cleared, and one is added to the value of the gear change flag and bit zero of the mflag is set. The mflag is the minute flag. When any flag is incremented the minute flag is set to indicate that there was a change or out-of-range measurement during that minute. After the mflag is tested at the end of each minute, the mflag is shifted to the left. This allows the program to determine if the flags were set during any of the previous eight minutes.

Memory Storage

The computer RAM serves as a temporary storage location for calculations and for storing information to be recorded on tape. The main storage area for saving data on tape is arranged in sets of 10 bytes starting with the most current data at address 200 hex. Each time data is added, it is moved up ten bytes in memory. This stacking arrangement of the data in memory occupies memory from 200 hex to the end of the 4K of RAM (Table 6a).

The data was either 4-second or 1-minute data depending when it was saved into memory (Table 6b). The 4-second data is stored in memory every 4 seconds, whenever the clock minute value ends in a 5 or 0. The first seven bytes are averages of the four previous 1-second samples. As a means of checking the output routines, each 4-second save used the last three bytes to store the number of flags for gear change, transmission change, and overload. There were 15 data sets for each minute of 4-second saves.

The 1-minute data is stored for each minute that the 4-second data is not stored. The values stored are the sums of the 4-second averages for that minute. The program saves data on tape during one of the minute saves four times per hour. The save takes approximately

10 seconds, and data collection is terminated during the save on tape so the number of 4-second samples are counted and recorded to prevent errors in the minute averages.

Keyboard Display

The main program also is used to update and scan the keyboard display on the SYM-1 computer. This display is located on the computer and is not accessible to the operator, but it is necessary in monitoring the parameters or memory values when trouble shooting. The real time clock and the other monitored values are displayed in a sequential repeating format on the SYM-1 keyboard display (Table 6c).

Main Program Initialization

The main program consists of a combination of monitoring, calculating, and recording routines. As the program resets, it assigns the interrupt vectors and copies the initialization values from ROM to the appropriate RAM locations. The program then sets the input and output ports. The memory used to store data is then set at zero. The program then jumps to the main program.

One Second Calculations

The program monitors the seconds of the external clock. Whenever the second's value changes, the program jumps to the interrupt routine. This interrupt stops the keyboard display routine, then reads the engine and transmission parameters into the RAM one-second locations. The counters for engine and transmission speed are then set at zero, and the counters restarted. The value for seconds is then compared to the seconds value during the last interrupt to check if more than one second has elapsed since the last interrupt occurred.

If it has been longer than one second since the last interrupt, the program will return from interrupt to the display program until the next interrupt. If it has been one second since the last interrupt count1, the number of 1-second averages since the last 4-second calculation, is incremented, and the 1-second values are added to the 4-second sums. The second's value is then checked to see if it is time to do the 4-second calculations. If it is not time, the program returns from interrupt to the display routine.

Four Second Calculations

If the second's value is divisable by four, count1 is tested to see if there are four 1-second values in the 4-second sums. If there are not, the 4-second sums are set to zero and the program jumps past the 4-second calculations and checks if it is time to do minute averaging.

If count1 is 4, count1 is set to zero and count2, which is the number of four-second averages since the last minute calculations, is incremented. The ratio of transmission and engine pulses are compared to a gear ratio table to determine the present operating gear. This gear ratio is compared to the last 4-second gear ratio to determine if the operator has changed gear ratios. If the gear ratio has changed or the ground speed is zero, the gear change flag bit seven of SFLG2 is set. If the gear ratio has not changed, the gear change flag is tested. If bit seven is set and the gear ratio is the same as the previous 4-second average, the SFLG2 is incremented, bit 7 is cleared and bit zero of MFLG is set. The 4-second values are divided by four to get the 4-second averages.

Next, the tractor ground speed and engine load are checked. If the ground speed is not between three and 10 mph then SFLG3, the ground speed out-of-range indicator, is set and bit zero of MFLG is set. If the engine rpm is less than 1500 and the rack is greater than 95 percent, the program checks bit seven of SFLG4, the overload indicator flag. If it is not set, the program sets bit seven. If it is set SFLG4 is incremented, bit seven of SFLG4 is cleared; and bit zero of MFLG is set. The 4-second averages then are added to the minute sums, the 4-second averages and count2 are set to zero, and count3, which is the number of 4-second averages added to the minute averages, is incremented.

If the clock's minute value ends in either 5 or 0, the 4-second averages are copied to the data area of RAM for storing on tape at a later time. The program checks to see if the seconds value is 56. If it is not, the program returns from interrupt to the display routine. Otherwise the program checks the status of the display. If it has been on during the last minute, the display is turned off and bit zero of mflag is set to prevent the display from coming on for the next minute.

1-Minute Calculations

First, bit zero of mflag is checked to determine if operation is within operating parameters. If mflag is not zero, the program shifts the mflag left and jumps to see if it is time to record on tape, then returns from interrupt to the display routine. If mflag is zero, the minute sums are divided by count3 and mflag is shifted left. These values are used as the average rack position, engine speed, and ground speed for the last minute. The minute averages are used to calculate the average horsepower (equation 1, Chapter 5), fuel flow (equation 3, Chapter 5), ground speed, and the gear ratio for the last minute. The memory locations reserved for these calculated values are set to zero. Values for fuel flow, engine speed, and rack are estimated for the higher gear ratios.

The estimated values assume the same average horsepower because the ground speed is assumed constant. By knowing the present gear ratio and the ground speed, the next higher gear ratio is used to calculate the new engine rpm. If this calculated engine speed is greater than 1500 rpm, the program calculates the new rack value. (equation 3, Chapter 5). If the calculated rack is less than 95 percent of the maximum rack, the fuel flow is calculated using the values for engine speed and rack value (equation 1, Chapter 5). The program repeats the tests and calculations for the next higher gear. These calculated values are stored in memory according to the gear ratio used for each calculation (Table 6d). The calculations continue until the engine rpm is less than 1500 or the calculated rack is greater than 95 percent of maximum.

After the calculations for all gear ratios within the specified range of engine speed and rack are complete, the program determines the minimum computed fuel flow. This fuel flow is compared to the previous minute's fuel flow. If the savings is .5 gal/hr or greater the program sets display output flag. A second check is performed to determine if the gear ratio corresponding to the minimum fuel flow provides a savings of .2 gallons/hour more than the next lower gear ratio. If the optimum gear does not provide a savings of at least .2 gal/hr more than the next lower gear, that lower gear was recommended to the operator.

The fuel flow, engine rpm, and fuel savings were converted to and stored in decimal format so they can be sent out the port to the latches and decoder drivers in the display. The gear ratio was decoded for the display by a look-up table in ROM (Table 6e). This table was used to indicate the positions of the three shift levers. The selected gear ratio, engine rpm, fuel flow, fuel savings, and time were also stored in RAM for recording on tape. The program checks the output flag to determine if the optimization results should be displayed to the operator. If the output flag is set, the recommended values for T/A, range, gear, and engine speed are displayed with the present fuel flow and estimated savings.

Saving Data on Tape

The program sets the minute averages to zero and checks to determine if it is time to record the data on tape. If the minute value was 56, the header data which contains the time and flags, has moved to the stack, the interrupts are disabled, and the data for the last 30 minutes is recorded on tape. The program then enables the interrupts and returns to the display routine and the main program starts over.

Location	Contents
First 6 bytes	Year, Month, Day, Hour, Minute, Seconds (Header)
Next 10 bytes	Minute data from minute 15
Next 10 bytes	15th 4-second data from minute 15
Next 10 bytes	14th 4-second data from minute 15
Next 10 bytes	13th 4-second data from minute 15
Next 10 bytes	12th 4-second data from minute 15
Next 10 bytes	11th 4-second data from minute 15
Next 10 bytes	10th 4-second data from minute 15
Next 10 bytes	9th 4-second data from minute 15
Next 10 bytes	8th 4-second data from minute 15
Next 10 bytes	7th 4-second data from minute 15
Next 10 bytes	6th 4-second data from minute 15
Next 10 bytes	5th 4-second data from minute 15
Next 10 bytes	4th 4-second data from minute 15
Next 10 bytes	3rd 4-second data from minute 15
Next 10 bytes	2nd 4-second data from minute 15
Next 10 bytes	1st 4-second data from minute 15
Next 10 bytes	Minute data from minute 14
Next 10 bytes	Minute data from minute 13
Next 10 bytes	Minute data from minute 12
Next 10 bytes	Minute data from minute 11
Next 10 bytes	15th 4-second data from minute 10
Next 10 bytes	14th 4-second data from minute 10
Next 10 bytes	13th 4-second data from minute 10
Next 10 bytes	12th 4-second data from minute 10
Next 10 bytes	11th 4-second data from minute 10
Next 10 bytes	10th 4-second data from minute 10
Next 10 bytes	9th 4-second data from minute 10
Next 10 bytes	8th 4-second data from minute 10
Next 10 bytes	7th 4-second data from minute 10
Next 10 bytes	6th 4-second data from minute 10
Next 10 bytes	5th 4-second data from minute 10
Next 10 bytes	4th 4-second data from minute 10
Next 10 bytes	3rd 4-second data from minute 10
Next 10 bytes	2nd 4-second data from minute 10
Next 10 bytes	1st 4-second data from minute 10
Next 10 bytes	Minute data from minute 9
Next 10 bytes	Minute data from minute 8
Next 10 bytes	Minute data from minute 7
Next 10 bytes	Minute data from minute 6
Next 10 bytes	15th 4-second data from minute 5
Next 10 bytes	14th 4-second data from minute 5
Next 10 bytes	13th 4-second data from minute 5
Next 10 bytes	12th 4-second data from minute 5
Next 10 bytes	11th 4-second data from minute 5
Next 10 bytes	10th 4-second data from minute 5
Next 10 bytes	9th 4-second data from minute 5
Next 10 bytes	8th 4-second data from minute 5
Next 10 bytes	7th 4-second data from minute 5
Next 10 bytes	6th 4-second data from minute 5
Next 10 bytes	5th 4-second data from minute 5
Next 10 bytes	4th 4-second data from minute 5
Next 10 bytes	3rd 4-second data from minute 5
Next 10 bytes	2nd 4-second data from minute 5
Next 10 bytes	1st 4-second data from minute 5
Next 10 bytes	Minute data from minute 4
Next 10 bytes	Minute data from minute 3
Next 10 bytes	Minute data from minute 2
Next 10 bytes	Minute data from minute 1

FORMAT FOR DATA SAVE ON CASSETTE TAPE
Table 6a

Contents of 4-Second Data

Byte	
00-01	4-second average of transmission speed pulses
02-03	4-second average of engine speed pulses
04-05	4-second average of rack pulses
06	Number of 1-second samples in the 4-second averages
07	4-second sum of Flag 2
08	4-second sum of Flag 3
09	4-second sum of Flag 4

Contents of 1-Minute Data

00-02	1-minute sum of transmission speed pulses
03-05	1-minute sum of engine speed pulses
06-08	1-minute sum of rack positions
09	Number of 1-minute samples in the 1-minute sums

DATA STORAGE TYPES
Table 6b

Sequence Number*	Contents
01	Year Month Day
02	Hour Minutes Seconds
03	Transmission Speed
04	Engine Speed
05	Rack Position

* Sequence numbers may be selected manually to observe a specific display, otherwise the sequence is repeated with each sequence displayed for two seconds.

SYM-1 KEYBOARD DISPLAY
Table 6c

MEMORY STORAGE FOR CALCULATED VALUES DURING OPTIMIZATION

Memory Location	Content
0142	Fuel Flow for gear ratio 1
0143	Fuel Flow for gear ratio 2
0144	Fuel Flow for gear ratio 3
0145	Fuel Flow for gear ratio 4
0146	Fuel Flow for gear ratio 5
0147	Fuel Flow for gear ratio 6
0148	Fuel Flow for gear ratio 7
0149	Fuel Flow for gear ratio 8
014A	Fuel Flow for gear ratio 9
014B	Fuel Flow for gear ratio 10
014C	Fuel Flow for gear ratio 11
014D	Fuel Flow for gear ratio 12
014E	Fuel Flow for gear ratio 13
014F	Fuel Flow for gear ratio 14
0150	Fuel Flow for gear ratio 15
0151	Fuel Flow for gear ratio 16
0152	Engine Speed for gear ratio 1
0153	Engine Speed for gear ratio 2
0154	Engine Speed for gear ratio 3
0155	Engine Speed for gear ratio 4
0156	Engine Speed for gear ratio 5
0157	Engine Speed for gear ratio 6
0158	Engine Speed for gear ratio 7
0159	Engine Speed for gear ratio 8
015A	Engine Speed for gear ratio 9
015B	Engine Speed for gear ratio 10
015C	Engine Speed for gear ratio 11
015D	Engine Speed for gear ratio 12
015E	Engine Speed for gear ratio 13
015F	Engine Speed for gear ratio 14
0160	Engine Speed for gear ratio 15
0161	Engine Speed for gear ratio 16
0162	Rack Position for gear ratio 1
0163	Rack Position for gear ratio 2
0164	Rack Position for gear ratio 3
0165	Rack Position for gear ratio 4
0166	Rack Position for gear ratio 5
0167	Rack Position for gear ratio 6
0168	Rack Position for gear ratio 7
0169	Rack Position for gear ratio 8
016A	Rack Position for gear ratio 9
016B	Rack Position for gear ratio 10
016C	Rack Position for gear ratio 11
016D	Rack Position for gear ratio 12
016E	Rack Position for gear ratio 13
016F	Rack Position for gear ratio 14
0170	Rack Position for gear ratio 15
0171	Rack Position for gear ratio 16

CALCULATED VALUES DURING OPTIMIZATION
Table 6d

Gear	Binary #	Display Lights: T/A ON	T/A OFF	Range LO	Range HI	Gear 1	Gear 2	Gear 3	Gear 4
1	15	*		*		*			
2	16		*	*		*			
3	25	*		*			*		
4	26		*	*			*		
5	45	*		*				*	
6	46		*	*				*	
7	85	*		*					*
8	86		*	*					*
9	19	*			*	*			
10	1A		*		*	*			
11	29	*			*		*		
12	2A		*		*		*		
13	49	*			*			*	
14	4A		*		*			*	
15	89	*			*				*
16	8A		*		*				*

* Indicates light is on

LOOK-UP TABLE TO CONVERT GEAR NUMBER
TO DISPLAY OUTPUTS
Table 6e

Chapter 7

TESTING

Laboratory Testing

Testing of the software and hardware was accomplished in two phases. The first phase of tests was conducted in the Agricultural Engineering Laboratories. The tractor was connected to a pto dynamometer to allow loading of the tractor. The transmission pulse input was connected to a signal generator to simulate different ground speeds. By selecting the load and transmission pulse input, different field conditions were simulated.

During the initial testing of the instrumentation the program was intermittently reset and data was lost. After observing the tractor operation it was determined that when the electric fuel transfer pump was activated the SYM-1 would reset. The reset was a result of the inductive voltage spikes on the power supply for the SYM-1. These inductive spikes were eliminated by the use of an LC filter between the 5 vdc supply and the SYM-1 computer.

After two days of testing, oil began to leak from the digital encoder. This was caused by the crankcase pressure forcing oil around the shaft seal of the encoder. The encoder was designed with a dust seal but without an oil seal. To eliminate this problem, the adapter plate for the encoder was machined to allow an oil seal between the adapter plate and the encoder. An oil drip line also was added between the seal and the engine to reduce the pressure against the seal and to discharge the accumulated oil. Returning the oil to the engine would have required extensive design and the the quantity of oil was so small that the oil was allowed to drip below the engine to the ground.

Field Testing

During the second phase of testing the tractor was operated by the research personnel on the Delbert Stadel farm near Manhattan. The purpose was to operate the tractor in as many different loading conditions as possible to check the program before putting the tractor in the field with the cooperators. During the first few days of the field tests the rack encoder failed. This failure went undetected until the data was anlayzed due to the operation in lightly loaded field conditions. The encoder is a gray code to binary encoder so when the power source failed the failure mode created a binary output of 55. This rack reading corresponds to a low rack value. This resulted in the program always iterating until the engine speed was 1500 rpm. This failure indicates the need to add a test for the external sensors to the software if further development is pursued.

After replacing and recalibrating the encoder the testing was continued. The tractor was operated with a relatively light load by using an undersized field cultivator. The tractor was operated at a ground speed of 4 mph with a low gear ratio to allow wide open throttle operation. After the display came on to indicate the optimum operating gear, the tractor was shifted up one gear instead of changing to the recommended gear ratio. The engine speed was set to provide the same ground speed. This condition was maintained until the display came on again. By observing the outputs as the gear range was changed, it was observed that if speed was held constant and the savings potential was above the .5 gph minimum the device would always indicate the same optimum gear and engine rpm independent of the operating gear. This test was repeated at different ground speeds and load conditions. The results were repeatable even with some variations of field conditions.

The tractor was operated in the Manhattan area for several days by Delbert and Lee Stadel. They were instructed to operate the tractor during different field operations and to implement any changes recommended by the optimization routines unless the tractor could not be operated in the recommended gear range and engine speed. This in field testing allowed for checking of reliability of the system and also provided verification of the optimization routines.

Collecting Operating Data

After testing the tractor and equipment in the Manhattan area, the tractor was taken to various locations throughout Kansas. During this testing the operators were allowed to operate the tractor for at least two days without the display. They were instructed to operate the tractor the same way they would operate their own tractor. During this period the instrumentation was recording all the data but without the display. This provided the base fuel consumption used in calculating the fuel savings during implementation. To determine the type of field operations and implements being used during the tests, each operator was given a log sheet (Fig. 7a) and was instructed to complete it at the end of each day or whenever implements were changed.

When the tractor was moved between cooperators the cassette tapes containing the field data were brought to the Agricultural Engineering Department and read using a data transfer routine. This routine was in ROM on a SYM-1 that was dedicated for data transfers. The routine read the tape and transferred the data into data files on the PDP/1134.

Estimated savings for the four operators during the first year was 19.8%, (Fig. 7b). The range of savings for each operator ranged from 0% to 37%. The operator that had no savings was proficient in the use of gear up and throttle down. Since he was operating within

commented that he would periodically shift to a lower gear and higher engine speed so the display would come on and he could compare his previous setting to the optimum. The maximum savings occured on the lightest loading when the tractor was operated at wide open throttle.

The reliability of the instrumentation was demonstrated by another researcher, Michael Blumanhourst. His research included improving the accuracy of the model over a wider range of loads. He operated the tractor and instrumentation over a period of two more years with no changes to the hardware. This further testing validated the durability and practicality of the design. A complete description of the data analysis is described in the research thesis by Michael Blumanhourst, Agricultural Engineering, 1984.

Chapter 8

CONCLUSION

A gear selection aid for agricultural tractors can be implemented, and it can increase fuel efficiency in a variety of field operations. By providing the operator with sufficient information, it was shown that savings up to 37 percent are possible, Blumanhourst (1979). The average savings for the first 10 operators using this aid was 12.5 percent. The savings is dependent upon the operator's knowledge and the nature of the loading of the tractor. Most operators noted the aid provided them additional savings, even if they were aware of the gear up and throttle down practice.

During the first two years of testing, the equipment experienced only a few problems. Most of the problems were correcting during the first few months of operation and were associated with the hardware. This low failure rate indicates the hardware used during this series of tests was able to withstand the harsh environments associated with field operations.

To prevent underloading, a method of determining load variability needs to be implemented. An example for this need would be a tractor operating with intermittent field loading such as turning around at the end of the field. When the tractor turns around, it may be operated within the ground speed criteria for field operations, but the implement will be out of the ground thus giving a false average loading. Unless the operator changes the gear ratio or clutches the tractor, the optimization routine would use these values and could recommend an operating range that could cause overloading.

A recommendation made by several of the operators was to leave the fuel-flow display on all the time. This would give the operator an indication of engine loading and would indicate that the device was operating.

For this technology to be implemented economically and to gain widespread use, the manufacturers of tractors need to be involved. This would allow minimizing of equipment costs by integrating the hardware and software into the existing instrumentation. This would also provide credibility compared with an add-on device.

Further research is needed to allow more exact selection of the limits of the optimization routines. Because this project involved only one tractor, any estimations of savings for implementation to other tractors may be premature. By implementing this concept onto more tractors with different engine sizes, a better relationship between engine size and savings could be determined.

REFERENCES

1. Hauck, D., V.L. Hofman, Gear Up...Throttle Down! North Dakota State University Cooperative Extension Service, 1979.

2. Chancellor, W.J., Substituting Information For Energy In Agriculture, Transactions of the ASAE, Vol. 24, No. 4, p.802-807, 813, 1981.

3. Stevens, L.E., A.D. Spencer, V.G. Floyd, and W.W. Brixius, Energy Requirements for Tillage and Planting, ASAE paper 81-1512, 1981.

4. Schwarz, M.D., Data Logger Using the SYM-1 Microcomputer, Masters Thesis for the Dept. of Agricultural Engineering, KSU, 1984.

5. Wu, T., and K.J. McAulay, Predicting Diesel Engine Performance at Various Ambient Conditions, SAE 730148, Warrendale, PA, 1973.

6. Blumanhourst, M.B., Evaluation of a Gear Selection Aid for Agricultural Tractors, Masters Thesis for the Dept. of Agricultural Engineering, KSU, 1984.

APPENDIX

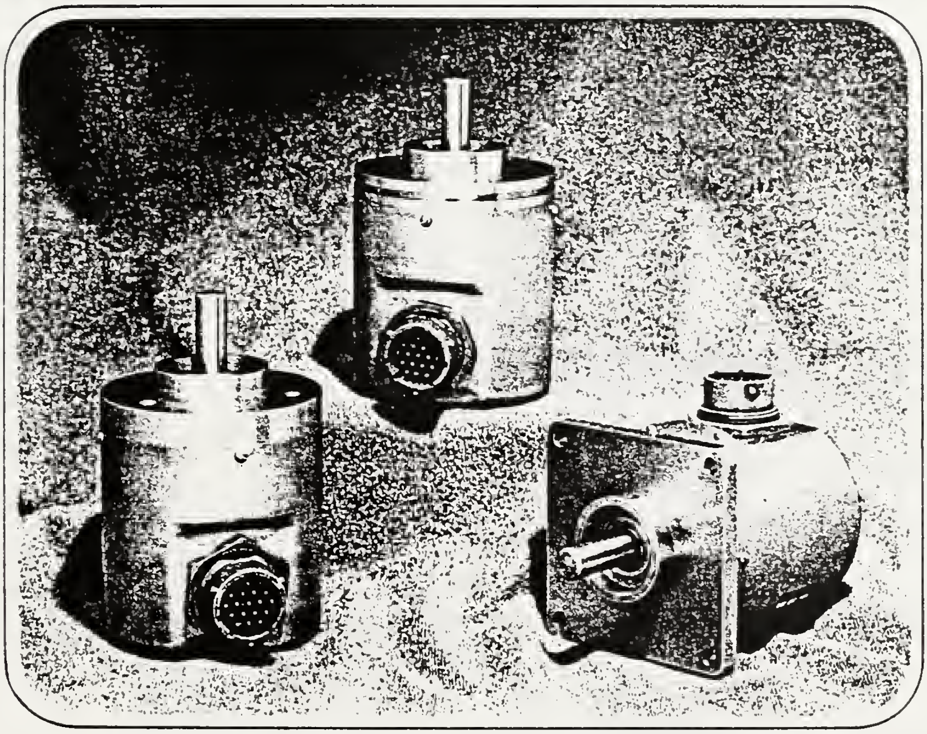
Appendix:

Appendix A

Litton Encoder Data Sheet

MODEL 76

LOW COST - ABSOLUTE SHAFT POSITION ENCODER



Designed specifically for those demanding applications which require high immunity to mechanical stress, cannot tolerate a failure of the illumination source and where absolute (whole-word) encoding is essential.

OUR GUARANTEE
LITTON ENCODER DIVISION WILL REPLACE
ANY ILLUMINATION SOURCE WHICH FAILS
WITHIN 5 YEARS FROM DATE OF SHIPMENT.

Litton **ENCODER DIVISION**

FEATURES
- LOW COST • ABSOLUTE ENCODING
- CHOICE OF 3 CODE FORMATS
- SOLID-STATE ILLUMINATION SOURCE
- SIMPLE DESIGN • HIGH RELIABILITY
- CHOICE OF 10 RESOLUTIONS
- DTL AND TTL COMPATIBLE OUTPUTS
- 3 MOUNTING CONFIGURATIONS
- 2 SHAFT SIZES

APPLICATIONS
- NC MACHINE TOOLS
- COMPUTING SCALES
- PROCESS CONTROL
- DIVIDER HEADS
- PLOTTERS • PRINTERS
- ANTENNAS
- TRANSLATION STAGES
- NAVIGATION SYSTEMS

GENERAL DESCRIPTION

MODEL 76 has been engineered to provide the potential user the maximum flexibility in selecting the physical and electrical characteristics dictated by the application. There is the choice of three mounting configurations with the input/output connector mounted on the end or side of the housing; two input shaft styles; three code formats to choose from — Gray Code, Natural Binary and 8421 Binary Coded Decimal — and 10 standard resolutions.

MODEL 76 uses solid-state illumination sources carrying Litton's 5 YEAR GUARANTEE against field failures; only a single 5VDC power supply is required for operation and the outputs are fully buffered to provide direct DTL and TTL compatibility.

Appendix B

Ametek Strain Gage Transducer Data Sheet

BA SERIES *Low Range, Low Price, High Efficiency*

Specifications

RATED CAPACITIES (lbs.): 5, 10, 25, 50, 75, 100, 150, 200

RATED OUTPUT: 3 mV/V ±10%

ZERO BALANCE: ±1% R.O.

MAXIMUM EXCITATION: 10 VDC

NON-LINEARITY: ±0.03% R.O.

HYSTERESIS: ±0.02% R.O.

NON-REPEATABILITY: ±0.01% R.O.

COMPENSATED TEMP. RANGE: 50 to 150° F (10 to 66° C)

SAFE OPERATING TEMP. RANGE: -65 to 200° F (-54 to 93° C)

TEMP. EFFECT ON ZERO BALANCE: $\frac{\pm 0.5\% \text{ R.O.}}{100° \text{ F } (55.6° \text{ C})}$

TEMP. EFFECT ON OUTPUT: $\frac{\pm 0.08\% \text{ R.O.}}{100° \text{ F } (55.6° \text{ C})}$

CREEP: $\frac{\pm 0.03\% \text{ R.O.}}{20 \text{ Min}}$

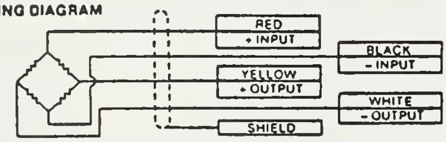
TERMINAL RESISTANCE:
INPUT: 418 ±4 ohms
OUTPUT: 350 ohms ±2 ohms

INSULATION RESISTANCE: 2000 megohms @ 100 VDC

OVERLOAD RATINGS:
Safe: 150% Rated Capacity
Ultimate: 200% Rated Capacity

R.O. - Rated Output

WIRING DIAGRAM



NOTE:
1. POSITIVE OUTPUT IN THE DIRECTION OF TENSION LOADING

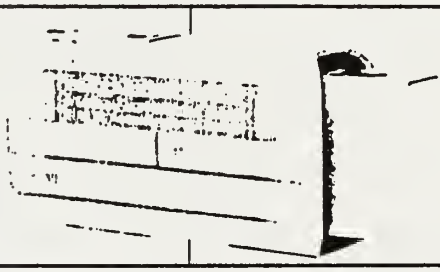
Features

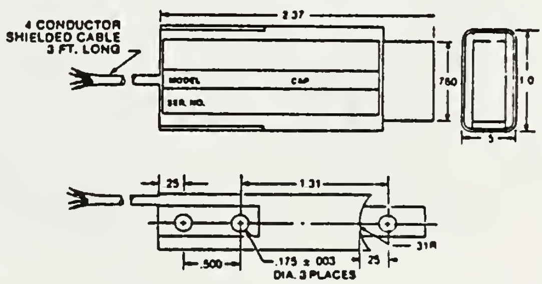
- UNIVERSAL — TENSION & COMPRESSION LOADS
- COMPACT
- LIGHTWEIGHT ALUMINUM
- EXCELLENT ACCURACY
- LOW FORCE RANGES

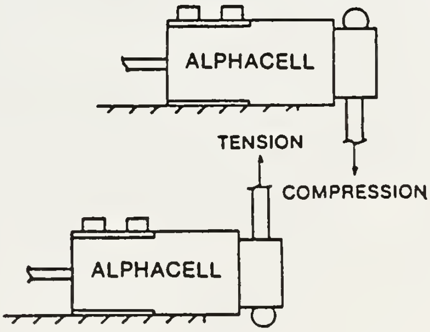
ORDERING INFORMATION

Series	Capacity
BA	•

• Capacities 5-lb., 10-lb., 25-lb., 50-lb., 75-lb., 100-lb., 150-lb., 200-lb.







Appendix C

Calex V/F Converter Data Sheet

MODELS 166 and 167 BRIDGESENSORS

GENERAL DESCRIPTION

The Models 166 and 167 Bridgesensors are complete load cell signal conditioners in modular form. They consist of three basic sections—an adjustable regulated power supply to drive the load cell, a differential input instrumentation amplifier, and a voltage to frequency converter to provide a frequency output. Figure 1 shows a simplified block diagram of the Bridgesensors. The Models 166 and 167 were designed with weighing applications in mind. When used with a counter and load cell they can form a complete system with minimum parts count. Provision is made to offset the output which makes it possible to easily subtract tare weight. The unit operates from a standard ±15 volt power supply.

INSTRUMENT AMPLIFIER

The instrumentation amplifier section of the Models 166/167 is a true differential, high input impedance, low drift amplifier. The design is optimized to perform well with low impedance sources such as a load cell. The drift of the amplifier offset voltage is less than 0.5μV/°C which is the type of performance needed for a strain gage load cell amplifier. For example, with a bridge supply voltage of 10 volts, a 2mV/Volt load cell has an output of 20mV full scale. Amplifier drift of 0.5μV/°C thus represents an error of 0.0025%/°C of full scale.

Common mode range is ±6 volts which is adequate when using a 10 volt bridge supply. Amplifier output is brought out separately for use with or without the voltage to frequency converter. It is also possible to offset the amplifier output from an external low impedance source.

BRIDGE POWER SUPPLY

The bridge power supply is an adjustable regulated supply specifically designed to drive load cell bridges from 120 to 350 ohms. A curve of maximum output current versus output voltage is shown in Figure 6. The voltage is adjusted by means of an external potentiometer.

Voltage stability is excellent and is derived from a zener reference with a 0.002%/°C temperature coefficient. The power supply uses a series pass regulator together with a frequency stabilized op-amp to provide a ripple free and well regulated voltage source to drive the load cell.

Power supply sense lines are provided on the module so that remote sensing may be used. They can be used to compensate for the voltage drop in long leads to the transducer or to add an external current booster without degrading regulation.

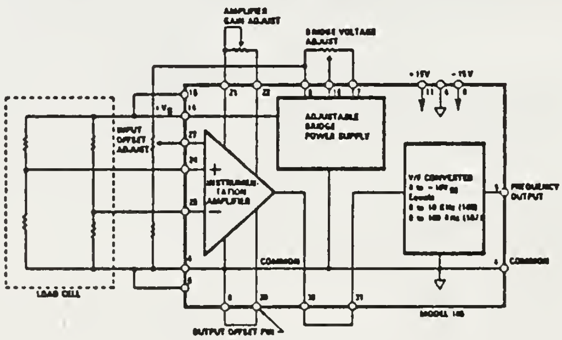


FIGURE 1. SIMPLIFIED BLOCK DIAGRAM

CALEX MFG. CO., INC., 3355 Vincent Road, Pleasant Hill, CA 94523
Telephone: (415) 932-3911 Telex: 338 506

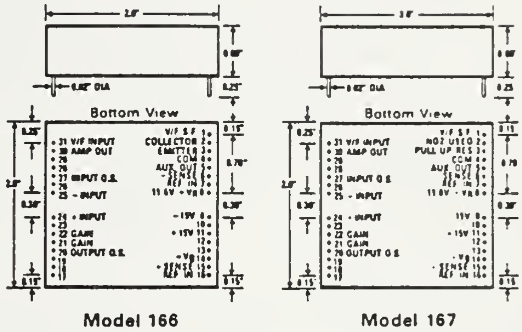
SPECIFICATIONS

ELECTRICAL

(Typical at +25°C rated supply unless otherwise noted).

MODEL	166	167
INPUT AMPLIFIER		
GAIN		
Range, Ext. Adj.	10 to 1000	
Equation	G = 10 + 200kΩ/Rg	
Equation Accuracy	±2%	
Nonlinearity, Max.	±0.01%	
Temp. Coefficient	±50ppm/°C	
INPUT		
Input Impedance - Diff.	10MΩ	
Input Impedance -CM	500MΩ	
Input Voltage Range, Diff. & CM	±6V	
Common-Mode Rejection, DC to 60Hz, G = 100	100dB typ	
INPUT OFFSETS		
Input Offset Voltage (RTI) @ G = 1000 and +25°C (Adj. to Zero)	±100µV	
vs. Temperature, Max.	±0.5µV/°C	
vs. Supply (V_s)	50µV/V	
Input Bias Current at +25°C, Max	+250nA	
Input Difference Current vs. Temperature,Max	0.1nA/°C	
OUTPUT		
Rated Output-Voltage	±10V	
Rated Current-Output	±5mA	
FREQUENCY RESPONSE		
Bandwidth, −3dB at G = 100	10kHz	
REFERENCE OUTPUT		
Nominal Value ($+V_H$)	+11.0V to 12.2V	
Temperature Coefficient, max	±0.01%/°C	
BRIDGE SUPPLY ($+V_B$)		
Range of Adjustment	+4V to +10V	
Temperature Coefficient	±0.01%/°C max	
Output Voltage Noise	1mVrms	
Output Current (See Fig. 6)	0 to +100mA	
REGULATION		
Output Voltage vs. Supply ($\Delta V_H/\Delta V_S$)	1mV/V	
Regulation, No Load to Full Load	0.01% max.	
V/F CONVERTER		
Input Voltage	0 to −10V	
Input Impedance	100KΩ	
Output Frequency	0 to 10kHz	0 to 100kHz
Direct Output Transistor (Q_1)		
V_{CEO}	25 Volts	
V_{EBO}	5 Volts	
I_C	50mA	
Isolated Output Transistor (Q_2)		
V_{CEO}	30V	N.A.
V_{EBO}	7V	N.A.
Max. Power Dissipation	150mW	N.A.
Pulse Width at Collector of Q_1	80µS typ	8µS typ
GENERAL SPECIFICATIONS		
Supply Voltage (Rated Specs)	±15V	
Supply Voltage Range	±14 to ±16V	
Quiescent Current Drain	+30mA and −10mA	
TEMPERATURE RANGE	0°C to +70°C	
SIZE (INCHES)	2 × 2 × 0.6	
UNIT PRICE 1—9	$138.00	
Model MK166/7	$48.00	

MECHANICAL



Shaded pins not installed. Shown for position only.

FIGURE 3. OUTLINE DIMENSIONS

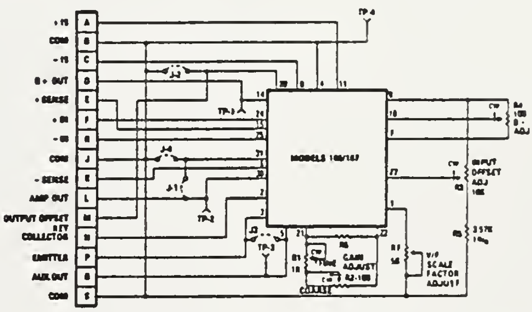


FIGURE 4. MK 166/7 MOUNTING KIT SCHEMATIC

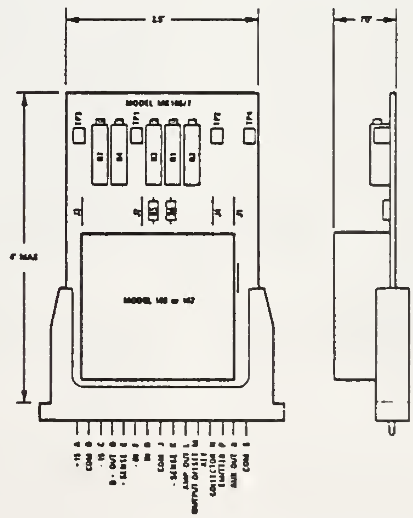


FIGURE 5. MK 166/7 MOUNTING KIT DIMENSIONS

ADJUSTMENT PROCEDURES

GAIN

Amplifier gain is set with one external resistor. The MK166/7 mounting kit provides two potentiometers in series for a fine and coarse gain adjustment. There is also a place on the P.C. card to install a single fixed resistor in place of the potentiometers. The gain equation is $G = 10 + 200k\Omega/Rg$ where Rg is the external gain resistor. To illustrate, a gain of 500 would require an Rg of 408 ohms. The accuracy of the gain equation is ±2%. If it is necessary to set the gain very accurately, the best procedure would be to calibrate the amplifier against a known voltage standard.

BRIDGE POWER SUPPLY

The bridge power supply voltage is adjusted with a single 10K potentiometer. To reduce internal heating which could cause undesired amplifier drift, the load current should be kept within the limits indicated in Figure 6. The MK166/7 includes an adjustment potentiometer on the P.C. card. It is also possible to remotely adjust the bridge supply voltage by applying a positive reference voltage to pin 16 of the 166 or 167 modules. The output voltage will follow the reference voltage, that is, +8 volts applied to pin 16 will produce a +8 volt bridge supply voltage.

The + and – sense lines can be used to provide load regulation at the load. If it is necessary to drive more than one or two load cells, the sense lines in combination with a separate power supply and transistor will allow the same regulation and stability but with more output. For example, consider a typical case where four 120 ohm load cells were to be operated in parallel. Current required is 334mA at 10 volts. Figure 7 shows how to connect the Models 166/167 to solve this problem.

INPUT OFFSET

The external adjustment circuit shown in Figures 1 and 2 will allow the amplifier input offset to be changed over a range of approximately ±2mV referred to the input. The primary purpose is to adjust the internal amplifier offset to zero; it is not intended to compensate for an unbalanced load cell bridge. When the Model 166 or 167 is purchased on an MK166/7 mounting kit, the offset potentiometer is factory set for minimum offset. If it is necessary to adjust input offset, first short the two inputs to common (pins F, H and J) and then adjust the input offset potentiometer until the amplifier output voltage is minimum (zero volts).

If it is necessary to use this adjustment to compensate for an unbalanced load cell bridge, it can be done, but it should be remembered that in so doing, the amplifier offset drift with temperature will be degraded.

OUTPUT OFFSET

The output of the instrumentation amplifier can be intentionally offset from zero by applying a voltage to pin 20 of the module. It should be noted that the offset introduced by this means is not amplified by the gain, while input offset is. The output can be offset to allow for tare weight compensation. For example, if the container weighs 50 pounds when using a load cell of 1000 pound range, the output of the amplifier may be offset to +0.5 volt. The weight of the container will then cause the amplifier output to go to zero volts and as load is added the amplifier output will increase in the negative direction causing the V/F converter to operate. In order to minimize the effect of degrading the common mode rejection ratio, the voltage applied to pin 20 should come from a low impedance source such as the output of an operational amplifier.

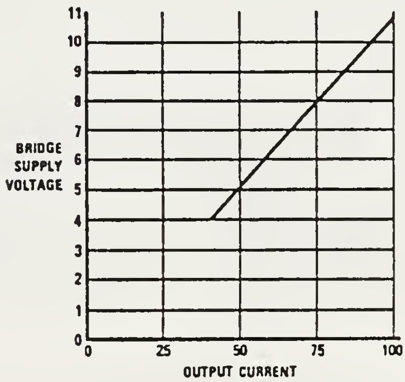


FIGURE 6. BRIDGE OUTPUT CURRENT

V/F SCALE FACTOR ADJUST

To set the V/F scale factor, connect an external resistance from pin 1 of the module to common. The value of the resistance is approximately 3K ohms. Calibration is performed by applying −10.000 volts to pin 31 and then adjusting the external resistor until the output frequency is 10.000kHz or 100.00kHz as appropriate. When the Model 166/7 is purchased with a mounting kit, MK166/7, a multiturn potentiometer is provided for this purpose on the MK166/7. It is factory set for a scale factor of 1kHz or 10kHz per volt. The temperature coefficient of the mounting kit pot is ±100ppm/°C. If better temperature stability is required, the scale factor pot should be replaced with a precision, temperature stable resistor.

Scaling adjustment is done by changing the amplifier gain or by the V/F scale factor adjustment. These two adjustments allow the user to treat the amplifier and the V/F converter independently if desired. In Figure 2, the amplifier gain would be set so that −10 volts output would represent full scale, 1000 pounds for example. The V/F scale factor would be set for full scale output of 10kHz or 100kHz. If a 0.1 second time base were selected for the Model 166 and 0.01 second for the Model 167 then a load of 999 pounds would be displayed as 999.

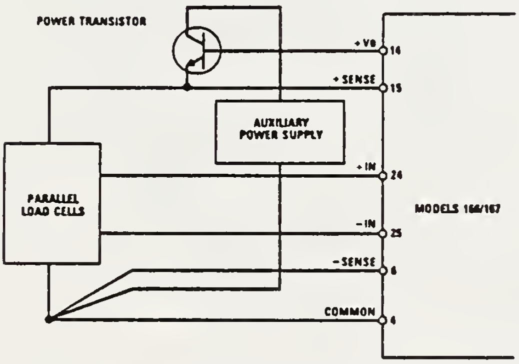
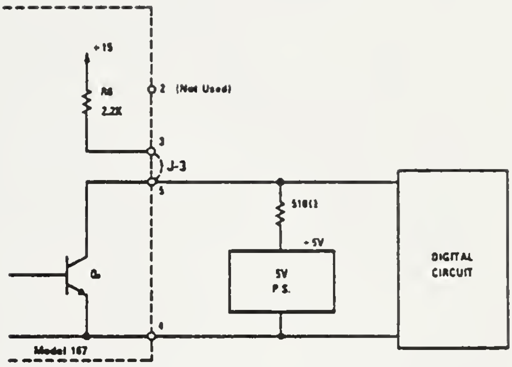


FIGURE 7. USING AN EXTERNAL CURRENT BOOSTER

V/F CONVERTER OUTPUT

Model 166 provides for auxiliary output or optically isolated output. The auxiliary output is taken between the collector of Q_1 and common. Q_1 can sink 50mA. When used as a source, the auxiliary output can supply a 10 volt pulse into a 3K load resistor.



To drive CMOS, eliminate the 5V P.S. and the 510Ω resistor and install J-3

FIGURE 8. MODEL 167 OUTPUT CIRCUIT

Maximum current through the LED portion of the optical coupler is 13mA, which results in a minimum phototransistor current of 2mA. If the phototransistor is used to switch 5 volts, then its collector resistor should be limited to approximately 1K.

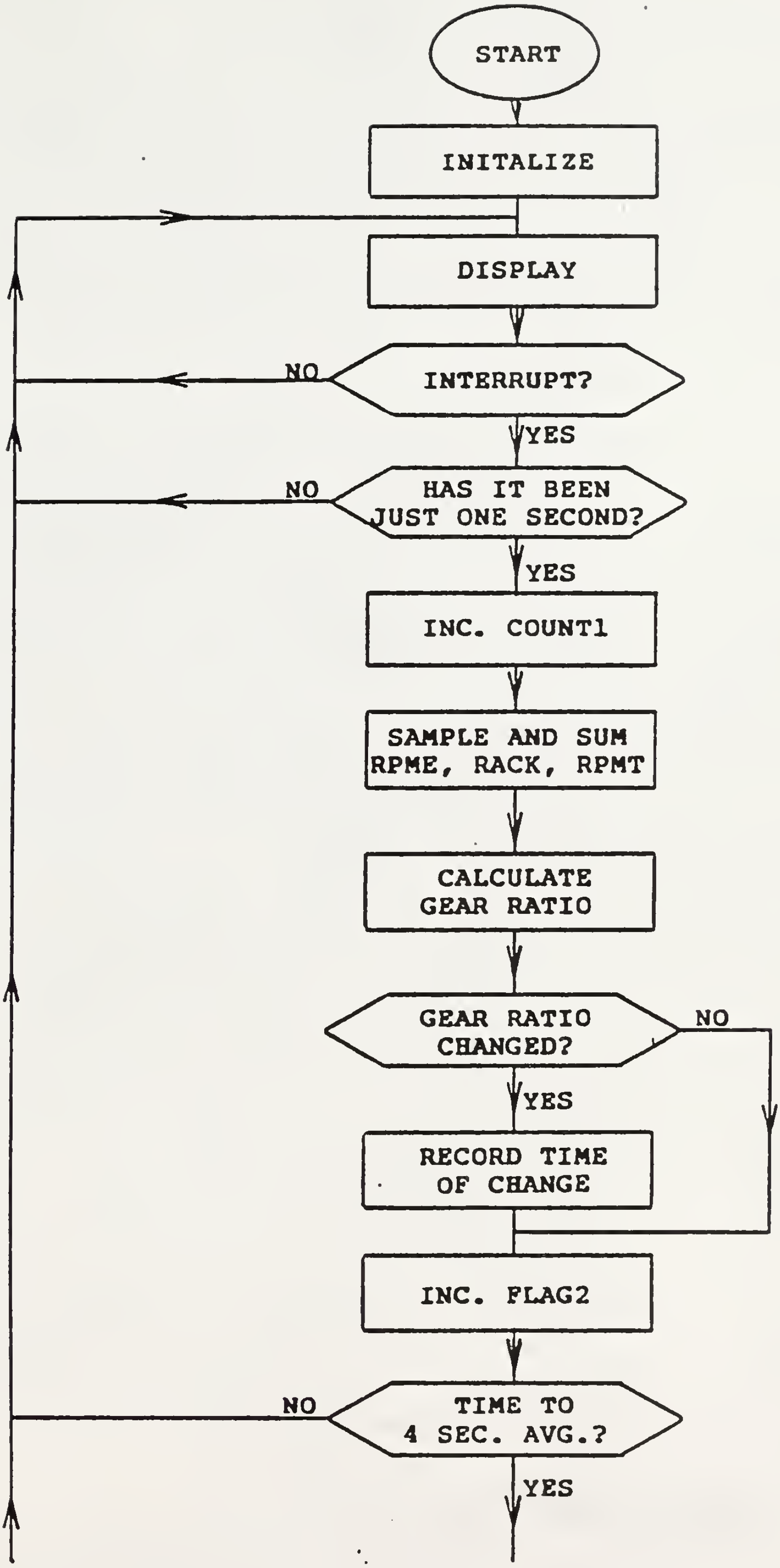
The Model 167 output circuit provides for sinking 50mA, sourcing 2mA into 5K or for using a separate collector supply. For example, if TTL digital circuitry is to be driven by the Model 167, the external jumper between pin 3 and 5 can be left out. Then a separate 5 volt source can be connected to the collector of Q_1 through pin 5 and a load resistor. Figure 8 shows a typical application.

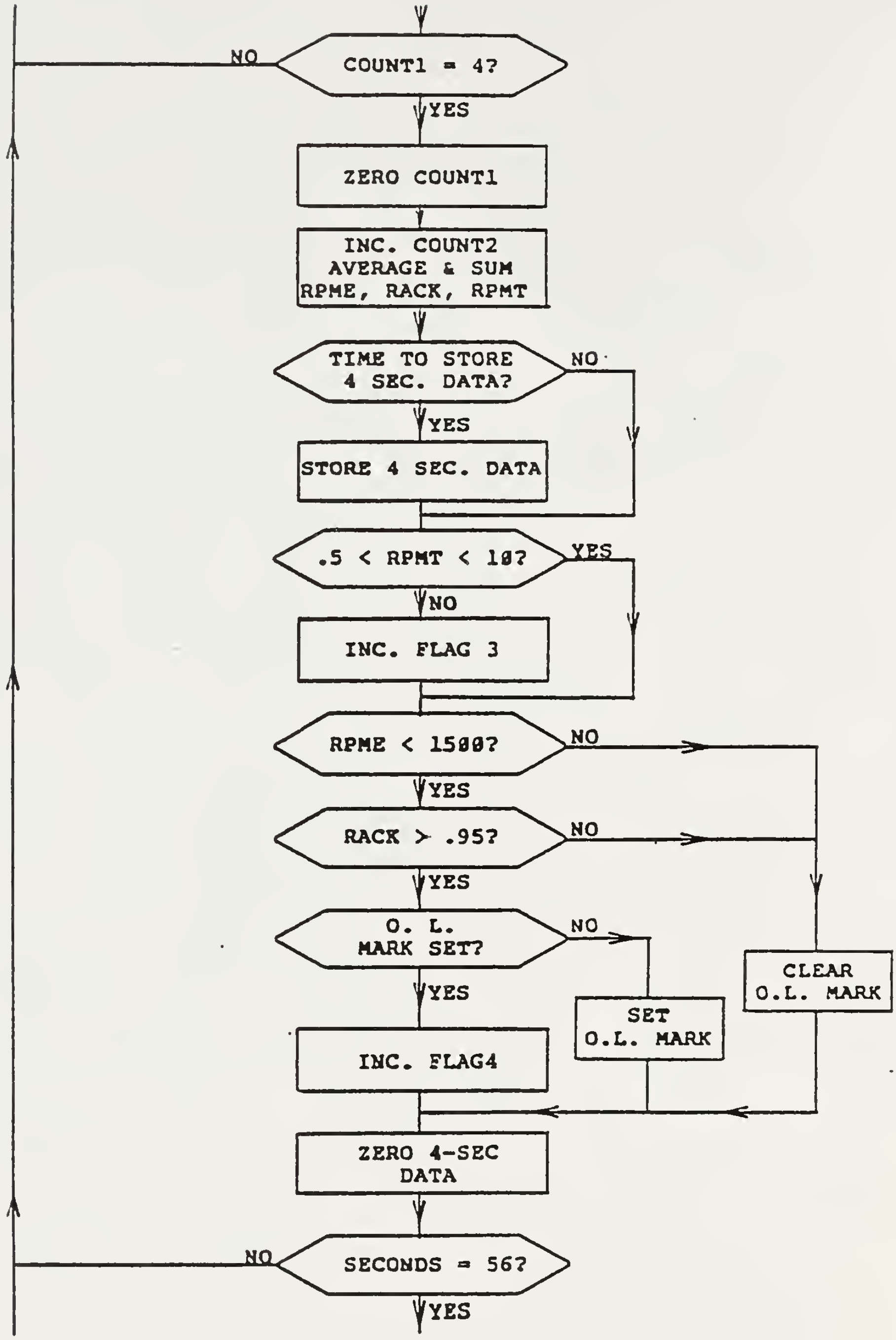
AMPLIFIER FREQUENCY RESPONSE

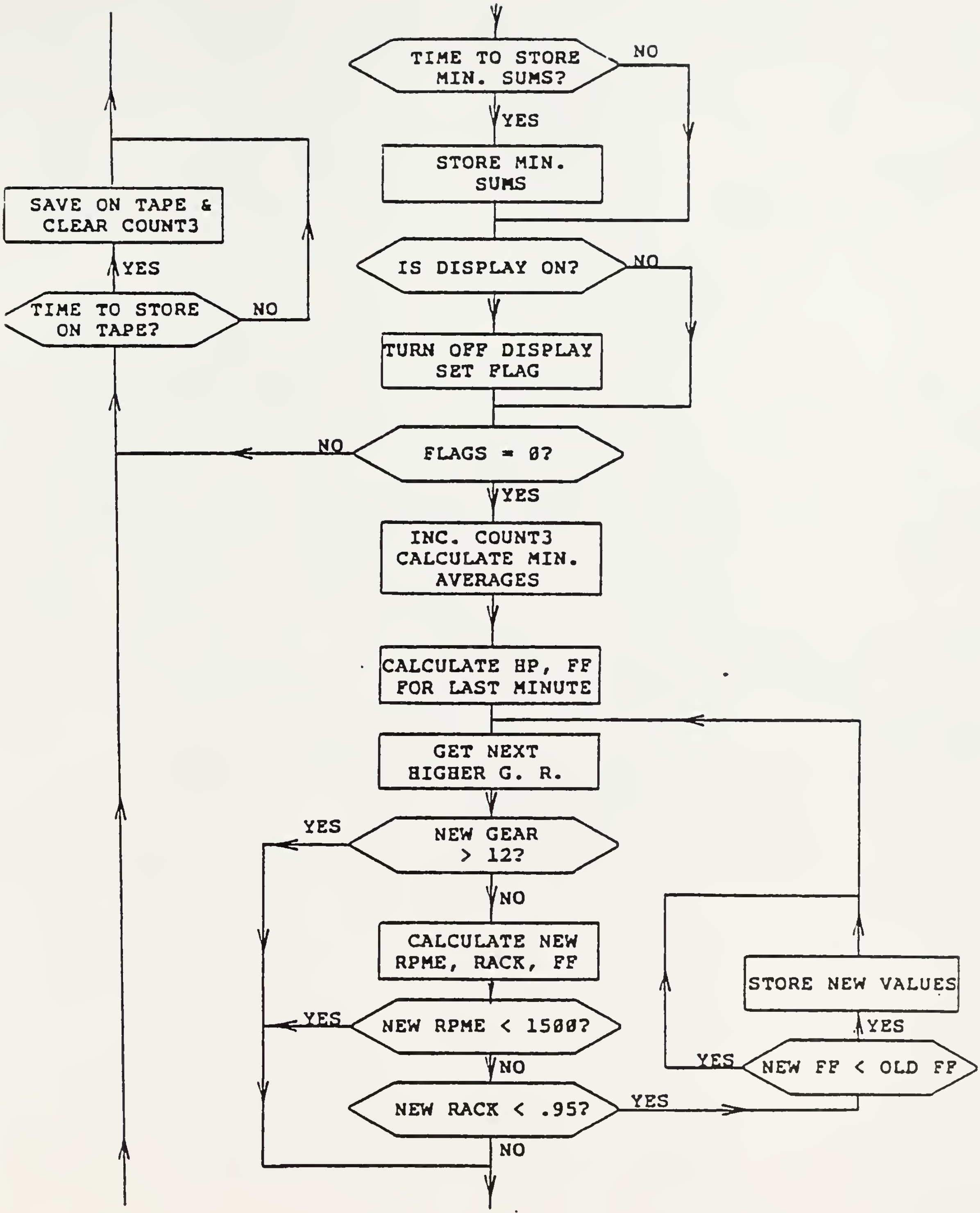
The amplifier bandwidth is 10KHZ at a gain of 100. The rolloff response curve is 20db per decade so the 3db down frequency can be predicted by knowing the gain setting. For example, at a gain setting of 1000, BW = 1KHZ, and at 10, BW = 100KHZ. It is sometimes desirable to intentionally limit the amplifier frequency response in order to minimize the effect of high frequency noise. The input stage of the V/F converter is an active integrator with a time constant of about 0.5mS, (Model 166), it therefore does not require a bandwidth limit. However, if the amplifier output is also to be monitored by an external device such as a scope or recorder then the user may wish to use additional filtering. This can be done by connecting a simple RC network or an active filter between the monitoring device and the amplifier output. Capacitors should not be connected directly across the amplifier output since this may cause instability.

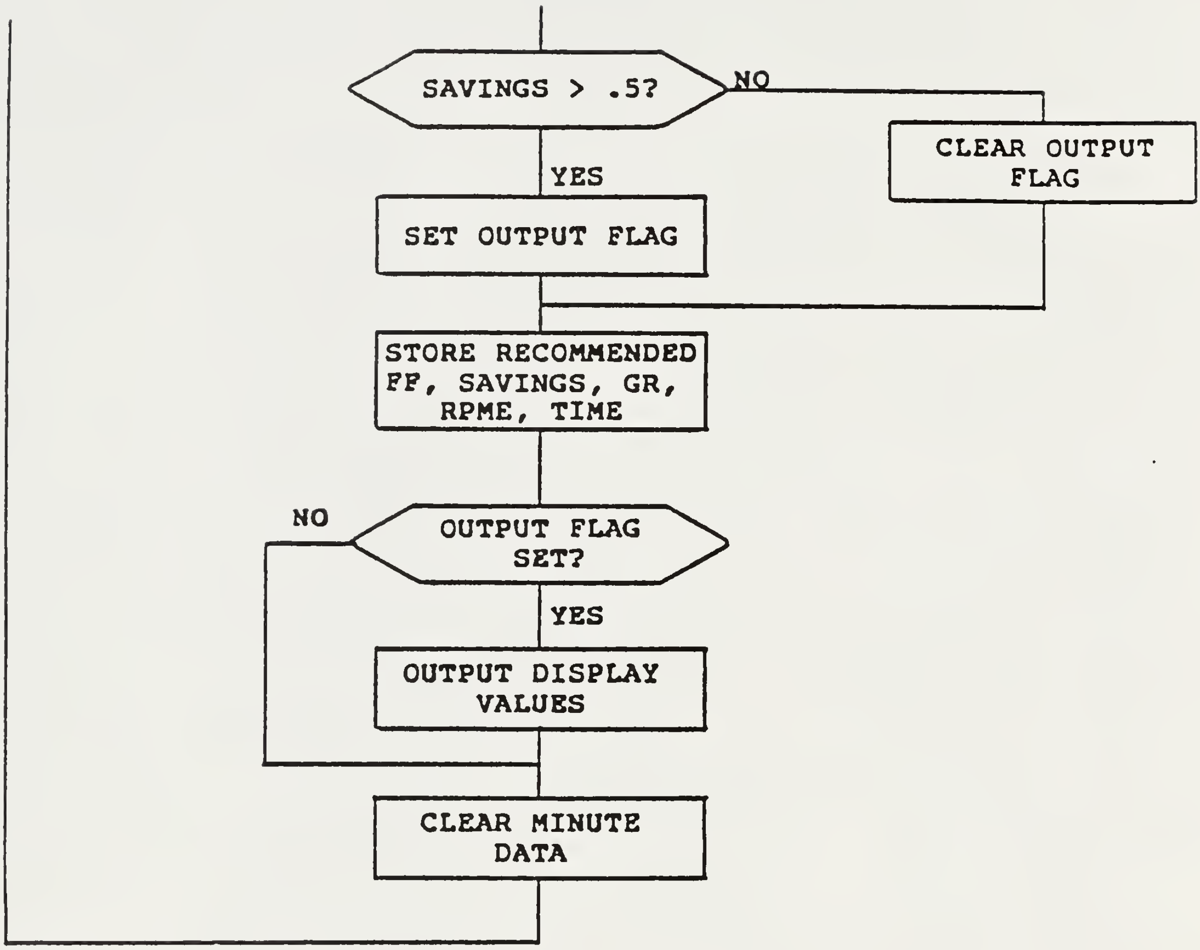
Appendix D

Software Flow Diagram


START
INITALIZE
DISPLAY
INTERRUPT?
NO
YES
HAS IT BEEN
JUST ONE SECOND?
NO
YES
INC. COUNT1
SAMPLE AND SUM
RPME, RACK, RPMT
CALCULATE
GEAR RATIO
GEAR RATIO
CHANGED?
NO
YES
RECORD TIME
OF CHANGE
INC. FLAG2
TIME TO
4 SEC. AVG.?
NO
YES


COUNT1 = 4?
NO
YES
ZERO COUNT1
INC. COUNT2
AVERAGE & SUM
RPME, RACK, RPMT
TIME TO STORE
4 SEC. DATA?
NO
YES
STORE 4 SEC. DATA
.5 < RPMT < 10?
YES
NO
INC. FLAG 3
RPME < 1500?
NO
YES
RACK > .95?
NO
YES
O. L.
MARK SET?
NO
YES
INC. FLAG4
SET
O.L. MARK
CLEAR
O.L. MARK
ZERO 4-SEC
DATA
SECONDS = 56?
NO
YES


TIME TO STORE MIN. SUMS?
NO
YES
STORE MIN. SUMS
IS DISPLAY ON?
NO
TURN OFF DISPLAY SET FLAG
FLAGS = 0?
NO
YES
INC. COUNT3 CALCULATE MIN. AVERAGES
CALCULATE HP, FF FOR LAST MINUTE
GET NEXT HIGHER G. R.
NEW GEAR > 12?
YES
NO
CALCULATE NEW RPME, RACK, FF
NEW RPME < 1500?
YES
NO
NEW RACK < .95?
YES
NO
NEW FF < OLD FF
YES
STORE NEW VALUES
YES
TIME TO STORE ON TAPE?
NO
YES
SAVE ON TAPE & CLEAR COUNT3


SAVINGS > .5?
NO
CLEAR OUTPUT FLAG
YES
SET OUTPUT FLAG
STORE RECOMMENDED FF, SAVINGS, GR, RPME, TIME
NO
OUTPUT FLAG SET?
YES
OUTPUT DISPLAY VALUES
CLEAR MINUTE DATA

Appendix E

Program Listing

```
IAS I.

10-10-82
ASSEMBLY OF IM PERFORMANCE IMPROVER



0B6A  324A-3DB4  IMADDRES.SD



01E1  324A-342B  FPVARS.R
^G                 0030 INPRDI     ^B
!02 AT LINE 0030
^G                 A8DB 99
!0C AT LINE A8DB
^G                 A8DB 9:
!0C AT LINE A8DB
^G                 DC88 X
!06 AT LINE DC88
^G                 DBC6 _
!06 AT LINE DBC6
^G                 A6A8 L
!06 AT LINE A6A8
^G                 A8DB 9;
!0C AT LINE A8DB
^G                 DC88 X
!06 AT LINE DC88
^G                 DBC5 _
!06 AT LINE DBC5
^G                 A6A8 L
!06 AT LINE A6A8
^G                 A8DB 9<
!0C AT LINE A8DB
^G                 DC88 X
!06 AT LINE DC88



0A73  324A-3CBD  IMMAIN.SP



0589  324A-37D3  IMMACRO.P



065E  37D3-3E31  IMSEC.P



063B  37D3-3E0E  IM4SEC.P
```

0242 37D3-3A15 IHMIN.P

074E 37D3-3F21 IHFILE.P

02B4 37D3-3A87 IHHPHAT.P

0369 37D3-3B3C IHFFHAT.P

0B26 37D3-42F9 IHNEWVAL.P

0761 37D3-3F34 IHFUEL.P

02B6 37D3-3A89 IHOUTPUT.P

0B8E 37D3-4361 IHSHOW.S

0D34 37D3-4507 IHCLKSUBS

0106 37D3-38D9 IHSETPORT

```
00B0  37D3-3883  IHSTARTCNT



0335  37D3-3B08  IHREADPORT



03D5  37D3-3BA8  IHCONSTANTS.D

END OF MAE PASS!

                 0010 ;PUT 'IHASSEMBLE'
                 0020
                 0030            .CE
                 0040            .CT
                 0050            .OS
                 0060            .ES                 ; CAUSES MACROS TO BE EXPA
                 0064            .PR '10-10-82'
                 0070
                 0080            .PR 'ASSEMBLY OF IH PERFORMANCE IMPROVER'
                 0090            .BA $0
                 0100            .FI 'IHADDRES.SD'



0B6A  324A-3DB4  IHADDRES.SD

                 0010 ;PUT 'IHADDRES.SD'
                 0020 ;  **** THESE ARE STORED IN RAM ****
                 0030 ; BEGINNING OF 1 SECOND DATA *****
0000-            0040 RPMTH      .DS 2
0002-            0050 RPMEH      .DS 2
0004-            0060 RACKH      .DS 2
0006-            0070 LIMITS     .DS 1
                 0080 ; END OF 1 SECOND DATA *****
                 0090 ; BEGINNING OF 4 SEC DATA *****
0007-            0100 SRPMTH     .DS 2               ;SUM OF 1 SECOND READINGS
0009-            0110 SRPMEH     .DS 2
000B-            0120 SRACKH     .DS 2
000D-            0130 COUNT1     .DS 1               ;1 SECOND COUNT
                 0140 ; END OF 4 SEC DATA *****
                 0150 ; BEGINNING OF MINUTE DATA *****
000E-            0160 SFLG2      .DS 1               ;SIGN BIT IS USED TO PREVE
000F-            0180 SFLG3      .DS 1               ;COUNTS
0010-            0185 SFLG4      .DS 1
0011-            0190 MRPMTX     .DS 3
0014-            0200 MRPMEX     .DS 3
0017-            0210 MRACKX     .DS 3
001A-            0220 COUNT2     .DS 1               ;4 SEC AVG. COUNT
001B-            0230 MFLG       .DS 1
001C-            0240 SFLG1      .DS 1               ;SUM OF FLAGS FOR SAVED TI
                 0250 ; END OF MINUTE DATA *****
                 0260 ; BEGINNING OF DATA CLEARED ON SAVE
001D-            0270 OUTPNT     .DS 1               ;POINTER FOR OUTTIME RECOR
001E-            0280 OUTTIME    .DS 20              ;TIME DISPLAY WAS OUTPUT
0032-            0290 RSPTIME    .DS 20              ;TIME RESPONSE WAS MADE
0046-            0300 OFF        .DS 10              ;OUTPUT VALUES
0050-            0310 OFS        .DS 10
005A-            0320 ORPM       .DS 10
```

```
0064-     DGR        .DS 10
          ;    *******BEGINNING OF STORE SAVE******
006E-     DAY        .DS 6
          ;    ****** END OF SAVE VALUES ******
0074-     DISPFLG    .DS 1                ;DISPLAY FLAG
0075-     SFLG       .DS 1                ;LAST 8 SECOND FLAG INDICA
0076-     NEWPNT     .DS 1
0077-     MGEAR      .DS 1                ;MINUTE GR
0078-     NGR        .DS 1                ;NEW GEAR USED IN CALCULAT
0079-     DGR        .DS 1                ;DECODED GEAR RATIO FOR LI
007A-     DATAEND    .DS 2
007C-     DATASTART  .DS 2
007E-     MEMEND     .DS 2
0080-     LENGTH     .DS 2
0082-     DISVEL     .DS 1
0083-     DISCNT     .DS 2
0085-     JMPVEC     .DS 2
0087-     CYCLE      .DS 1
0088-     LCNT1      .DS 1
0089-     LCNT2      .DS 1
008A-     KEYCNT     .DS 1
008B-     FULL       .DS 2
008D-     LASTSEC    .DS 1
008E-     NUMBER     .DS 1
008F-     LATCH      .DS 1
                     .BA $100
          ;     FP NUMBERS MUST BE ADJUSTED TO GIVE CORRECT DECIMAL O
0100-     FPTEMP     .DS 4
0104-     FMRPMT     .DS 4                ;MINUTE AVG. CALCULATED
0108-     FMRPME     .DS 4                ;BY USING MINUTE SUMS
010C-     FMRACK     .DS 4
0110-     FMGR       .DS 4                ;MINUTE AVG. CALCULATED BY
0114-     FMFF       .DS 4                ;USING THE EQUATIONS
0118-     FMHP       .DS 4
011C-     FNGR       .DS 4                ;NEW CALCULATIONS
0120-     FNRE       .DS 4
0124-     FNRAC      .DS 4
0128-     FNFF       .DS 4
012C-     BLMFF      .DS 4                ;LAST MINUTE FF
0130-     BMFF       .DS 1                ;BINARY MINUMUM FUEL FLOW
0131-     BMFG       .DS 1                ;GEAR FOR MIN FF
0132-     BFFS       .DS 16               ;CALCULATED FUEL SAVINGS
0142-     BFF        .DS 16               ;CALCULATED FF
0152-     BRE        .DS 16               ;CALCULATED RPME
0162-     BRAC       .DS 16               ;CALCULATED RACK
0172-     COUNT3     .DS 1                ;MINUTE COUNT
          ;  ********** DON'T ZERO PAST HERE *********
          ;  ********** ON THE SAVE          *********
0173-     FLGTIME    .DS 3                ;TIME LAST FLAG WAS RECORD
0176-     GEAR       .DS 1                ;LAST CALCULATED GEAR (RAW
0177-     FSGR       .DS 4                ;1 SEC. GEAR RATIO
017B-     FNSGR      .DS 4                ;NEW 1 SEC. GEAR RATIO

          VIA1       .DE $A000
          VIA2       .DE $A800            ;RPMT(6),LIMIT(0),DOWNSHIF
          ; VIA2+1 IS RACK
          VIA3       .DE $AC00            ;RPME(6),LATCHES(0-3),BLIN
          ; DISPLAY DETECT(5), DISPLAYINDICAT (7)
          ; VIA3+1 IS DISPLAY DIGITS
          OUTBYT     .DE $82FA
          OUTXAH     .DE $82F4
          DISBUF     .DE $A640
          PARM       .DE $8220
          PARN       .DE $A64A
          PARNR      .DE $A649
          ACCESS     .DE $8886
          INTVEC     .DE $A678
          SCAND      .DE $8906
          GOVEC      .DE $A659
          MONITOR    .DE $8000
          BEEP       .DE $8972
          TAPDEL     .DE $A630
          SAVE2      .DE $87EA
          MON        .DE $8003
          EPROM2     .DE $D000
          FP10       .DE EPROM2+0
          SAVTIME    .DE EPROM2+8
          FGEARS     .DE EPROM2+12
```

```
                   1110 FPBASE     .DE $DC00
                   1120 FPNORM     .DE FPBASE+$024
                   1130 FPADD      .DE FPBASE+$0C7
                   1140 FPSUB      .DE FPBASE+$0C0
                   1150 FPMULT     .DE FPBASE+$12F
                   1160 FPDIV      .DE FPBASE+$1A5
                   1170 FPOUT      .DE FPBASE+$257
                   1180 FPDISP     .DE FPBASE+$323
                   1190 ; PUT 'IHADDRES.SD'
                   0110
                   0120            .BA $D0
                   0130            .FI D26 'FPVARS.B'



01E1  324A-342B  FPVARS.B

                   0001 ;PUT 'FPVARS.B'
                   0002
                   0003 ;VARIABLES FOR MATH ROUTINES
                   0004
00D0-              0005 FMPNT      .DS 2
00D2-              0006 TOPNT      .DS 2
00D4-              0007 CNTR       .DS 1
00D5-              0008 OVFL       .DS 1
00D6-              0009 SIGNS      .DS 1
00D7-              0010 FPLSWE     .DS 1
00D8-              0011 FPLSW      .DS 1
00D9-              0012 FPNSW      .DS 1
00DA-              0013 FPMSW      .DS 1
00DB-              0014 FPACCE     .DS 1
00DC-              0015 WORK0      .DS 1
00DD-              0016 WORK1      .DS 1
00DE-              0017 WORK2      .DS 1
                   0018 WORK3
00DF-              0019 FOLSWE     .DS 1
00E0-              0020 FOPLSW     .DS 1
00E1-              0021 FOPNSW     .DS 1
00E2-              0022 FOPMSW     .DS 1
00E3-              0023 FOPEXP     .DS 1
                   0024 ;    VARIABLES FOR I/O ROUTINES
00E4-              0025 IOSIGN     .DS 1
00E5-              0026 IOEXPD     .DS 1
                   0027
                   0028 OUTBUF
00E6-              0029 TEMP1      .DS 1
00E7-              0030 INPRDI     .DS 1
00E8-              0031 TPLSW      .DS 1
00E9-              0032 TPNSW      .DS 1
00EA-              0033 TPMSW      .DS 1
00EB-              0034 TPEXP      .DS 1
00EC-              0035            .DS 10
                   0036
                   0037 ;PUT 'FPVARS.B'
                   0140            .BA $C000
                   0150            .MC $1000
                   0160            .FI 'IHMAIN.SP'



0A73  324A-3CBD  IHMAIN.SP

                   0010 ;PUT 'IHMAIN.SP'
                   0020
                   0030 MAIN
C000- 20 86 8B     0040            JSR ACCESS
C003- 20 1A C0     0050            JSR INIT              ;INITIAL DATA IF NECESSARY
C006- A9 50        0060            LDA #L,INTERRUPT
C008- 8D 78 A6     0070            STA INTVEC
C00B- A9 C0        0080            LDA #H,INTERRUPT
C00D- 8D 79 A6     0090            STA INTVEC+1
C010- 20 C6 CC     0100            JSR SETUPCLOCK
```

```
C013- 58        0110             CLI
C014- 20 54 CA  0120             JSR OFFOUT
C017- 20 72 CA  0130             JSR SHOW
                0140
                0150 ;THIS ROUTINE INITIALIZES THE VALUES
                0160
                0170 INIT
C01A- A9 00     0180             LDA #0
C01C- AA        0190             TAX
C01D- 95 00     0200 INIT1       STA *0,X
C01F- E8        0210             INX
C020- E0 F8     0220             CPX #$F8           ;IS ALL STORAGE ZEROED
C022- D0 F9     0230             BNE INIT1          ;NO
C024- AA        0240             TAX
                0250 INIT2
C025- 9D 00 01  0260             STA FPTEMP,X
C028- E8        0270             INX
C029- E0 F8     0280             CPX #$F8
C02B- D0 F8     0290             BNE INIT2
C02D- A2 08     0300             LDX $8
C02F- BD 47 C0  0310             LDA INITVAL,X
C032- 95 7A     0320             STA *DATAEND,X
C034- CA        0330             DEX
C035- 10 F8     0340             BPL *-7
                0350 INIT3
C037- A9 00     0360             LDA #0
C039- A0 FF     0370             LDY #$FF
                0380 INI3
C03B- 91 7C     0390             STA (DATASTART),Y
C03D- 88        0400             DEY
C03E- D0 FB     0410             BNE INI3
C040- 20 05 CD  0420             JSR SETPORT
C043- 20 28 CD  0430             JSR STRTCNT
C046- 60        0440             RTS
                0450 ;
                0460 INITVAL
C047- 27 07     0470             .SE $727           ;2*LENGTH +$200
C049- 00 02     0480             .SE $200
C04B- FF 0F     0490             .SE $FFF
C04D- 0A 00     0500             .SE $0A
C04F- 10        0510             .BY $10
                0520 ;
                0530 ;THIS ROUTINE SERVICES THE CLOCK INTERRUPTS.
                0540 ;IT CALLS SAMPLE, AVERAGE, AND STORE AT THE
                0550 ;PROPER TIMES
                0560 ;
                0570 INTERRUPT
C050- 48        0580             PHA
C051- 8A        0590             TXA
C052- 48        0600             PHA
C053- 98        0610             TYA
C054- 48        0620             PHA
C055- 20 3F CC  0630             JSR READCLOCK      ;PUT NEW TIME IN DAY+...
C058- 20 37 CD  0640             JSR GTDATA         ;GET DATA FROM PORTS
C05B- 20 28 CD  0650             JSR STRTCNT
C05E- 20 34 C1  0660             JSR CKLIMIT        ;CHECK FOR OVER LIMITS
                0670 SECSUM
C061- F8        0680             SED
C062- 18        0690             CLC
C063- A5 8D     0700             LDA *LASTSEC
C065- 69 01     0710             ADC #1
C067- C9 60     0720             CMP #$60
C069- D8        0730             CLD
C06A- 90 02     0740             BCC SECSU
C06C- A9 00     0750             LDA #0
                0760 SECSU
C06E- 85 8D     0770             STA *LASTSEC
C070- C5 73     0780             CMP *DAY+5         ;HAS IT BEEN 1 SEC.
C072- F0 07     0790             BEQ SEC
C074- A5 73     0800             LDA *DAY+5
C076- 85 8D     0810             STA *LASTSEC
C078- 4C 09 C1  0820             JMP ENDINT
                0830 SEC
C07B- 20 6C C1  0840             JSR SECS
                0850 FOUR
C07E- A5 73     0860             LDA *DAY+5
C080- 20 0F C1  0870             JSR BINARY
C083- 29 03     0880             AND #$03
```

```
C085- F0 03                  BEQ =+4
C087- 4C 09 C1               JMP OUT
C08A- A5 0D                  LDA *COUNT1
C08C- C9 04                  CMP #04          ;ARE THERE 4 ONE SEC. SAMP
C08E- D0 1C                  BNE SUMFOUR
C090- 20 7B C1               JSR CALCG        ;CHECK FOR GEAR CHANGE
C093- 20 02 C2               JSR AVG4
C096- 20 12 C2               JSR TRANCHK      ;CHECK TRANS. SPEED
C099- 20 48 C2               JSR OVLCHK       ;CHECK FOR OVERLOAD
C09C- 20 73 C2               JSR FOURSUM      ;ADD TO MINUTE SUM
C09F- A5 72                  LDA *DAY+4       ;TIME FOR 4 SEC RECORD
C0A1- 29 0F                  AND #$0F
C0A3- F0 04                  BEQ STOS         ;YES
C0A5- C9 05                  CMP #5
C0A7- D0 03                  BNE SUMFOUR      ;NO
                  STOS
C0A9- 20 B2 C2               JSR STOSEC       ;STORE 4 SECOND DATA FOR R
                  SUMFOUR
C0AC- 20 A6 C2               JSR CLRSECSM
C0AF- A5 73                  LDA *DAY+5       ;CHECK FOR TIME TO MIN. AV
C0B1- C9 56                  CMP #$56
C0B3- D0 54                  BNE OUT          ;NOT TIME TO MIN. AVG.
C0B5- A5 72                  LDA *DAY+4
C0B7- 29 0F                  AND #$0F
C0B9- F0 07                  BEQ SUMFO
C0BB- C9 05                  CMP #5
C0BD- F0 03                  BEQ SUMFO
                  SUMF
C0BF- 20 45 C3               JSR STOMIN
                  SUMFO
C0C2- A5 74                  LDA *DISPFLG     ;IS DISPLAY ON?
C0C4- 10 07                  BPL SUMFOU       ;NO
C0C6- 20 54 CA               JSR OFFOUT       ;YES, SO TURN OFF AND SET
C0C9- E6 1B                  INC *MFLG
C0CB- E6 1D                  INC *OUTPNT
                  SUMFOU
C0CD- A5 1B                  LDA *MFLG        ;ANY FLAGS LAST MIN?
C0CF- F0 06                  BEQ CHF
C0D1- 38                     SEC
C0D2- 26 75                  ROL *SFLG
                  CH
C0D4- 38                     SEC
C0D5- B0 1B                  BCS STMIN
                  CHF
C0D7- 18                     CLC
C0D8- 26 75                  ROL *SFLG
C0DA- A9 01                  LDA #1
C0DC- 25 75                  AND *SFLG
C0DE- D0 12                  BNE STMIN
C0E0- 20 C3 C2               JSR MINAVE       ;CALCULATE MIN. AVG. COUNT
C0E3- 20 03 C4               JSR HPHAT        ;CALCULATE LAST MIN. AVG.
C0E6- 20 E8 C4               JSR FFHAT        ;CALCULATE LAST MIN. AVG.
C0E9- 20 0D C6               JSR GRCHK        ;CHECK FOR OPTIMUM OPERATI
C0EC- 20 81 C6               JSR NXTGR
C0EF- 20 4B C9               JSR FUELSAV      ;CHECK POSSIBLE SAVINGS
                  STMIN
C0F2- 20 1E CA               JSR OUTPUT
C0F5- 20 F4 C9               JSR CLRMINSM     ;CLEAR ALL MINUTE SUMS
C0F8- A2 03                  LDX #3
                  STM
C0FA- A5 72                  LDA *DAY+4
C0FC- DD 08 D0               CMP SAVTIME,X    ;TIME TO SAVE ON TAPE?
C0FF- F0 05                  BEQ TAPE         ;YES
C101- CA                     DEX
C102- 10 F6                  BPL STM
C104- 30 03                  BMI OUT
                  TAPE
C106- 20 56 C3               JSR SAVE
                  ; NEED TO HAVE LATCH RELAY IN PARALLEL WITH
                  ; VIA3 RELAY
                  OUT
                  ENDINT
C109- 68                     PLA
C10A- A8                     TAY
C10B- 68                     PLA
C10C- AA                     TAX
C10D- 68                     PLA
C10E- 40                     RTI
```

```
                    1670
                    1680 ;DO A BCD TO BINARY CONVERSION
                    1690
                    1700 BINARY
C10F- 48            1710             PHA
C110- 4A            1720             LSR A
C111- 4A            1730             LSR A
C112- 4A            1740             LSR A
C113- 4A            1750             LSR A
C114- AA            1760             TAX
C115- 68            1770             PLA
C116- CA            1780             DEX
C117- 10 01         1790             BPL =+2
C119- 60            1800             RTS
C11A- 38            1810             SEC
C11B- E9 06         1820             SBC #$06
C11D- B0 F7         1830             BCS =-8               ;ALWAYS
                    1840
                    1850 ; PUT 'IHMAIN.SP'
                    0170             .FI 'IHMACRO.P'
```

```
0589  324A-37D3  IHMACRO.P

                    0010 ;PUT 'IHMACRO.P'
                    0020
                    0030 ;   **** THESE ARE THE ROUTINES USED TO MOVE ****
                    0040 ;   **** AND NORMALIZE DATA USED IN THE PROGRAM ****
                    0050
                    0060             .MG
                    0070 !!!MV4      .MD (...GET ...PUT) ;MOVE 4 BYTES FROM GET TO P
                    0080             LDX #03
                    0090             LDA ...GET,X
                    0100             STA ...PUT,X
                    0110             DEX
                    0120             BPL =-8
                    0130             .ME
                    0140 !!!MV2N     .MD (...FRM)          ;MOVE 2 BTES AND NORMALIZE
                    0150             LDX ...FRM
                    0160             LDA ...FRM+1
                    0170             JSR I2TOF
                    0180             .ME
                    0190 !!!MV3N     .MD (...FROM)         ;MOVE 3 BYTES AND NORMALIZ
                    0200             LDY ...FROM
                    0210             LDX ...FROM+1
                    0220             LDA ...FROM+2
                    0230             JSR I3TOF
                    0240             .ME
                    0250 !!!MV4I     .MD (...GET ...PUT) ;GET 4 BYTES INDEXED FROM G
                    0260             ASL A
                    0270             ASL A
                    0280             TAY
                    0290             LDX #0
                    0300             LDA ...GET,Y          ;AND MOVE THEM INDEXED FRO
                    0310             STA *...PUT,X
                    0320             INY
                    0330             INX
                    0340             CPX #4
                    0350             BNE =-10
                    0360             .ME
                    0370 !!!M4I      .MD (...GT ...PT) ;GET 4 BYTES BEGINNING AT GT
                    0380             ASL A
                    0390             ASL A                 ;MULT BY 4
                    0400             TAY
                    0410             LDX #0
                    0420             LDA *...GT,X          ;AND MOVE THEM INDEXED FRO
                    0430             STA ...PT,Y
                    0440             INY
                    0450             INX
                    0460             CPX #4
                    0470             BNE =-10
                    0480             .ME
                    0490 !!!MV2      .MD (...FRO ...TO)
                    0500             LDA *...FRO
```

```
                0510            STA *...TO
                0520            LDA $...FRO+1
                0530            STA *...TO+1
                0540            .ME
                0550 !!!MV1N    .MD (...FR)          ;MOVE 1 BYTE AND NORMALIZE
                0560            LDA ...FR
                0570            JSR I1TOF
                0580            .ME
                0590 !!!CMP2    .MD (...LIMIT ...VAR) ;COMPARE VARIBLES TO THEI
                0600            LDA ...LIMIT         ;HIGH BYTE
                0610            CMP *...VAR          ;RETURN WITH CARRY AS INDI
                0620            BNE -+6
                0630            LDA ...LIMIT+1
                0640            CMP *...VAR+1        ;LOW BYTE
                0650            .ME
                0660
                0670 I1TOF
C11F- A2 00     0680            LDX #0
                0690 I2TOF
C121- A0 00     0691            LDY #0
                0700 I3TOF
C123- 85 D8     0710            STA *FPLSW
C125- 86 D9     0720            STX *FPNSW
C127- 84 DA     0730            STY *FPMSW
C129- A9 00     0740            LDA #0
C12B- 85 D7     0750            STA *FPLSWE
C12D- A9 17     0760            LDA #23
C12F- 85 DB     0770            STA *FPACCE
C131- 4C 24 DC  0780            JMP FPNORM
                0781
                0790 ;PUT 'IMMACRO.P'
                0180            .FI 'IHSEC.P'
```

```
065E  3703-3E31  IHSEC.P

                0010 ;PUT 'IHSEC.P'
                0020 ;   **** IHSEC ****
                0030 ;   **** THIS ROUTINE HAPPENS EVERY SECOND ****
                0040 CKLIMIT
C134- A5 06     0050            LDA *LIMITS          ;EGT WITHIN LIMITS?
C136- F0 15     0060            BEQ LIM              ;YES
C138- 20 5C C1  0070            JSR SETFTIME         ;NO
C13B- A5 1C     0080            LDA *SFLG1           ;WAS FLAG SET LAST SECOND
C13D- 10 01     0090            BPL DOWNSHIFT        ;NO
C13F- 60        0100            RTS
                0110 DOWNSHIFT
C140- E6 1C     0120            INC *SFLG1           ;NO
C142- E6 1B     0130            INC *MFLG
C144- A9 80     0140            LDA #$80
C146- 0D 00 A8  0150            ORA VIA2             ;OUTPUT DOWNSHIFT
C149- 8D 00 A8  0160            STA VIA2
C14C- 60        0170            RTS
                0180 LIM
C14D- A9 7F     0190            LDA #$7F
C14F- 25 1C     0200            AND *SFLG1           ;CLEAR LAST SECOND INDICAT
C151- 85 1C     0210            STA *SFLG1
C153- A9 7F     0220            LDA #$7F
C155- 2D 00 A8  0230            AND VIA2             ;CLEAR DOWNSHIFT LIGHT
C158- 8D 00 A8  0240            STA VIA2
C15B- 60        0250            RTS
                0260 SETFTIME
C15C- A5 71     0270            LDA *DAY+3
C15E- 8D 73 01  0280            STA FLGTIME
C161- A5 72     0290            LDA *DAY+4           ;RECORD TIME WHEN FLAG WAS
C163- 8D 74 01  0300            STA FLGTIME+1
C166- A5 73     0310            LDA *DAY+5
C168- 8D 75 01  0320            STA FLGTIME+2
C16B- 60        0330            RTS
                0340 SECS
C16C- E6 0D     0350            INC *COUNT1
C16E- A2 05     0360            LDX #5
C170- 18        0370            CLC
                0380 SSUM
```

```
C171- B5 00       0390             LDA *RPMTH,X           ;SUM SECONDS DATA
C173- 75 07       0400             ADC *SRPMTH,X
C175- 95 07       0410             STA *SRPMTH,X
C177- CA          0420             DEX
C178- 10 F7       0430             BPL SSUM
C17A- 60          0440             RTS                    ;REMOVE WHEN FIXED
                  0450 CALCG
C17B- A5 07       0460             LDA *SRPMTH            ;IS TRACTOR MOVING?
C17D- D0 11       0470             BNE CGR
C17F- A5 08       0480             LDA *SRPMTH+1
C181- D0 0D       0490             BNE CGR                ;YES
C183- A9 00       0500             LDA #0                 ;NO
C185- A2 03       0510             LDX #3
                  0520 GRZ
C187- 9D 7B 01    0530             STA FNSGR,X
C18A- CA          0540             DEX
C18B- 10 FA       0550             BPL GRZ
C18D- 4C EE C1    0560             JMP GRCHG              ;NO
                  0570 CGR
                  0580             MV2N (SRPMEH)          ;YES

C190- AE 09 00
C193- AD 0A 00
C196- 20 21 C1

                  0590             MV4 (FPLSW FOPLSW)

C199- A2 03
C19B- BD D8 00
C19E- 9D E0 00
C1A1- CA
C1A2- 10 F7

                  0600             MV2N (SRPMTH)

C1A4- AE 07 00
C1A7- AD 08 00
C1AA- 20 21 C1

C1AD- 20 A5 DD    0610             JSR FPDIV
                  0620             MV4 (FPLSW FNSGR) ;STORE NEW ONE SECOND GEAR RA

C1B0- A2 03
C1B2- BD D8 00
C1B5- 9D 7B 01
C1B8- CA
C1B9- 10 F7

                  0630             MV4 (FPLSW FMGR)

C1BB- A2 03
C1BD- BD D8 00
C1C0- 9D 10 01
C1C3- CA
C1C4- 10 F7

C1C6- 20 48 C6    0640             JSR GRCALC
C1C9- A5 77       0650             LDA *MGEAR
C1CB- CD 76 01    0660             CMP GEAR
C1CE- D0 1E       0670             BNE GRCHG
C1D0- A5 0E       0680             LDA *SFLG2             ;NO. DID GR CHANGE BEFORE
C1D2- 30 01       0690             BMI OUTOFF             ;YES
C1D4- 60          0700             RTS                    ;NO
                  0710 OUTOFF
C1D5- A9 7F       0720             LDA #$7F
C1D7- 25 0E       0730             AND *SFLG2             ;CLEAR G.R. CHANGE FLAG
C1D9- 85 0E       0740             STA *SFLG2
C1DB- A5 74       0750             LDA *DISPFLG           ;IS DISPLAY ON
C1DD- 30 01       0760             BMI OUTOF              ;YES
C1DF- 60          0770             RTS                    ;NO
                  0780 OUTOF
C1E0- A5 1D       0790             LDA *OUTPNT
C1E2- 0A          0800             ASL A
C1E3- AA          0810             TAX
C1E4- A5 72       0820             LDA *DAY+4
C1E6- 95 32       0830             STA *RSPTIME,X
C1E8- E8          0840             INX
C1E9- A5 73       0850             LDA *DAY+5
```

```
C1EB- 95 32                       STA *RSPTIME,X
C1ED- 60                          RTS
                 GRCHG
C1EE- 8D 76 01                    STA GEAR
C1F1- 20 5C C1                    JSR SETFTIME
C1F4- A5 0E                       LDA *SFLG2
C1F6- 10 01                       BPL GRCH           ;GR CHANGED OR WAS ZERO LA
C1F8- 60                          RTS
                 GRCH
C1F9- A9 80                       LDA #$80
C1FB- 05 0E                       ORA *SFLG2         ;SET GEAR CHANGE INDICATOR
C1FD- 85 0E                       STA *SFLG2
C1FF- E6 0E                       INC *SFLG2
                 ;INC *HFLG
C201- 60                          RTS
                 ;PUT 'IHSEC.P'
                                  .FI 'IH4SEC.P'



0638  37D3-3E0E  IH4SEC.P

                 ;PUT 'IH4SEC.P'
                 ;    ***** THIS HAPPENS EVERY 4 SECONDS*****
                 AVG4
C202- 20 05 C2                    JSR AVG4+3
C205- 46 09                       LSR *SRPMEH        ;YES, SO DIVIDE BY 4
C207- 66 0A                       ROR *SRPMEH+1
C209- 46 07                       LSR *SRPMTH
C20B- 66 08                       ROR *SRPMTH+1
C20D- 46 0B                       LSR *SRACKH
C20F- 66 0C                       ROR *SRACKH+1
C211- 60                          RTS
                 TRANCHK
                                  CMP2 (HLRPMTH SRPMTH)

C212- AD C8 CD
C215- C5 07
C217- D0 05
C219- AD C9 CD
C21C- C5 08

C21E- 90 15                       BCC FLG3           ;AVERAGE TO HIGH
                 HTOK
                                  CMP2 (LLRPMTH SRPMTH)

C220- AD CA CD
C223- C5 07
C225- D0 05
C227- AD CB CD
C22A- C5 08

C22C- B0 07                       BCS FLG3           ;AVERAGE RPMT TO LOW
                 ZT
C22E- A9 7F                       LDA #$7F           ;CLEAR LAST SECOND INDICAT
C230- 25 0F                       AND *SFLG3
C232- 85 0F                       STA *SFLG3
C234- 60                          RTS
                 FLG3
C235- 20 5C C1                    JSR SETFTIME
C238- A5 0F                       LDA *SFLG3         ;WAS IT OUT OF RANGE LAST
C23A- 10 01                       BPL SFL3           ;NO
C23C- 60                          RTS                ;YES
                 SFL3
C23D- E6 0F                       INC *SFLG3         ; INC. COUNTER FOR OUT OF
C23F- E6 1B                       INC *MFLG
C241- A9 80                       LDA #$80
C243- 05 0F                       ORA *SFLG3
C245- 85 0F                       STA *SFLG3         ;SET LAST SEC. INDICATOR
C247- 60                          RTS
                 OVLCHK           ;CHECK FOR ENGINE OVERLOAD
                                  CMP2 (LRACKH SRACKH)

C248- AD CE CD
C24B- C5 0B
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```
C24D- D0 05
C24F- AD CF CD
C252- C5 0C

C254- B0 16      0370          BCS CLRMRK          ;RACK OK
                 0380 CKMRK
C256- A5 10      0390          LDA *SFLG4          ;IS MARK4 SET
C258- 10 0B      0400          BPL SETMRK          ;NO
C25A- E6 10      0410          INC *SFLG4          ;YES
C25C- E6 1B      0420          INC *MFLG
C25E- 20 40 C1   0430          JSR DOWNSHIFT
C261- 20 5C C1   0440          JSR SETFTIME
C264- 60         0450          RTS
                 0460 SETMRK
C265- A9 50      0470          LDA #80             ;SET LAST SECOND MARKER
C267- 05 10      0480          ORA *SFLG4
C269- 85 10      0490          STA *SFLG4
C26B- 60         0500          RTS
                 0510 CLRMRK
C26C- A9 7F      0520          LDA #$7F            ;CLEAR LAST SECOND MARKER
C26E- 25 10      0530          AND *SFLG4
C270- 85 10      0540          STA *SFLG4
C272- 60         0550          RTS
                 0560 FOURSUM
C273- A2 01      0570          LDX #01             ;SUM 4 SEC. AVE. INTO MIN.
C275- 18         0580          CLC
                 0590 TSUM
C276- B5 07      0600          LDA *SRPMTH,X
C278- 75 12      0610          ADC *MRPMTX+1,X
C27A- 95 12      0620          STA *MRPMTX+1,X
C27C- CA         0630          DEX
C27D- 10 F7      0640          BPL TSUM
C27F- 90 02      0650          BCC *+3
C281- E6 11      0660          INC *MRPMTX
C283- A2 01      0670          LDX #01
C285- 18         0680          CLC
                 0690 ESUM
C286- B5 09      0700          LDA *SRPMEH,X
C288- 75 15      0710          ADC *MRPMEX+1,X
C28A- 95 15      0720          STA *MRPMEX+1,X
C28C- CA         0730          DEX
C28D- 10 F7      0740          BPL ESUM
C28F- 90 02      0750          BCC *+3
C291- E6 14      0760          INC *MRPMEX
C293- A2 01      0770          LDX #1
C295- 18         0780          CLC
                 0790 RSUM
C296- B5 0B      0800          LDA *SRACKH,X
C298- 75 18      0810          ADC *MRACKX+1,X
C29A- 95 18      0820          STA *MRACKX+1,X
C29C- CA         0830          DEX
C29D- 10 F7      0840          BPL RSUM
C29F- 90 02      0850          BCC *+3
C2A1- E6 17      0860          INC *MRACKX
                 0870 CNT2
C2A3- E6 1A      0880          INC *COUNT2
C2A5- 60         0890          RTS
                 0900 CLRSECSM
C2A6- A2 00      0910          LDX #00
C2A8- A9 00      0920          LDA #00
                 0930 CLS
C2AA- 95 07      0940          STA *SRPMTH,X
C2AC- E8         0950          INX
C2AD- E0 07      0960          CPX #7
C2AF- D0 F9      0970          BNE CLS
C2B1- 60         0980          RTS
                 0990 STOSEC
C2B2- 20 EF C3   1000          JSR CLRDATA
C2B5- A0 09      1010          LDY #9
C2B7- B9 07 00   1020          LDA SRPMTH,Y
C2BA- 91 7C      1030          STA (DATASTART),Y
C2BC- 88         1040          DEY
C2BD- 10 F8      1050          BPL STOSEC+5
C2BF- 20 6C C3   1060          JSR MOVEDATA
C2C2- 60         1070          RTS
                 1080 ;PUT 'IH4SEC.P'
                 0200          .FI 'IHMIN.P'
```

```
0242  37D3-3A15   IMMIN.P

                        ;PUT 'IMMIN.P'
                        ; **** THIS IS THE ROUTINES THAT RUN EVERY MINUTE ****
                        MINAVE      ;CALCULATE THE MINUTE AVERAGES FROM THE MINUTE
                                    MV3M (MRPMTX)

C2C3- AC 11 00
C2C6- AE 12 00
C2C9- AD 13 00
C2CC- 20 23 C1
                                    MV4 (FPLSW FOPLSW)

C2CF- A2 03
C2D1- BD D8 00
C2D4- 9D E0 00
C2D7- CA
C2D8- 10 F7
                                    MV1M (COUNT2

C2DA- AD 1A 00
C2DD- 20 1F C1

C2E0- 20 A5 DD                      JSR FPDIV
                                    MV4 (FPLSW FMRPMT) ;STORE AVG. RPMT

C2E3- A2 03
C2E5- BD D8 00
C2E8- 9D 04 01
C2EB- CA
C2EC- 10 F7
                                    MV3M (MRPMEX)

C2EE- AC 14 00
C2F1- AE 15 00
C2F4- AD 16 00
C2F7- 20 23 C1
                                    MV4 (FPLSW FOPLSW)

C2FA- A2 03
C2FC- BD D8 00
C2FF- 9D E0 00
C302- CA
C303- 10 F7
                                    MV1M (COUNT2)

C305- AD 1A 00
C308- 20 1F C1

C30B- 20 A5 DD                      JSR FPDIV
                                    MV4 (FPLSW FMRPME) ;STORE AVG. RPME

C30E- A2 03
C310- BD D8 00
C313- 9D 08 01
C316- CA
C317- 10 F7
                                    MV3M (MRACKX)

C319- AC 17 00
C31C- AE 18 00
C31F- AD 19 00
C322- 20 23 C1
                                    MV4 (FPLSW FOPLSW)

C325- A2 03
```

```
C327- BD D8 00
C32A- 9D E0 00
C32D- CA
C32E- 10 F7
                   0160           MV1N (COUNT2)

C330- AD 1A 00
C333- 20 1F C1

C336- 20 A5 DD     0170           JSR FPDIV
                   0180           MV4 (FPLSW FMRACK) ;STORE AVG. RACK

C339- A2 03
C33B- BD D8 00
C33E- 9D 0C 01
C341- CA
C342- 10 F7

C344- 60           0190           RTS
                   0200 STOMIN
C345- 20 EF C3     0210           JSR CLRDATA
C348- A0 09        0220           LDY #9
C34A- B9 11 00     0230           LDA MRPMTX,Y
C34D- 91 7C        0240           STA (DATASTART),Y
C34F- 88           0250           DEY
C350- 10 F8        0260           BPL STOMIN+5
C352- 20 6C C3     0270           JSR MOVEDATA
C355- 60           0280           RTS
                   0290 ;PUT 'IMMIN.P'
                   0210           .FI 'IHFILE.P'




074E  3703-3F21  IHFILE.P

                   0010 ;PUT 'IHFILE.P'
                   0020
                   0030 ;INIT STOREAGE (IN ORDER)
                   0040 ;        *DATAEND        2
                   0050 ;        *DATASTART      2
                   0060 ;        *MEMEND         2
                   0070
                   0080 ;INTERFACE ROUTINES CALLED FROM THE INTERRUPT
                   0090 ;ROUTINE,  ANY ROUTINE TO BE CALLED AT THE APPROPIATE
                   0100 ;TIME SHOULD BE HERE.
                   0110
                   0120 SAVE
C356- 20 EF C3     0130           JSR CLRDATA
C359- 20 D7 C3     0150           JSR MOVEOUT
C35C- 20 EF C3     0154           JSR CLRDATA
C35F- 20 CA C3     0155           JSR MOVECLOCK          ;SAVE HEADER IN DATA
C362- 20 AF C3     0160           JSR STORE
C365- 20 6C C3     0165           JSR MOVEDATA
C368- 20 F9 C3     0170           JSR CLRSAVE
C36B- 60           0180           RTS
                   0190 ;MOVE DATA UP IN STOREAGE AREA SO NEWEST
                   0200 ;DATA IS KEPT AT THE BEGINNING
                   0210
                   0220 MOVEDATA
C36C- 38           0230           SEC
C36D- A5 7E        0240           LDA *MEMEND            ;SET POINTERS TO END
C36F- 85 D2        0250           STA *TOPNT
C371- E5 80        0260           SBC *LENGTH            ;POINTER TO MOVE FROM
C373- 85 D0        0270           STA *FMPNT
C375- A5 7F        0280           LDA *MEMEND+1
C377- 85 D3        0290           STA *TOPNT+1
C379- E5 81        0300           SBC *LENGTH+1
C37B- 85 D1        0310           STA *FMPNT+1
                   0320
C37D- 38           0330           SEC                    ;SUB REMAINDER OF A PAGE
C37E- A5 D0        0340           LDA *FMPNT
C380- E5 7C        0350           SBC *DATASTART
C382- 85 D0        0360           STA *FMPNT             ;TEMPORARY: PARTIAL PAGE
C384- A8           0370           TAY
```

```
C385- B0 02      0380                 BCS =+3
C387- C6 D1      0390                 DEC *FMPNT+1
C389- 38         0400                 SEC
C38A- A5 D2      0410                 LDA *TOPNT
C38C- E5 D0      0420                 SBC *FMPNT
C38E- 85 D2      0430                 STA *TOPNT
C390- B0 02      0440                 BCS =+3
C392- C6 D3      0450                 DEC *TOPNT+1
C394- A5 7C      0460                 LDA *DATASTART
C396- 85 D0      0470                 STA *FMPNT          ;FINISHED WITH POINTERS
C398- 4C 9C C3   0480                 JMP @MOVEDATA
                 0490
C39B- 88         0500                 DEY
                 0510 @MOVEDATA
C39C- B1 D0      0520                 LDA (FMPNT),Y       ;TRANSFER A PAGE
C39E- 91 D2      0530                 STA (TOPNT),Y
C3A0- C0 00      0540                 CPY #0
C3A2- D0 F7      0550                 BNE @MOVEDATA-1
C3A4- C6 D1      0560                 DEC *FMPNT+1        ;NEXT PAGE
C3A6- C6 D3      0570                 DEC *TOPNT+1
C3A8- A5 D1      0580                 LDA *FMPNT+1
C3AA- C5 7D      0590                 CMP *DATASTART+1    ;END OF TRANSFER
C3AC- B0 ED      0600                 BCS @MOVEDATA-1
C3AE- 60         0610                 RTS
                 0620
                 0630 ;THIS ROUTINE SAVES THE DATA ON CASSETTE
                 0640 ;IN HS FORMAT.
                 0650
                 0660 STORE
C3AF- A9 01      0670                 LDA #1
C3B1- 8D 4E A6   0680                 STA PARN+4
C3B4- A2 03      0690                 LDX #3
C3B6- B5 7A      0700                 LDA *DATAEND,X
C3B8- 9D 4A A6   0710                 STA PARN,X
C3BB- CA         0720                 DEX
C3BC- 10 F8      0730                 BPL =-7
C3BE- A9 01      0740                 LDA #1
C3C0- 8D 30 A6   0750                 STA TAPDEL          ;SHORTEN LEADER TO 1.5 SEC
C3C3- 08         0760                 PHP
C3C4- 78         0770                 SEI
C3C5- 20 EA 87   0780                 JSR SAVE2           ;SAVE ON TAPE
C3C8- 28         0790                 PLP
C3C9- 60         0800                 RTS
                 0810
                 0820 ;MOVE CLOCK TO DATA FIELD
                 0830
                 0840 MOVECLOCK
C3CA- A0 05      0850                 LDY #5
C3CC- A2 05      0860                 LDX #5
C3CE- B5 6E      0870                 LDA *DAY,X
C3D0- 91 7C      0880                 STA (DATASTART),Y
C3D2- 88         0890                 DEY
C3D3- CA         0900                 DEX
C3D4- 10 F8      0910                 BPL MOVECLOCK+4
C3D6- 60         0920                 RTS
                 0930 MOVEOUT
C3D7- A2 06      0940                 LDX #6
                 0950 MOVEOU
C3D9- 20 6C C3   0960                 JSR MOVEDATA
C3DC- CA         0970                 DEX
C3DD- 10 FA      0980                 BPL MOVEOU
C3DF- A2 4F      0990                 LDX #79
C3E1- A0 4F      1000                 LDY #79
                 1010 MOVEO
C3E3- B5 1E      1020                 LDA *OUTTIME,X
C3E5- 91 7C      1030                 STA (DATASTART),Y
C3E7- CA         1040                 DEX
C3E8- 88         1050                 DEY
C3E9- 10 F8      1060                 BPL MOVEO
C3EB- 20 6C C3   1070                 JSR MOVEDATA
C3EE- 60         1080                 RTS
                 1090 CLRDATA
C3EF- A9 00      1100                 LDA #0
C3F1- A0 09      1110                 LDY #9
                 1120 CLRDA
C3F3- 91 7C      1130                 STA (DATASTART),Y
C3F5- 88         1140                 DEY
C3F6- 10 FB      1150                 BPL CLRDA
```

```
C3F8- 60            1160             RTS
                    1170
                    1180 CLRSAVE
C3F9- A2 50         1190             LDX #80
C3FB- A9 00         1200             LDA #0
                    1210 CLRSA
C3FD- 85 1D         1220             STA *OUTPNT,X        ;RESET OUTPUT POINTER
C3FF- CA            1230             DEX
C400- 10 FB         1240             BPL CLRSA
C402- 60            1250             RTS
                    1260
                    1270 ;PUT 'IHFILE.P'
                    0220             .FI 'IHHPHAT.P'



02B4  37D3-3A87  IHHPHAT.P

                    0010 ;PUT 'IHHPHAT.P'
                    0020
                    0030 ;    *** THIS CALCULATES THE HP USING THE VALUES ***
                    0040 ; *** FROM MINUTE AVERAGES IN THE ZERO PAGE ADDRESSES ***
                    0050
                    0060 HPHAT       ;CALCULATE HORSEPOWER
                    0070             MV4 (FMRPME FPLSW)

C403- A2 03
C405- BD 08 01
C408- 9D D8 00
C40B- CA
C40C- 10 F7

                    0080             MV4 (C2M FOPLSW)

C40E- A2 03
C410- BD 88 CD
C413- 9D E0 00
C416- CA
C417- 10 F7

C419- 20 2F DD      0090             JSR FPMULT
                    0100             MV4 (FPLSW FPTEMP)

C41C- A2 03
C41E- BD D8 00
C421- 9D 00 01
C424- CA
C425- 10 F7

                    0110             MV4 (FMRACK FPLSW)

C427- A2 03
C429- BD 0C 01
C42C- 9D D8 00
C42F- CA
C430- 10 F7

                    0120             MV4 (C3M FOPLSW)

C432- A2 03
C434- BD 8C CD
C437- 9D E0 00
C43A- CA
C43B- 10 F7

C43D- 20 2F DD      0130             JSR FPMULT
                    0140             MV4 (FPTEMP FOPLSW)

C440- A2 03
C442- BD 00 01
C445- 9D E0 00
C448- CA
C449- 10 F7

C44B- 20 C7 DC      0150             JSR FPADD
```

```
                                MV4 (C1M FOPLSW)

C44E- A2 03
C450- BD 84 CD
C453- 9D E0 00
C456- CA
C457- 10 F7

C459- 20 C7 DC                  JSR FPADD
                                MV4 (FPLSW FPTEMP)

C45C- A2 03
C45E- BD D8 00
C461- 9D 00 01
C464- CA
C465- 10 F7

                                MV4 (C4M FPLSW)

C467- A2 03
C469- BD 90 CD
C46C- 9D D8 00
C46F- CA
C470- 10 F7

                                MV4 (FMRPME FOPLSW)

C472- A2 03
C474- BD 08 01
C477- 9D E0 00
C47A- CA
C47B- 10 F7

C47D- 20 2F DD                  JSR FPMULT
                                MV4 (FMRPME FOPLSW)

C480- A2 03
C482- BD 08 01
C485- 9D E0 00
C488- CA
C489- 10 F7

C48B- 20 2F DD                  JSR FPMULT
                                MV4 (FPTEMP FOPLSW)

C48E- A2 03
C490- BD 00 01
C493- 9D E0 00
C496- CA
C497- 10 F7

C499- 20 C7 DC                  JSR FPADD
                                MV4 (FPLSW FPTEMP)

C49C- A2 03
C49E- BD D8 00
C4A1- 9D 00 01
C4A4- CA
C4A5- 10 F7

                                MV4 (C5M FPLSW)

C4A7- A2 03
C4A9- BD 94 CD
C4AC- 9D D8 00
C4AF- CA
C4B0- 10 F7

                                MV4 (FMRPME FOPLSW)

C4B2- A2 03
C4B4- BD 08 01
C4B7- 9D E0 00
C4BA- CA
C4BB- 10 F7

C4BD- 20 2F DD                  JSR FPMULT
                                MV4 (FMRACK FOPLSW)
```

```
C4C0- A2 03
C4C2- BD 0C 01
C4C5- 9D E0 00
C4C8- CA
C4C9- 10 F7

C4CB- 20 2F DD  0310            JSR FPMULT
                0320            MV4 (FPTEMP FOPLSW)

C4CE- A2 03
C4D0- BD 00 01
C4D3- 9D E0 00
C4D6- CA
C4D7- 10 F7

C4D9- 20 C7 DC  0330            JSR FPADD
                0340            MV4 (FPLSW FMHP)

C4DC- A2 03
C4DE- BD D8 00
C4E1- 9D 18 01
C4E4- CA
C4E5- 10 F7

C4E7- 60        0350            RTS
                0360
                0370 ;PUT 'IHHPHAT.P'
                0230            .FI 'IHFFHAT.P'




0369  37D3-383C  IHFFHAT.P

                0010 ;PUT 'IHFFHAT.P'
                0020
                0030 ; *** THIS ROUTINE CALCULATES THE FUEL FLOW ***
                0040 ; *** USING THE MINUTE AVERAGES IN ZERO PAGE ADDRESSES ***
                0050 ; *** AND THE ADJUSTED VALUES FROM H.P. CALCULATIONS ***
                0060
                0070 FFHAT
                0080            MV4 (C9N FPLSW)

C4E8- A2 03
C4EA- BD 9C CD
C4ED- 9D D8 00
C4F0- CA
C4F1- 10 F7

                0090            MV4 (FMRPME FOPLSW)

C4F3- A2 03
C4F5- BD 08 01
C4F8- 9D E0 00
C4FB- CA
C4FC- 10 F7

C4FE- 20 2F DD  0100            JSR FPMULT
                0110            MV4 (C8N FOPLSW)

C501- A2 03
C503- BD 98 CD
C506- 9D E0 00
C509- CA
C50A- 10 F7

C50C- 20 C7 DC  0120            JSR FPADD
                0130            MV4 (FPLSW FPTEMP)

C50F- A2 03
C511- BD D8 00
C514- 9D 00 01
C517- CA
C518- 10 F7
```

```
                  0140          MV4 (C10N FPLSW)

C51A- A2 03
C51C- BD A0 CD
C51F- 9D D8 00
C522- CA
C523- 10 F7
                  0150          MV4 (FMRACK FOPLSW)

C525- A2 03
C527- BD 0C 01
C52A- 9D E0 00
C52D- CA
C52E- 10 F7

C530- 20 2F DD    0160          JSR FPMULT
                  0170          MV4 (FPTEMP FOPLSW)

C533- A2 03
C535- BD 00 01
C538- 9D E0 00
C53B- CA
C53C- 10 F7

C53E- 20 C7 DC    0180          JSR FPADD
                  0190          MV4 (FPLSW FPTEMP)

C541- A2 03
C543- BD D8 00
C546- 9D 00 01
C549- CA
C54A- 10 F7
                  0200          MV4 (FMRPME FOPLSW)

C54C- A2 03
C54E- BD 08 01
C551- 9D E0 00
C554- CA
C555- 10 F7
                  0210          MV4 (FMRPME FPLSW)

C557- A2 03
C559- BD 08 01
C55C- 9D D8 00
C55F- CA
C560- 10 F7

C562- 20 2F DD    0220          JSR FPMULT
                  0230          MV4 (C11N FOPLSW)

C565- A2 03
C567- BD A4 CD
C56A- 9D E0 00
C56D- CA
C56E- 10 F7

C570- 20 2F DD    0240          JSR FPMULT
                  0250          MV4 (FPTEMP FOPLSW)

C573- A2 03
C575- BD 00 01
C578- 9D E0 00
C57B- CA
C57C- 10 F7

C57E- 20 C7 DC    0260          JSR FPADD
                  0270          MV4 (FPLSW FPTEMP)

C581- A2 03
C583- BD D8 00
C586- 9D 00 01
C589- CA
C58A- 10 F7
                  0280          MV4 (FMRACK FPLSW)
```

```
C58C- A2 03
C58E- BD 0C 01
C591- 9D D8 00
C594- CA
C595- 10 F7

                    0290          MV4 (FMRACK FOPLSW)

C597- A2 03
C599- BD 0C 01
C59C- 9D E0 00
C59F- CA
C5A0- 10 F7

C5A2- 20 2F DD      0300          JSR FPMULT
                    0310          MV4 (C12N FOPLSW)

C5A5- A2 03
C5A7- BD A8 CD
C5AA- 9D E0 00
C5AD- CA
C5AE- 10 F7

C5B0- 20 2F DD      0320          JSR FPMULT
                    0330          MV4 (FPTEMP FOPLSW)

C5B3- A2 03
C5B5- BD 00 01
C5B8- 9D E0 00
C5BB- CA
C5BC- 10 F7

C5BE- 20 C7 DC      0340          JSR FPADD
                    0350          MV4 (FPLSW FPTEMP)

C5C1- A2 03
C5C3- BD D8 00
C5C6- 9D 00 01
C5C9- CA
C5CA- 10 F7

                    0360          MV4 (FMRPME FPLSW)

C5CC- A2 03
C5CE- BD 08 01
C5D1- 9D D8 00
C5D4- CA
C5D5- 10 F7

                    0370          MV4 (FMRACK FOPLSW)

C5D7- A2 03
C5D9- BD 0C 01
C5DC- 9D E0 00
C5DF- CA
C5E0- 10 F7

C5E2- 20 2F DD      0380          JSR FPMULT
                    0390          MV4 (C13N FOPLSW)

C5E5- A2 03
C5E7- BD AC CD
C5EA- 9D E0 00
C5ED- CA
C5EE- 10 F7

C5F0- 20 2F DD      0400          JSR FPMULT
                    0410          MV4 (FPTEMP FOPLSW)

C5F3- A2 03
C5F5- BD 00 01
C5F8- 9D E0 00
C5FB- CA
C5FC- 10 F7

C5FE- 20 C7 DC      0420          JSR FPADD
                    0430          MV4 (FPLSW FMFF)
```

```
C601- A2 03
C603- BD D8 00
C606- 9D 14 01
C609- CA
C60A- 10 F7
C60C- 60                        RTS

           ;PUT 'IHFFHAT.P'
                                .FI 'IHNEWVAL.P'


0B26  37D3-42F9  IHNEWVAL.P

           ;PUT 'IHNEWVAL.P'
           ; *** GEAR RATIO IS RATIO OF RPME OVER RPMT ***
           ; *** TO KEEP INTEGER NUMBERS ***
           GRCHK
C60D- A9 00                     LDA #0
C60F- A2 56                     LDX #COUNT3-FMGR
           GRC
C611- 9D 1C 01                  STA FMGR,X            ;ZERO
C614- CA                        DEX
C615- 10 FA                     BPL GRC
                                MV3N (MRPMEX)

C617- AC 14 00
C61A- AE 15 00
C61D- AD 16 00
C620- 20 23 C1

                                MV4 (FPLSW FOPLSW)

C623- A2 03
C625- BD D8 00
C628- 9D E0 00
C62B- CA
C62C- 10 F7

                                MV3N (MRPMTX)

C62E- AC 11 00
C631- AE 12 00
C634- AD 13 00
C637- 20 23 C1

C63A- 20 A5 DD                  JSR FPDIV
                                MV4 (FPLSW FMGR) ;STORE MINUTE GEAR RATIO

C63D- A2 03
C63F- BD D8 00
C642- 9D 10 01
C645- CA
C646- 10 F7

           GRCALC
C648- A9 10                     LDA #16               ;LOAD WITH HIGH GEAR
C64A- 85 78                     STA *NGR
           LOWER
C64C- C6 78                     DEC *NGR
C64E- 10 01                     BPL LOW
C650- 60                        RTS
           LOW
C651- A5 78                     LDA *NGR
                                MV4I (FGEARS FOPLSW)

C653- 0A
C654- 0A
C655- A8
C656- A2 00
C658- B9 0C D0
C65B- 95 E0
C65D- C8
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```
C65E- E8
C65F- E0 04
C661- D0 F5

C663- 18          0241            CLC
C664- A9 01       0242            LDA #$01
C666- 65 DA       0243            ADC *FPMSW
C668- 85 DA       0244            STA *FPMSW
                  0250            MV4 (FMGR FPLSW)

C66A- A2 03
C66C- BD 10 01
C66F- 9D D8 00
C672- CA
C673- 10 F7

C675- 20 C0 DC    0260            JSR FPSUB          ;COMPARE MIN. AVG. TO GEAR
C678- A5 DA       0270            LDA *FPMSW         ;IS G.R. LOWER
C67A- 30 D0       0280            BMI LOWER          ;YES
C67C- A5 78       0290            LDA *NGR
C67E- 85 77       0300            STA *MGEAR         ;NO. STORE GEAR NUMBER
C680- 60          0305            RTS
                  0310 NXTGR
C681- E6 78       0320            INC *NGR
C683- A9 0C       0330            LDA #12            ;THIS IS MAX FIELD GEAR
C685- C5 78       0340            CMP *NGR
C687- B0 01       0350            BCS =+2
C689- 60          0360            RTS
                  0370            MV4 (FMRPMT FPLSW)

C68A- A2 03
C68C- BD 04 01
C68F- 9D D8 00
C692- CA
C693- 10 F7

C695- A5 78       0380            LDA *NGR
                  0390            MV4I (FGEARS FOPLSW)

C697- 0A
C698- 0A
C699- A8
C69A- A2 00
C69C- B9 0C D0
C69F- 95 E0
C6A1- C8
C6A2- E8
C6A3- E0 04
C6A5- D0 F5

C6A7- 20 2F DD    0400            JSR FPMULT         ;CALC. NEW RPME
                  0410            MV4 (FPLSW FNRE) ;STORE NEW RPME

C6AA- A2 03
C6AC- BD D8 00
C6AF- 9D 20 01
C6B2- CA
C6B3- 10 F7

                  0420            MV4 (FLRE FOPLSW)

C6B5- A2 03
C6B7- BD D0 CD
C6BA- 9D E0 00
C6BD- CA
C6BE- 10 F7

C6C0- 20 C0 DC    0430            JSR FPSUB
C6C3- A5 DA       0440            LDA *FPMSW
C6C5- 30 01       0450            BMI =+2
C6C7- 60          0460            RTS
                  0470 NRACHAT
                  0520            MV4 (FMHP FPLSW)

C6C8- A2 03
C6CA- BD 18 01
C6CD- 9D D8 00
C6D0- CA
```

```
C6D1-  10 F7

                 0530          MV4 (C16M FOPLSW)

C6D3-  A2 03
C6D5-  BD B8 CD
C6D8-  9D E0 00
C6DB-  CA
C6DC-  10 F7

C6DE-  20 2F DD  0540          JSR FPMULT
                 0550          MV4 (FPLSW FPTEMP)

C6E1-  A2 03
C6E3-  BD D8 00
C6E6-  9D 00 01
C6E9-  CA
C6EA-  10 F7

                 0560          MV4 (FMRE FPLSW)

C6EC-  A2 03
C6EE-  BD 20 01
C6F1-  9D D8 00
C6F4-  CA
C6F5-  10 F7

                 0570          MV4 (C15M FOPLSW)

C6F7-  A2 03
C6F9-  BD B4 CD
C6FC-  9D E0 00
C6FF-  CA
C700-  10 F7

C702-  20 2F DD  0580          JSR FPMULT
                 0590          MV4 (FPTEMP FOPLSW)

C705-  A2 03
C707-  BD 00 01
C70A-  9D E0 00
C70D-  CA
C70E-  10 F7

C710-  20 C7 DC  0600          JSR FPADD
                 0620          MV4 (C14M FOPLSW)

C713-  A2 03
C715-  BD B0 CD
C718-  9D E0 00
C71B-  CA
C71C-  10 F7

C71E-  20 C7 DC  0630          JSR FPADD
                 0640          MV4 (FPLSW FPTEMP)

C721-  A2 03
C723-  BD D8 00
C726-  9D 00 01
C729-  CA
C72A-  10 F7

                 0650          MV4 (FMRE FPLSW)

C72C-  A2 03
C72E-  BD 20 01
C731-  9D D8 00
C734-  CA
C735-  10 F7

                 0660          MV4 (FMRE FOPLSW)

C737-  A2 03
C739-  BD 20 01
C73C-  9D E0 00
C73F-  CA
C740-  10 F7
```

```
C742- 20 2F DD          JSR FPMULT
                        MV4 (C17M FOPLSW)

C745- A2 03
C747- BD BC CD
C74A- 9D E0 00
C74D- CA
C74E- 10 F7

C750- 20 2F DD          JSR FPMULT
                        MV4 (FPTEMP FOPLSW)

C753- A2 03
C755- BD 00 01
C758- 9D E0 00
C75B- CA
C75C- 10 F7

C75E- 20 C7 DC          JSR FPADD
                        MV4 (FPLSW FPTEMP)

C761- A2 03
C763- BD D8 00
C766- 9D 00 01
C769- CA
C76A- 10 F7

                        MV4 (FMMP FPLSW)

C76C- A2 03
C76E- BD 18 01
C771- 9D D8 00
C774- CA
C775- 10 F7

                        MV4 (FMRE FOPLSW)

C777- A2 03
C779- BD 20 01
C77C- 9D E0 00
C77F- CA
C780- 10 F7

C782- 20 2F DD          JSR FPMULT
                        MV4 (C18M FOPLSW)

C785- A2 03
C787- BD C0 CD
C78A- 9D E0 00
C78D- CA
C78E- 10 F7

C790- 20 2F DD          JSR FPMULT
                        MV4 (FPTEMP FOPLSW)

C793- A2 03
C795- BD 00 01
C798- 9D E0 00
C79B- CA
C79C- 10 F7

C79E- 20 C7 DC          JSR FPADD
                        MV4 (FPLSW FMRAC)

C7A1- A2 03
C7A3- BD D8 00
C7A6- 9D 24 01
C7A9- CA
C7AA- 10 F7

                        MV4 (FLRAC FOPLSW)

C7AC- A2 03
C7AE- BD D4 CD
C7B1- 9D E0 00
C7B4- CA
C7B5- 10 F7
```

```
C7B7- 20 C0 DC  0820             JSR FPSUB
C7BA- AD DA 00  0830             LDA FPMSW
C7BD- 10 01     0840             BPL =+2
C7BF- 60        0850             RTS
                0860 NFFMAT
                0870             MV4 (C9N FPLSW)

C7C0- A2 03
C7C2- BD 9C CD
C7C5- 9D D8 00
C7C8- CA
C7C9- 10 F7

                0880             MV4 (FMRE FOPLSW)

C7CB- A2 03
C7CD- BD 20 01
C7D0- 9D E0 00
C7D3- CA
C7D4- 10 F7

C7D6- 20 2F DD  0890             JSR FPMULT
                0900             MV4 (C8N FOPLSW)

C7D9- A2 03
C7DB- BD 98 CD
C7DE- 9D E0 00
C7E1- CA
C7E2- 10 F7

C7E4- 20 C7 DC  0910             JSR FPADD
                0920             MV4 (FPLSW FPTEMP)

C7E7- A2 03
C7E9- BD D8 00
C7EC- 9D 00 01
C7EF- CA
C7F0- 10 F7

                0921             MV4 (FMRAC FOPLSW)

C7F2- A2 03
C7F4- BD 24 01
C7F7- 9D E0 00
C7FA- CA
C7FB- 10 F7

                0930             MV4 (C10N FPLSW)

C7FD- A2 03
C7FF- BD A0 CD
C802- 9D D8 00
C805- CA
C806- 10 F7

C808- 20 2F DD  0950             JSR FPMULT
                0960             MV4 (FPTEMP FOPLSW)

C80B- A2 03
C80D- BD 00 01
C810- 9D E0 00
C813- CA
C814- 10 F7

C816- 20 C7 DC  0970             JSR FPADD
                0980             MV4 (FPLSW FPTEMP)

C819- A2 03
C81B- BD D8 00
C81E- 9D 00 01
C821- CA
C822- 10 F7

                0990             MV4 (FMRE FOPLSW)

C824- A2 03
C826- BD 20 01
C829- 9D E0 00
```

```
C82C- CA
C82D- 10 F7

                  1000            MV4 (FMRE FPLSW)

C82F- A2 03
C831- BD 20 01
C834- 9D D8 00
C837- CA
C838- 10 F7

C83A- 20 2F DD    1010            JSR FPMULT
                  1020            MV4 (C11N FOPLSW)

C83D- A2 03
C83F- BD A4 CD
C842- 9D E0 00
C845- CA
C846- 10 F7

C848- 20 2F DD    1030            JSR FPMULT
                  1040            MV4 (FPTEMP FOPLSW)

C84B- A2 03
C84D- BD 00 01
C850- 9D E0 00
C853- CA
C854- 10 F7

C856- 20 C7 DC    1050            JSR FPADD
                  1060            MV4 (FPLSW FPTEMP)

C859- A2 03
C85B- BD D8 00
C85E- 9D 00 01
C861- CA
C862- 10 F7

                  1070            MV4 (FMRAC FPLSW)

C864- A2 03
C866- BD 24 01
C869- 9D D8 00
C86C- CA
C86D- 10 F7

                  1080            MV4 (FMRAC FOPLSW)

C86F- A2 03
C871- BD 24 01
C874- 9D E0 00
C877- CA
C878- 10 F7

C87A- 20 2F DD    1090            JSR FPMULT
                  1100            MV4 (C12N FOPLSW)

C87D- A2 03
C87F- BD A8 CD
C882- 9D E0 00
C885- CA
C886- 10 F7

C888- 20 2F DD    1110            JSR FPMULT
                  1120            MV4 (FPTEMP FOPLSW)

C88B- A2 03
C88D- BD 00 01
C890- 9D E0 00
C893- CA
C894- 10 F7

C896- 20 C7 DC    1130            JSR FPADD
                  1140            MV4 (FPLSW FPTEMP)

C899- A2 03
C89B- BD D8 00
C89E- 9D 00 01
```

```
C8A1- CA
C8A2- 10 F7

                 1150           MV4 (FNRE FPLSW)

C8A4- A2 03
C8A6- BD 20 01
C8A9- 9D D8 00
C8AC- CA
C8AD- 10 F7

                 1160           MV4 (FNRAC FOPLSW)

C8AF- A2 03
C8B1- BD 24 01
C8B4- 9D E0 00
C8B7- CA
C8B8- 10 F7

C8BA- 20 2F DD   1170           JSR FPMULT
                 1180           MV4 (C13N FOPLSW)

C8BD- A2 03
C8BF- BD AC CD
C8C2- 9D E0 00
C8C5- CA
C8C6- 10 F7

C8C8- 20 2F DD   1190           JSR FPMULT
                 1200           MV4 (FPTEMP FOPLSW)

C8CB- A2 03
C8CD- BD 00 01
C8D0- 9D E0 00
C8D3- CA
C8D4- 10 F7

C8D6- 20 C7 DC   1210           JSR FPADD
                 1220           MV4 (FPLSW FNFF)

C8D9- A2 03
C8DB- BD D8 00
C8DE- 9D 28 01
C8E1- CA
C8E2- 10 F7

                 1230 SVVAL
                 1240 ;THIS ROUTINE TAKES THE FP CALCULATED VALUES
                 1250 ;AND CONVERTS THEM TO BINARY NUMBERS AND
                 1260 ;STORES THE VALUES IN A TABLE STARTING AT BFF
                 1270           MV4 (FP10 FOPLSW)

C8E4- A2 03
C8E6- BD 00 D0
C8E9- 9D E0 00
C8EC- CA
C8ED- 10 F7

C8EF- 20 2F DD   1280           JSR FPMULT            ;CONVERT TO TENTHS
C8F2- 20 37 C9   1290           JSR FTOB
C8F5- A5 DA      1300           LDA *FPMSW
C8F7- A6 78      1310           LDX *NGR
C8F9- 9D 42 01   1320           STA BFF,X
                 1330           MV4 (FNRE FOPLSW)

C8FC- A2 03
C8FE- BD 20 01
C901- 9D E0 00
C904- CA
C905- 10 F7

                 1340           MV4 (FP100 FPLSW)

C907- A2 03
C909- BD C4 CD
C90C- 9D D8 00
C90F- CA
C910- 10 F7
```

```
C912- 20 A5 DD  1350            JSR FPDIV          ;CONVERT TO RPM*100
C915- 20 37 C9  1360            JSR FTOB
C918- A5 DA     1370            LDA *FPMSW
C91A- A6 78     1380            LDX *NGR
C91C- 9D 52 01  1390            STA BRE,X
                1400            MV4 (FMRAC FPLSW)

C91F- A2 03
C921- BD 24 01
C924- 9D D8 00
C927- CA
C928- 10 F7

C92A- 20 37 C9  1410            JSR FTOB
C92D- A5 DA     1420            LDA *FPMSW
C92F- A6 78     1430            LDX *NGR
C931- 9D 62 01  1440            STA BRAC,X
C934- 4C 81 C6  1450            JMP NXTGR
                1470 ;    *******MOVE THIS TO THE FP ROUTINES********
                1480 FTOB
C937- A5 DB     1490            LDA *FPACCE        ;THIS ROUTINE CONVERTS A F
C939- 38        1491            SEC
C93A- E9 08     1500            SBC #8             ;IN FPACCUMILATOR TO A BIN
C93C- B0 0A     1510            BCS OVRFLO         ; OF THE FPMANTESSA
C93E- AA        1520            TAX
                1530 LABELA
C93F- E8        1540            INX
C940- D0 01     1550            BNE =+2
C942- 60        1560            RTS
C943- 46 DA     1570            LSR *FPMSW
C945- 4C 3F C9  1580            JMP LABELA
                1590 OVRFLO
C948- A9 99     1591            LDA #$99
C94A- 60        1600            RTS
                1610 ;PUT 'IHNEWVAL.P'
                0250            .FI 'IHFUEL.P'



0761  37D3-3F34  IHFUEL.P

                0010 ;PUT 'IHFUEL.P'
                0020 ;   *********THIS ROUTINE GETS THE MINIMUM FUEL USAGE******
                0030 ;   **********AND CHECKES TO SEE IF IT SHOULD BE OUTPUT*****
                0040 FUELSAV
C94B- A9 FF     0050            LDA #$FF
C94D- 8D 30 01  0060            STA BMFF           ;SET THE MINIMUM FUEL HIGH
C950- A6 78     0070            LDX *NGR           ;START IN HIGHEST GEAR
                0080 FUELSA
C952- CA        0090            DEX                ;ARE WE OUT OF GEARS
C953- EC 77 00  0100            CPX NGEAR
C956- 90 13     0110            BCC FUELS          ;YES
C958- BD 42 01  0120            LDA BFF,X          ;NO
C95B- F0 F5     0130            BEQ FUELSA         ;NO FF VALUE
C95D- CD 30 01  0140            CMP BMFF           ;IS IT LESS THAN PRESENT V
C960- B0 F0     0150            BCS FUELSA         ;NO
C962- 8D 30 01  0160            STA BMFF           ;YES, SO STORE
C965- 8E 31 01  0170            STX BMFG           ;SAVE MINIMUM FF GEAR
C968- 4C 52 C9  0180            JMP FUELSA
                0190 FUELS
C96B- AE 31 01  0200            LDX BMFG           ;GET OPTIMUM GEAR
C96E- D0 01     0210            BNE FUEL
C970- 60        0220            RTS
                0230 FUEL
C971- CA        0240            DEX                ;GET NEXT LOWER GEAR
C972- BD 42 01  0250            LDA BFF,X
C975- F0 0B     0260            BEQ FUE-1
C977- 38        0270            SEC
C978- ED 30 01  0280            SBC BMFF           ;DOES HIGHEST GEAR HAVE EN
C97B- F0 06     0290            BEQ FUE            ;NO
C97D- CD D9 CD  0300            CMP MFFG
C980- 90 01     0310            BCC FUE            ;NO
C982- E8        0320            INX                ;YES
                0330 FUE
```

```
C983- 86 78     0340            STX *NGR             ;STORE NEW GEAR RATIO
C985- BD DA CD  0350            LDA GRTAB,X
C988- A6 1D     0360            LDX *OUTPNT
C98A- 95 64     0370            STA *OGR,X           ;RECORD OUTPUT GR
C98C- A6 78     0380            LDX *NGR
C98E- BD 52 01  0390            LDA BRE,X
C991- F0 5A     0400            BEQ NOOUT
C993- 20 FE C9  0410            JSR BTOD
C996- A6 1D     0420            LDX *OUTPNT
C998- 95 5A     0430            STA *ORPM,X          ;STORE OUTPUT RPM
                0440 FU
                0450            MV4 (FMFF FPLSW) ;GET LAST MINUTE FUEL FLOW

C99A- A2 03
C99C- BD 14 01
C99F- 9D D8 00
C9A2- CA
C9A3- 10 F7

                0460            MV4 (FP10 FOPLSW)

C9A5- A2 03
C9A7- BD 00 D0
C9AA- 9D E0 00
C9AD- CA
C9AE- 10 F7

C9B0- 20 2F DD  0470            JSR FPMULT
C9B3- 20 37 C9  0480            JSR FTOB
C9B6- A5 DA     0490            LDA *FPMSW
C9B8- 20 FE C9  0500            JSR BTOD
C9BB- A6 1D     0510            LDX *OUTPNT
C9BD- 95 46     0520            STA *OFF,X           ;STORE OUTPUT FUEL FLOW
C9BF- 38        0530            SEC
C9C0- A6 78     0540            LDX *NGR
C9C2- A5 DA     0550            LDA *FPMSW           ;GET BINARY FF FOR LAST MI
C9C4- FD 42 01  0560            SBC BFF,X
C9C7- 20 FE C9  0570            JSR BTOD
C9CA- A6 1D     0580            LDX *OUTPNT
C9CC- 95 50     0590            STA *OFS,X           ;STORE OUTPUT FF SAVINGS
C9CE- D5 46     0600            CMP *OFF,X
C9D0- 10 1B     0610            BPL NOOUT
C9D2- CD D8 CD  0620            CMP MFFC             ;IS THERE ENOUGH SAVINGS
C9D5- 90 16     0630            BCC NOOUT            ;NO
C9D7- A9 80     0640            LDA #$80             ;YES
C9D9- 05 74     0650            ORA *DISPFLG
C9DB- 85 74     0660            STA *DISPFLG
C9DD- E6 74     0670            INC *DISPFLG
C9DF- A5 1D     0680            LDA *OUTPNT
C9E1- 0A        0690            ASL A
C9E2- AA        0700            TAX
C9E3- A5 72     0710            LDA *DAY+4
C9E5- 95 1E     0720            STA *OUTTIME,X
C9E7- E8        0730            INX
C9E8- A5 73     0740            LDA *DAY+5
C9EA- 95 1E     0750            STA *OUTTIME,X
C9EC- 60        0760            RTS
                0770 NOOUT
C9ED- A9 7F     0780            LDA #$7F
C9EF- 25 74     0790            AND *DISPFLG
C9F1- 85 74     0800            STA *DISPFLG
C9F3- 60        0810            RTS
                0820 CLRMINSM
C9F4- A9 00     0830            LDA #0
C9F6- A2 0E     0840            LDX #14
                0850 CLRME
C9F8- 95 0E     0860            STA *SFLG2,X
C9FA- CA        0870            DEX
C9FB- 10 FB     0880            BPL CLRME
C9FD- 60        0890            RTS
                0900 BTOD
C9FE- 38        0910            SEC
C9FF- A2 FF     0920            LDX #$FF             ;FOR COMPENSATION
CA01- E8        0930            INX
CA02- E9 64     0940            SBC #100             ;SUBTRACT 100
CA04- B0 FB     0950            BCS BTOD+3
CA06- 69 64     0960            ADC #100             ;ADD BACK 100.
CA08- 48        0970            PHA
```

0B8E 3703-4361 IHSHOW.S

```
                 ;PUT 'IHSHOW.S'

                 ;DISPLAY ROUTINE. THIS ROUTINE
                 ;WILL DISPLAY ONE VALUE OR CYCLE
                 ;THROUGH ALL VALUES ON DEMAND.
                 ;INDIVIDUAL ROUTINES ARE CALLED FROM
                 ;JUMPTABLE TO PUT THE DIFFERENT
                 ;PARAMETERS INTO THE DISPLAY BUFFER
                 ;
                 SHOW
CA72- 20 86 8B           JSR ACCESS
CA75- A5 83              LDA *DISCNT
CA77- 0A                 ASL A            ;MULT BY 2
CA78- AA                 TAX
CA79- BD 42 CB           LDA JMPTAB,X     ;GET ROUTINE ADDRESS
CA7C- 85 85              STA *JMPVEC
CA7E- BD 43 CB           LDA JMPTAB+1,X   ;2ND BYTE
CA81- 85 86              STA *JMPVEC+1
CA83- C9 FF              CMP #$FF
CA85- D0 08              BNE AHEAD
CA87- A9 00              LDA #$00
CA89- 85 83              STA *DISCNT      ;START AT ZERO IF AT END
CA8B- 85 84              STA *DISCNT+1
CA8D- F0 E3              BEQ SHOW
                 AHEAD
CA8F- 78                 SEI
CA90- 20 A3 CA           JSR SHOWDISP
CA93- 58                 CLI
CA94- 90 10              BCC SHOWLOOP     ;VALID IF CARRY CLEAR
CA96- A9 00              LDA #$00
CA98- 85 84              STA *DISCNT+1    ;INCREMENT TO NEXT #
CA9A- C5 87              CMP *CYCLE
CA9C- D0 D4              BNE SHOW         ;SAME ROUTINE IF NONZERO
CA9E- E6 83              INC *DISCNT
CAA0- 4C 72 CA           JMP SHOW
                 SHOWDISP
CAA3- 6C 85 00           JMP (JMPVEC)     ;PUT VALUES IN DISPLAY BUF
                 SHOWLOOP
CAA6- 20 B2 CA           JSR LOOP         ;DISPLAY VALUES
CAA9- 24 87              BIT *CYCLE
CAAB- 30 C5              BMI SHOW
CAAD- E6 84              INC *DISCNT+1
CAAF- 4C 72 CA           JMP SHOW
                 ;
                 ;THIS ROUTINE SCANS DISPLAY WITH
                 ;VALUES STORED IN DISPLAY BUFFER
                 ;
                 LOOP
CAB2- A5 82              LDA *DISVEL      ;DISPLAY VELOCITY
CAB4- 85 89              STA *LCNT2
                 LOOP1
CAB6- A9 38              LDA #56
CAB8- 85 88              STA *LCNT1
                 LOOP2
CABA- 20 06 89           JSR SCAND        ;SCAN DISPLAY
CABD- D0 0D              BNE KEY          ;IF KEY DEPRESSED, KEY
CABF- A9 28              LDA #40
CAC1- 85 8A              STA *KEYCNT
CAC3- C6 88              DEC *LCNT1
CAC5- D0 F3              BNE LOOP2
CAC7- C6 89              DEC *LCNT2
CAC9- D0 EB              BNE LOOP1
CACB- 60                 RTS
                 ;
                 ;KEY ROUTINE. CHECKS FOR VALID
                 ;KEY INPUTS, AND DETERMINES WHAT
                 ;KEY IS DEPRESSED.
                 ;
                 KEY
CACC- C6 8A              DEC *KEYCNT
CACE- D0 EA              BNE LOOP2
CAD0- A9 FF              LDA #$FF
CAD2- 85 87              STA *CYCLE       ;STOP CYCLING
```

```
CAD4- 20 20 82                 JSR PARM                ;GET PARAMETERS
CAD7- D0 1C                    BNE KEY2                ;CRT NO,KEY2
CAD9- AE 49 A6                 LDX PARNR               ;GET NUMBER OF PARAMETERS
CADC- F0 52                    BEQ GOMON               ;IF NO PARAM THEN GOTO MON
CADE- AD 4A A6                 LDA PARN
CAE1- 85 84                    STA *DISCNT+1
CAE3- CA                       DEX
CAE4- D0 01                    BNE =+2                 ;IF NOT 0 SKIP RTS STATEME
CAE6- 60                       RTS
CAE7- AD 4C A6                 LDA PARN+2
CAEA- 0A                       ASL A                   ;MULT BY 2
CAEB- C9 0A                    CMP #L,NUCHAN           ;OUT OF RANGE?
CAED- 30 02                    BMI =+3
CAEF- 10 2D                    BPL ERROR1
CAF1- 4A                       LSR A
CAF2- 85 83                    STA *DISCNT             ;SET ROUTINE #
CAF4- 60                       RTS
                    KEY2
CAF5- C9 3C                    CMP #'<                 ;BACK UP ONE CHANNEL
CAF7- D0 07                    BNE =+8
CAF9- A6 84                    LDX *DISCNT+1           ;DON'T DEC IF ZERRO
CAFB- F0 02                    BEQ =+3
CAFD- C6 84                    DEC *DISCNT+1
CAFF- 60                       RTS
CB00- C9 3E                    CMP #'>                 ;NEXT CHANNEL
CB02- D0 03                    BNE =+4
CB04- E6 84                    INC *DISCNT+1
CB06- 60                       RTS
CB07- C9 4D                    CMP #'M                 ;STOP CYCLING
CB09- D0 01                    BNE =+2
CB0B- 60                       RTS
CB0C- C9 52                    CMP #'R                 ;CYCLE ONLY ONE TYPE
CB0E- D0 05                    BNE =+6
CB10- A9 40                    LDA #$40
CB12- 85 87                    STA *CYCLE
CB14- 60                       RTS
CB15- C9 47                    CMP #'G                 ;CYCLE ON EVERYTHING
CB17- D0 05                    BNE ERROR1
CB19- A9 00                    LDA #$00
CB1B- 85 87                    STA *CYCLE
CB1D- 60                       RTS
                    ;
                    ERROR1
CB1E- A2 05                    LDX #$5
                    ERRMES
CB20- BD 4C CB                 LDA ERRTAB,X
CB23- 9D 40 A6                 STA DISBUF,X
CB26- CA                       DEX
CB27- 10 F7                    BPL ERRMES
CB29- A9 80                    LDA #$80
CB2B- 85 89                    STA $LCNT2
CB2D- 4C B6 CA                 JMP LOOP1
                    ;
                    GOMON
CB30- 38                       SEC
CB31- 68                       PLA                     ;PULL LOOP RETURN
CB32- 68                       PLA
CB33- 68                       PLA                     ;SHOW RETURN
CB34- E9 02                    SBC #$02                ;BACKUP TO CALL
CB36- 8D 59 A6                 STA GOVEC
CB39- 68                       PLA
CB3A- E9 00                    SBC #$00                ;SUB ANY BORROW
CB3C- 8D 5A A6                 STA GOVEC+1
CB3F- 4C 00 80                 JMP MONITOR             ;GO CR WILL CONT.
                    JMPTAB
CB42- A0 CB                    .SE CLOCKDISPLAY
CB44- 52 CB                    .SE DATADISPLAY
CB46- FF FF                    .SE $FFFF
CB48- 90 CB                    .SE MEMDISP
CB4A- FF FF                    .SE $FFFF
                    NUCHAN     .DE =-JMPTAB
CB4C- 79 50 50      ERRTAB     .BY $79 $50 $50 $5C $50 $00
CB4F- 5C 50 00

                    DATADISPLAY
CB52- AD 84 00                LDA DISCNT+1
CB55- C9 00                   CMP #0                   ;0: FUEL DISPLAY
CB57- F0 0A                   BEQ FUELDISP
```

```
CB59- C9 01     1510            CMP #$1
CB5B- F0 14     1520            BEQ RPMEDISP
CB5D- C9 02     1530            CMP #$2
CB5F- F0 1E     1540            BEQ RACKDISP
CB61- 38        1550            SEC
CB62- 60        1560            RTS
                1570 FUELDISP
CB63- A9 01     1580            LDA #$01
CB65- 20 FA 82  1590            JSR OUTBYT
CB68- A6 00     1600            LDX *RPMTH
CB6A- A5 01     1610            LDA *RPMTH+1
CB6C- 20 F4 82  1620            JSR OUTXAH
CB6F- 18        1630            CLC                    ;DISCNT OK
CB70- 60        1640            RTS
                1650 RPMEDISP
CB71- A9 02     1660            LDA #$02
CB73- 20 FA 82  1670            JSR OUTBYT
CB76- A6 02     1680            LDX *RPMEH
CB78- A5 03     1690            LDA *RPMEH+1
CB7A- 20 F4 82  1700            JSR OUTXAH
CB7D- 18        1710            CLC                    ;DISCNT OK
CB7E- 60        1720            RTS
                1730 RACKDISP
CB7F- A9 03     1740            LDA #$03
CB81- 20 FA 82  1750            JSR OUTBYT
CB84- A9 00     1760            LDA #0
CB86- 20 FA 82  1770            JSR OUTBYT
CB89- A5 05     1780            LDA *RACKH+1
CB8B- 20 FA 82  1790            JSR OUTBYT
CB8E- 18        1800            CLC
CB8F- 60        1810            RTS
                1820 MEMDISP
CB90- A2 00     1830            LDX #00
CB92- A5 84     1840            LDA *DISCNT+1
CB94- 20 F4 82  1850            JSR OUTXAH
CB97- A6 84     1860            LDX *DISCNT+1
CB99- B5 00     1870            LDA *$00,X
CB9B- 20 FA 82  1880            JSR OUTBYT
CB9E- 18        1890            CLC
CB9F- 60        1900            RTS
                1910
                1920 ;PUT 'IHSHOW.S'
                0280            .FI 'IHCLKSUBS'



0D34  37D3-4507   IHCLKSUBS

                0010 ;PUT 'IHCLKSUBS'
                0020
                0030 CLOCKDISPLAY
CBA0- A5 84     0040            LDA *DISCNT+1
CBA2- C9 00     0050            CMP #$00
CBA4- F0 15     0060            BEQ DATEDISP
CBA6- C9 01     0070            CMP #$01
CBA8- F0 24     0080            BEQ TIMEDISP
CBAA- C9 10     0090            CMP #$10
CBAC- F0 06     0100            BEQ DATEDISP-7
CBAE- C9 11     0110            CMP #$11
CBB0- F0 15     0120            BEQ TIMEDISP-7
CBB2- 38        0130            SEC
CBB3- 60        0140            RTS
                0150
CBB4- 20 14 CC  0160            JSR SETDATE
CBB7- A9 00     0170            LDA #$00               ;RESET CNTR TO DATEDISP
CBB9- 85 84     0180            STA *DISCNT+1
                0190 DATEDISP
CBBB- A5 6F     0200            LDA *DAY+1
CBBD- 20 FA 82  0210            JSR OUTBYT
CBC0- A6 70     0220            LDX *DAY+2
CBC2- A5 6E     0230            LDA *DAY
CBC4- 4C D7 CB  0240            JMP TIMEDISP+9
                0250
CBC7- 20 EC CB  0260            JSR SETIME
CBCA- A9 01     0270            LDA #$01               ;RESET CNTR TO TIMEDISP
```

```
CBCC- 85 84     0280            STA *DISCNT+1
                0290 TIMEDISP
CBCE- A5 71     0300            LDA *DAY+3
CBD0- 20 FA 82  0310            JSR OUTBYT
CBD3- A6 72     0320            LDX *DAY+4
CBD5- A5 73     0330            LDA *DAY+5
CBD7- 20 F4 82  0340            JSR OUTXAH
CBDA- AD 41 A6  0350            LDA DISBUF+1
CBDD- 09 80     0360            ORA #$80
CBDF- 8D 41 A6  0370            STA DISBUF+1
CBE2- AD 43 A6  0380            LDA DISBUF+3
CBE5- 09 80     0390            ORA #$80
CBE7- 8D 43 A6  0400            STA DISBUF+3
CBEA- 18        0410            CLC              ;DISCNT OK
CBEB- 60        0420            RTS
                0430
                0440 ;SET THE TIME HOURS AND MINUTES AND
                0450 ;RESET THE SECONDS TO ZERO
                0460
                0470 SETIME
CBEC- A2 0B     0480            LDX #11
CBEE- 20 EC CC  0490            JSR OUTMSG
CBF1- 20 20 82  0500            JSR PARM         ;GET TIME
CBF4- A9 02     0510            LDA #$02
CBF6- CD 49 A6  0520            CMP PARNR
CBF9- D0 44     0530            BNE READCLOCK
CBFB- A9 04     0540            LDA #$04         ;HOLD
CBFD- 20 A3 CC  0550            JSR STOPCLOCK
CC00- A2 05     0560            LDX #$05
CC02- AD 4C A6  0570            LDA PARN+2       ;HOUR
CC05- 09 80     0580            ORA #$80         ;SET 24 HOUR FORMAT
CC07- 20 82 CC  0590            JSR SETBYTE
CC0A- AD 4A A6  0600            LDA PARN         ;MINUTE
CC0D- 20 82 CC  0610            JSR SETBYTE
CC10- A9 00     0620            LDA #00          ;SECONDS
CC12- F0 25     0630            BEQ READCLOCK-6
                0640
                0650 ;SET THE YEAR,MONTH,AND DAY TO THE CLOCK
                0660 ;WITHOUT THE HOLD.
                0670
                0680 SETDATE
CC14- A2 05     0690            LDX #5
CC16- 20 EC CC  0700            JSR OUTMSG
CC19- 20 20 82  0710            JSR PARM
CC1C- A9 03     0720            LDA #$03
CC1E- CD 49 A6  0730            CMP PARNR
CC21- D0 1C     0740            BNE READCLOCK
CC23- A9 04     0750            LDA #$04         ;HOLD
CC25- 20 A3 CC  0760            JSR STOPCLOCK
CC28- A2 0C     0770            LDX #12
CC2A- AD 4A A6  0780            LDA PARN         ;YEAR
CC2D- 20 82 CC  0790            JSR SETBYTE
CC30- AD 4E A6  0800            LDA PARN+4       ;MONTH
CC33- 20 82 CC  0810            JSR SETBYTE
CC36- AD 4C A6  0820            LDA PARN+2       ;DAY
CC39- 20 82 CC  0830            JSR SETBYTE
CC3C- 20 C6 CC  0840            JSR SETUPCLOCK
                0850
                0860 ;SETIME AND SETDATE FALL THRU TO READCLOCK HERE
                0870 ;SUBROUTINE TO READ TIME FROM CLOCK
                0880 ;AND STORE IT IN 6 BYTES AT DAY
                0890
                0900 READCLOCK
CC3F- A9 06     0910            LDA #$06         ;HOLD & READ
CC41- 20 A3 CC  0920            JSR STOPCLOCK
CC44- A2 05     0930            LDX #5
CC46- A9 00     0940            LDA #0
CC48- 8D 01 A0  0950            STA VIA1+1
CC4B- 20 63 CC  0960            JSR READ3        ;READ HH:MM:SS
CC4E- EE 01 A0  0970            INC VIA1+1       ;SKIP DAY OF WK
CC51- 20 63 CC  0980            JSR READ3        ;READ YY:MM:DD
CC54- A5 71     0990            LDA *DAY+3       ;CLEAR 24 HR FLAG
CC56- 29 3F     1000            AND #$3F
CC58- 85 71     1010            STA *DAY+3
CC5A- A5 70     1020            LDA *DAY+2       ;CLEAR LEAPYEAR FLAG
CC5C- 29 3F     1030            AND #$3F
CC5E- 85 70     1040            STA *DAY+2
CC60- 4C C6 CC  1050            JMP SETUPCLOCK
```

```
                  1060
                  1070 ;READ 3 BYTES OF DATA FROM THE CLOCK
                  1080 ;AND PUT IT AT DAY,X TO DAY,X-2
                  1090 ;LEAVE X = X-3.
                  1100
                  1110 READ3
CC63- A0 03       1120          LDY #$03
CC65- AD 01 A0    1130          LDA VIA1+1
CC68- EE 01 A0    1140          INC VIA1+1          ;NEXT NIBBLE
CC6B- 4A          1150          LSR A
CC6C- 4A          1160          LSR A
CC6D- 4A          1170          LSR A
CC6E- 4A          1180          LSR A
CC6F- 95 6E       1190          STA *DAY,X          ;LOWER NIBBLE
CC71- AD 01 A0    1200          LDA VIA1+1
CC74- EE 01 A0    1210          INC VIA1+1          ;NEXT NIBBLE
CC77- 29 F0       1220          AND #%11110000      ;HIGH NIBBLE
CC79- 15 6E       1230          ORA *DAY,X          ;MERGE NIBBLES
CC7B- 95 6E       1240          STA *DAY,X
CC7D- CA          1250          DEX
CC7E- 88          1260          DEY
CC7F- D0 E4       1270          BNE READ3+2
CC81- 60          1280          RTS
                  1290
                  1300 ;SET 1 BYTE TO CLOCK AT LOCATION IN X
                  1310 ;AND X-1.
                  1320
                  1330 SETBYTE
CC82- 48          1340          PHA
CC83- 29 F0       1350          AND #$F0
CC85- 20 8D CC    1360          JSR =+8
CC88- 68          1370          PLA
CC89- 0A          1380          ASL A
CC8A- 0A          1390          ASL A
CC8B- 0A          1400          ASL A
CC8C- 0A          1410          ASL A
CC8D- 86 6E       1420          STX *DAY            ;USE AS TMP LOC
CC8F- 05 6E       1430          ORA *DAY
CC91- 8D 01 A0    1440          STA VIA1+1
CC94- AD 00 A0    1450          LDA VIA1
CC97- 29 FE       1460          AND #%11111110      ;WRITE PULSE
CC99- 8D 00 A0    1470          STA VIA1            ;WRITE
CC9C- 09 01       1480          ORA #%00000001      ;CLR WRITE(INV)
CC9E- 8D 00 A0    1490          STA VIA1
CCA1- CA          1500          DEX
CCA2- 60          1510          RTS
                  1520
                  1530 ;THIS ROUTINES DISABLES THE INTERRUPTS
                  1540 ;AND SETS THE OUTPUT LINES AS SET IN A
                  1550 ;2 PB IS SET TO OUTPUT IF WRITE FLAG IS SET
                  1560
                  1570 STOPCLOCK
CCA3- 78          1580          SEI
CCA4- 85 6E       1590          STA *DAY
CCA6- A9 10       1600          LDA #$10            ;DISABLE CB1 INT
CCA8- 8D 0E A0    1610          STA VIA1+14         ;DISABLE INTERRUPTS
CCAB- AD 00 A0    1620          LDA VIA1
CCAE- 09 07       1630          ORA #$07            ;SET STATUS BITS
CCB0- 45 6E       1640          EOR *DAY            ;INV NEW STAT BITS
CCB2- 8D 00 A0    1650          STA VIA1
CCB5- A9 02       1660          LDA #$02            ;READ BIT
CCB7- 24 6E       1670          BIT *DAY            ;SET FOR READ?
CCB9- D0 05       1680          BNE =+6
CCBB- A9 FF       1690          LDA #$FF
CCBD- 8D 03 A0    1700          STA VIA1+3          ;ALL OUTPUTS
CCC0- A2 1E       1710          LDX #30             ;DELAY FOR HOLD SETUP
CCC2- CA          1720          DEX
CCC3- D0 FD       1730          BNE =-2
CCC5- 60          1740          RTS
                  1750
                  1760 ;ROUTINE TO SETUP THE VIA'S FOR THE CLOCK
                  1770 ;SUBROUTINES
                  1780
                  1790 SETUPCLOCK
CCC6- AD 00 A0    1800          LDA VIA1
CCC9- 29 F8       1810          AND #%11111000      ;CLR STAT
CCCB- 09 05       1820          ORA #%00000101      ;SET NEG STAT
CCCD- 8D 00 A0    1830          STA VIA1            ;SET READ ONLY MODE
```

```
CCD0- AD 02 A0  1840            LDA VIA1+2
CCD3- 09 07     1850            ORA #%00000111      ;STAT BITS OUT
CCD5- 8D 02 A0  1860            STA VIA1+2
CCD8- A9 0F     1870            LDA #$0F
CCDA- 8D 01 A0  1880            STA VIA1+1          ;SET FOR INTERRUPTS
CCDD- 8D 03 A0  1890            STA VIA1+3          ;DATA DIRECTION REG.
CCE0- A9 10     1900            LDA #$10            ;CB1 INT
CCE2- 8D 0D A0  1910            STA VIA1+13         ;RESET INTERRUPTS
CCE5- A9 90     1920            LDA #$90            ;CB1 INT
CCE7- 8D 0E A0  1930            STA VIA1+14         ;ENABLE INTERRUPTS
CCEA- 58        1940            CLI
CCEB- 60        1950            RTS
                1960
                1970 ;PRINT A MESSAGE ON DISPLAY
                1980
                1990 OUTMSG
CCEC- A0 05     2000            LDY #$05
CCEE- BD F9 CC  2010            LDA OUTMSGS,X
CCF1- 99 40 A6  2020            STA DISBUF,Y
CCF4- CA        2030            DEX
CCF5- 88        2040            DEY
CCF6- 10 F6     2050            BPL OUTMSG+2
CCF8- 60        2060            RTS
                2070
                2080 OUTMSGS
                2090 ;DATE?
CCF9- 00 5E 77  2100            .BY $00 $5E $77 $78 $79 $53
CCFC- 78 79 53
                2110 ;TIME?
CCFF- 00 78 06  2120            .BY $00 $78 $06 $54 $79 $53
CD02- 54 79 53
                2130
                2140 ;PUT 'IHCLKSUBS'
                0290            .FI 'IHSETPORT'
```

0106   37D3-38D9   IHSETPORT

```
                0010 ; SET INPUT PORTS FOR DATA COLLECTION
                0020 SETPORT
CD05- A9 BF     0030            LDA #$BF
CD07- 8D 02 A8  0040            STA VIA2+2          ;RPM TRANS.
CD0A- A9 9F     0050            LDA #$9F
CD0C- 8D 02 AC  0060            STA VIA3+2          ;RPM ENGINE
CD0F- A9 00     0070            LDA #00
CD11- 8D 03 A8  0080            STA VIA2+3
CD14- A9 FF     0085            LDA #$FF
CD16- 8D 03 AC  0090            STA VIA3+3
CD19- A9 20     0140            LDA #$20
CD1B- 8D 0B A8  0150            STA VIA2+11
CD1E- 8D 0B AC  0160            STA VIA3+11
CD21- 0D 0B A0  0170            ORA VIA1+11
CD24- 8D 0B A0  0180            STA VIA1+11
CD27- 60        0190            RTS
                0200
                0210 ;PUT 'IHSETPORT'
                0300            .FI 'IHSTARTCNT'
```

00B0   37D3-3883   IHSTARTCNT

```
                0010 ; PUT 'IHSTARTCNT'
                0020 ; THIS ROUTINE SETS THE COUNTERS TO $FF TO BEGIN COUNTING
CD28- A9 FF     0030 STRTCNT    LDA #$FF
CD2A- 8D 09 A8  0040            STA VIA2+9
CD2D- 8D 08 A8  0050            STA VIA2+8
CD30- 8D 09 AC  0060            STA VIA3+9
CD33- 8D 08 AC  0070            STA VIA3+8
CD36- 60        0080            RTS
                0090 ; PUT 'IHSTARTCNT'
```

```
                 0310            .FI 'IHREADPORT'


0335  37D3-3B08  IHREADPORT

                 0010 ;PU 'IHREADPORT'
                 0020 ; READ DATA FROM PORTS AND STORE IN RAM
                 0030 GTDATA
CD37- AD 09 A8   0040 RPMT         LDA VIA2+9           ; HIGH BYTE OR TRANSMISSIO
CD3A- 85 00      0050              STA *RPMTH
CD3C- AD 08 A8   0060              LDA VIA2+8           ; LOW BIT
CD3F- 85 01      0070              STA *RPMTH+1
CD41- AD 09 A8   0080              LDA VIA2+9
CD44- C5 00      0090              CMP *RPMTH           ; CHECK IF BIT HAS CHANGED
CD46- F0 07      0100              BEQ RPME             ; NO
CD48- 85 00      0120              STA *RPMTH
CD4A- AD 08 A8   0130              LDA VIA2+8
CD4D- 85 01      0140              STA *RPMTH+1
CD4F- AD 09 AC   0150 RPME         LDA VIA3+9           ; HIGH BYTE OF ENGINE
CD52- 85 02      0160              STA *RPMEH
CD54- AD 08 AC   0170              LDA VIA3+8           ; LOW
CD57- 85 03      0180              STA *RPMEH+1
CD59- AD 09 AC   0190              LDA VIA3+9
CD5C- C5 02      0200              CMP *RPMEH           ; CHECK IF BYTE HAS CHANGE
CD5E- F0 07      0210              BEQ LIMIT            ; NO
CD60- 85 02      0230              STA *RPMEH
CD62- AD 08 AC   0240              LDA VIA3+8
CD65- 85 03      0250              STA *RPMEH+1
                 0260 ; THIS ROUTINE GETS THE LIMIT DATA
                 0270 LIMIT
CD67- A9 03      0280              LDA #3
CD69- 2D 00 A8   0290              AND VIA2
CD6C- 8D 06 00   0300              STA LIMITS
                 0310 ; THIS ROUTINE GETS THE RACK DATA AND STORES IT IN RAM
                 0320 GTRAK
CD6F- AD 01 A8   0330              LDA VIA2+1
CD72- 85 05      0340              STA *RACKH+1
CD74- A9 FF      0341              LDA #$FF
CD76- 85 04      0342              STA *RACKH
                 0350 COMP
                 0360 ; THIS ROUTINE COMPLIMENTS THE TIMER DATA AND THE RACK
CD78- A2 05      0365              LDX #5
CD7A- A9 FF      0370              LDA #$FF
CD7C- 55 00      0400              EOR *RPMTH,X
CD7E- 95 00      0410              STA *RPMTH,X
CD80- CA         0420              DEX
CD81- 10 F7      0430              BPL COMP+2
CD83- 60         0440              RTS
                 0450 ;PU 'IHREADPORT'
                 0320              .FI 'IHCONSTANTS.D'


03D5  37D3-3BA8  IHCONSTANTS.D

                 0010 ;PUT 'IHCONSTANTS.D'
                 0020
                 0030 ;  *********THESE ARE EPROM LABLES********
                 0040 ;****THESE SHOULD BE AT END OF PROGRAM IN FORM C1N .BY ##
CD84- C6 CA A7   0050 C1N          .BY $C6 $CA $A7 $05
CD87- 05
CD88- AA 11 70   0060 C2N          .BY $AA $11 $70 $F9
CD8B- F9
CD8C- 35 51 BE   0070 C3N          .BY $35 $51 $BE $FF
CD8F- FF
CD90- 0A 7A 93   0080 C4N          .BY $0A $7A $93 $EF
CD93- EF
CD94- ED 30 78   0090 C5N          .BY $ED $30 $78 $F5
CD97- F5
CD98- FA 53 60   0100 C8N          .BY $FA $53 $60 $04
CD9B- 04
```

```
CD9C- D5 2A 54   C9N          .BY $D5 $2A $54 $F8
CD9F- F8
CDA0- 8B 3E 98   C10N         .BY $8B $3E $98 $FF
CDA3- FF
CDA4- 46 84 B3   C11N         .BY $46 $84 $B3 $ED
CDA7- ED
CDA8- F6 6E 41   C12N         .BY $F6 $6E $41 $F8
CDAB- F8
CDAC- C2 0E 78   C13N         .BY $C2 $0E $78 $F3
CDAF- F3
CDB0- 48 AE 78   C14N         .BY $48 $AE $78 $07
CDB3- 07
CDB4- 92 0B B2   C15N         .BY $92 $0B $B2 $FC
CDB7- FC
CDB8- 37 33 55   C16N         .BY $37 $33 $55 $01
CDBB- 01
CDBC- 7C 5A 60   C17N         .BY $7C $5A $60 $EF
CDBF- EF
CDC0- 89 3B A7   C18N         .BY $89 $3B $A7 $F4
CDC3- F4
CDC4- 00 00 6E   FP100        .BY $00 $00 $6E $08 ;100*132/60
CDC7- 08
CDC8- 02         HLRPMTH      .BY $02
CDC9- BC         HLRPMTL      .BY $BC
CDCA- 00         LLRPMTH      .BY $00
CDCB- 8C         LLRPMTL      .BY $8C
CDCC- 05         LRPMEH       .BY $05
CDCD- 78         LRPMEL       .BY $78
CDCE- 00 8C      LRACKH       .BY $00 $8C
CDD0- 00 00 6A   FLRE         .BY $00 $00 $6A $0C ;1500 RPM
CDD3- 0C
CDD4- 00 00 41   FLRAC        .BY $00 $00 $41 $08
CDD7- 08
CDD8- 05         MFFC         .BY $05
CDD9- 02         MFFG         .BY $02

CDDA- 15 16 25   GRTAB        .BY $15 $16 $25 $26
CDDD- 26
CDDE- 45 46 85                .BY $45 $46 $85 $86
CDE1- 86
CDE2- 19 1A 29                .BY $19 $1A $29 $2A
CDE5- 2A
CDE6- 49 4A 89                .BY $49 $4A $89 $8A
CDE9- 8A

                 ;PUT 'IHCONSTANTS.D'
                 ; TO SAVE SPACE ONLY USE GEARS
                 ; 3-12 AND CHECK OUT OF RANGE
                              .EN
END OF MAE PASS!

 ---  LABEL FILE:  ---

@MOVEDATA =C39C          ACCESS =8B86             AHEAD =CA8F
AVG4 =C202               BEEP =8972               BFF =0142
BFFS =0132               BINARY =C10F             BLMFF =012C
BMFF =0130               BMFG =0131               BRAC =0162
BRE =0152                BTOD =C9FE               C10N =CDA0
C11N =CDA4               C12N =CDA8               C13N =CDAC
C14N =CDB0               C15N =CDB4               C16N =CDB8
C17N =CDBC               C18N =CDC0               C1N =CD84
C2N =CD88                C3N =CD8C                C4N =CD90
C5N =CD94                C8N =CD98                C9N =CD9C
CALCG =C17B              CGR =C190                CH =C0D4
CHF =C0D7                CKLIMIT =C134            CKMRK =C256
CLOCKDISPLAY =CBA0       CLRDA =C3F3              CLRDATA =C3EF
CLRME =C9F8              CLRMINSM =C9F4           CLRMRK =C26C
CLRSA =C3FD              CLRSAVE =C3F9            CLRSECSM =C2A6
CLS =C2AA                CNT2 =C2A3               CNTR =00D4
COMP =CD78               COUNT1 =000D             COUNT2 =001A
COUNT3 =0172             CYCLE =0087              DATADISPLAY =CB52
DATAEND =007A            DATASTART =007C          DATEDISP =CBBB
DAY =006E                DGR =0079                DISBUF =A640
DISCNT =0083             DISPFLG =0074            DISVEL =0082
DOWNSHIFT =C140          ENDINT =C109             EPROM2 =D000
ERRMES =CB20             ERROR1 =CB1E             ERRTAB =CB4C
ESUM =C286               FFMAT =C4E8              FGEARS =D00C
FLG3 =C235               FLGTIME =0173            FLRAC =CDD4
```

```
FLRE =CDD0            FMFF =0114            FMGR =0110
FMHP =0118            FMPNT =00D0           FMRACK =010C
FMRPME =0108          FMRPMT =0104          FNFF =0128
FNGR =011C            FNRAC =0124           FNRE =0120
FNSGR =017B           FOLSWE =00DF          FOPEXP =00E3
FOPLSW =00E0          FOPMSW =00E2          FOPNSW =00E1
FOUR =C07E            FOURSUM =C273         FP10 =D000
FP100 =CDC4           FPACCE =00DB          FPADD =DCC7
FPBASE =DC00          FPDISP =DF23          FPDIV =DDA5
FPLSW =00D8           FPLSWE =00D7          FPMSW =00DA
FPMULT =DD2F          FPNORM =DC24          FPNSW =00D9
FPOUT =DE57           FPSUB =DCC0           FPTEMP =0100
FSGR =0177            FTOB =C937            FU =C99A
FUE =C983             FUEL =C971            FUELDISP =CB63
FUELS =C96B           FUELSA =C952          FUELSAV =C94B
FULL =008B            GEAR =0176            GOMOM =CB30
GOVEC =A659           GRC =C611             GRCALC =C648
GRCH =C1F9            GRCHG =C1EE           GRCHK =C60D
GRTAB =CDDA           GRZ =C187             GTDATA =CD37
GTRAK =CD6F           HLRPMTH =CDC8         HLRPMTL =CDC9
HPHAT =C403           HTOK =C220            I1TOF =C11F
I2TOF =C121           I3TOF =C123           INI3 =C03B
INIT =C01A            INIT1 =C01D           INIT2 =C025
INIT3 =C037           INITVAL =C047         INPRDI =00E7
INTERRUPT =C050       INTVEC =A678          IOEXPD =00E5
IOSIGN =00E4          JMPTAB =CB42          JMPVEC =0085
KEY =CACC             KEY2 =CAF5            KEYCNT =008A
L =00E7               LABELA =C93F          LASTSEC =008D
LATCH =008F           LCNT1 =0088           LCNT2 =0089
LENGTH =0080          LIM =C14D             LIMIT =CD67
LIMITS =0006          LLRPMTH =CDCA         LLRPMTL =CDCB
LOOP =CAB2            LOOP1 =CAB6           LOOP2 =CABA
LOW =C651             LOWER =C64C           LRACKH =CDCE
LRPMEH =CDCC          LRPMEL =CDCD          MAIN =C000
MEMDISP =CB90         MEMEND =007E          MFFC =CDD8
MFFG =CDD9            MFLG =001B            MGEAR =0077
MINAVE =C2C3          MON =8003             MONITOR =8000
MOVECLOCK =C3CA       MOVEDATA =C36C        MOVEO =C3E3
MOVEOU =C3D9          MOVEOUT =C3D7         MRACKX =0017
MRPMEX =0014          MRPMTX =0011          NEWPNT =0076
NFFHAT =C7C0          NGR =0078             NOOUT =C9ED
NRACHAT =C6C8         NUCHAN =000A          NUMBER =008E
NXTGR =C681           OFF =0046             OFFOUT =CA54
OFS =0050             OGR =0064             ORPM =005A
OUT =C109             OUTBUF =00E6          OUTBYT =82FA
OUTMSG =CCEC          OUTMSGS =CCF9         OUTOF =C1E0
OUTOFF =C1D5          OUTPNT =001D          OUTPUT =CA1E
OUTT =CA36            OUTTIME =001E         OUTXAH =82F4
OVFL =00D5            OVLCHK =C248          OVRFLO =C948
P =00E7               PARM =8220            PARN =A64A
PARNR =A649           RACKDISP =CB7F        RACKH =0004
READ3 =CC63           READCLOCK =CC3F       RPME =CD4F
RPMEDISP =CB71        RPMEH =0002           RPMT =CD37
RPMTH =0000           RSPTIME =0032         RSUM =C296
SAVE =C356            SAVE2 =87EA           SAVTIME =D008
SCAND =8906           SEC =C07B             SECS =C16C
SECSU =C06E           SECSUM =C061          SETBYTE =CC82
SETDATE =CC14         SETFTIME =C15C        SETIME =CBEC
SETMRK =C265          SETPORT =CD05         SETUPCLOCK =CCC6
SFL3 =C23D            SFLG =0075            SFLG1 =001C
SFLG2 =000E           SFLG3 =000F           SFLG4 =0010
SHOW =CA72            SHOWDISP =CAA3        SHOWLOOP =CAA6
SIGNS =00D6           SRACKH =000B          SRPMEH =0009
SRPMTH =0007          SSUM =C171            SIM =C0FA
STMIN =C0F2           STOMIN =C345          STOPCLOCK =CCA3
STORE =C3AF           STOS =C0A9            STOSEC =C2B2
STRTCNT =CD28         SUMF =C0BF            SUMFO =C0C2
SUMFOU =C0CD          SUMFOUR =C0AC         SVVAL =C8E4
TAPDEL =A630          TAPE =C106            TEMP1 =00E6
TIMEDISP =CBCE        TOPNT =00D2           TRANCHK =C212
TSUM =C276            VIA1 =A000            VIA2 =A800
VIA3 =AC00            WORK0 =00DC           WORK1 =00DD
WORK2 =00DE           WORK3 =00DF           X =00E7
ZT =C22E              . =00E7
//0000,CDEA,1DEA
```

A Gear Selection Aid
For Agricultural Tractors

by

DENNIS K. MATTESON

B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTERS THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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A gear selection aid for agricultural tractors can be implemented and provide a savings to the operator. The technology necessary to implement the optimization is readily available and the financial incentive is rising as the cost of fuel prices increase. The purpose of this work was to design the hardware and develop the software required to assist the operators of a Model 3588 International Harvester tractor to operate the tractor at a more efficient engine speed and gear ratio.

The main criteria for development of the aid was 1) the unit be able to withstand the harsh environment associated with field equipment, 2) the unit easily be understood by the operator, 3) the unit have the confidence of the operator, 4) and the unit record data for analysis of savings. The unit consisted of three boxes and implemented some of the existing electronics on the tractor. The box containing the recording equipment would not be needed for final implementation. The design criteria was met, and the results were encouraging enough that research in the area of variable speed transmissions is now being pursued.

VITA

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Thesis: A Gear Selection Aid For Agricultural Tractors

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