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DESIGN AND INTEGRATION OF A HYDROSTATIC TRANSMISSION IN A 300-HP MARINE CORPS AMPHIBIOUS VEHICLE

by
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Department of Engine and Vehicle Research
Engines, Emissions and Vehicle Research Division

FINAL REPORT
Prepared under Contract No. N00167-82-C-0156

Prepared for
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This report will also summarize the test results obtained by the contractor regarding the performance and efficiency of this drivetrain option. The results of these tests indicate that the performance of the vehicle is potentially superior to that of the existing drivetrain while the efficiency is judged to be somewhat lower. All rationale regarding

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1. EXECUTIVE SUMMARY

1.1 ABSTRACT

This report summarizes the work performed to provide the design and integration of a hydrostatic transmission in a 300-hp Marine Corps amphibious vehicle. This project was initiated to evaluate the performance and efficiency that might be obtained by utilizing this transmission concept. To optimize the efficiency of the drivetrain, two significant design enhancements were incorporated into the vehicle design. The first enhancement involved the use of two-speed final drives which allow smaller and more efficient hydrostatic components to be used, and the second enhancement involved the use of a microcomputer-based control system to adjust in real time the transmission and engine settings to provide the best overall drivetrain efficiency.

This report will also summarize the test results obtained at SwRI regarding the performance and efficiency of this drivetrain option. The results of these tests indicate that the performance of the vehicle is potentially superior to that of the existing drivetrain while the efficiency is judged to be somewhat lower. All rationale regarding the selection of components, vehicle design, and control mechanism to obtain this conceptual vehicle design will also be delineated in this report.

1.2 INTRODUCTION

The static combat and peacetime performance demands of military vehicles is ever increasing. In combat the acceleration and maneuverability performance of the vehicle is becoming increasingly important to extend the likelihood of survival during enemy attack, especially while under assault from wire-line or line-of-sight weapons. During peacetime the performance demands are directed toward combat readiness while maintaining a high degree of reliability and training utility. A number of studies have been prepared to analyze the drivetrain components used in amphibious vehicles to determine the likelihood that increased performance could be obtained from alternate drivetrain designs. It has been concluded that hydrostatic transmissions may offer improved performance during a portion of their operating cycle because of their continuous transfer of power from the engine to the ground. The demonstration of the performance that is afforded by the use of hydrostatic transmissions best describes the objectives of the statement of work which governed this project.

Southwest Research Institute, under Contract No. N00167-82-C-0156 with the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), has provided the design and integration of a hydrostatic transmission in a Marine Corps amphibious vehicle. The intent of this program was to investigate the overall performance and efficiency of the drivetrain which included not only the transmission but the engine as well. To accentuate the performance and efficiency of the drivetrain, a microcomputer was chosen to control the transmission and engine settings during the operation of the vehicle. The driver of the vehicle maintains control through a steering wheel, accelerator pedal, brake pedal, and transmission selector. The way that these driver inputs translate into vehicle operation is the heart of the method for maximizing efficiency.

Hydrostatic transmissions have been found to be efficient systems for transmitting power over certain portions of their variable range. This program has sought and found two ways of extending the efficient operating range of the transmission. First, because the maximum operating speed of this and other similar military vehicles is much higher than any industrial application, a two-speed final drive was identified which provides greater speed capability at improved efficiencies. Second, because the engine is an integral part of the overall drivetrain efficiency, control logic was developed to run the engine at its most fuel efficient speed to provide the required power through the transmission.

With these control functions integrated into the microcomputer, the driver is allowed to increase his concentration on the vehicle's strategic positioning. The driver indicates his desired turn direction and turn radius by simple steering wheel control. He can vary the vehicle's direction of travel from a straight line to a spin turn by merely turning the steering wheel from its neutral position to its full turn position in one continuous motion. The driver can indicate his desired speed of travel by depressing the accelerator. If a rapid stop is desired the driver can apply his brakes. The driver can also easily change his desired direction of travel and gear ratio speed range through a single transmission selector.

The microcomputer was designed to manage the hydrostatic transmission settings and the engine speed setting to most efficiently provide the desired speed and direction of travel. The heart of this management system is the ability of the microcomputer to analyze the power required to operate at the desired speed under the existing soil conditions. Once the power requirement has been analyzed, the microcomputer directs the transmission to most efficiently provide the required output sprocket torque and speed. Additionally, the microcomputer analyzes the transmission efficiency and directs the engine to operate at a speed which most efficiently produces the required output power. This process of power analysis and drivetrain adjustment is performed ten times a second to provide a continuous flow of drivetrain component adjustments from the operator's commands.

As a result of the work performed to date, the use of hydrostatic transmissions for application in an amphibious vehicle is judged to be satisfactory from an applications point of view, superior from a performance and maneuverability point of view, superior from a component placement point of view, and somewhat inferior from the efficiency and survivability point of view. Although the survivability of the unit can be upgraded by additional protection of the hydraulic interconnections, defining the actual efficiency and improving the efficiency are of greatest priority.

This report details the analysis of this design and the test results that quantify the actual efficiency of the vehicle. Included herein is a description of the components selected for use, the efficiency of the system as predicted from manufacturers' product information and as obtained from dynamometer tests, and the control logic, microcomputer hardware, and electro-hydraulic actuators that transform operator inputs into drivetrain outputs. Also included is information regarding the component weights of the various drivetrain components.

The review of an interim report concerning this project is recommended if additional design data is desired. This report is entitled "Design and Integration of a Hydrostatic Transmission in a 300-HP Marine Corps Amphibious Vehicle" and is dated

03 November 1982. Detailed manufacturers' efficiency data is presented in this interim report that serves as supporting data for this present final report. Copies of this interim report can be obtained through the David Taylor Ship R&D Center, Bethesda, Maryland.

1.3 ACKNOWLEDGEMENTS

The authors wish to express appreciation to the personnel from the David W. Taylor Naval Ship Research and Development Center who have been involved in this development effort. Special appreciation is extended to Mr. Mark Rice, the Technical Project Officer during this contract, for his support and technical assistance. Appreciation is also extended to Mr. Mike Gallagher, who provided assistance during the testing phase of this project, and to Mr. Walt Zeitfuss, Department Head at DTNSRDC, for his critical review and administrative support. Appreciation is also extended to personnel at the Amphibious Vehicle Test Branch at Camp Pendleton, California, especially to Mr. David Overguard, who provided support during the field test activities there.

2. OVERALL SYSTEM DESCRIPTION

The test vehicle used for this project was an M113 armored personnel carrier weighing 22,000 pounds with a track gage of 86 inches, effective length of track on the ground of approximately 118 inches with a track shoe width of 15 inches. This vehicle was ballasted for an overall design weight of 24,000 pounds. To provide the required 300 net flywheel horsepower, a Detroit Diesel 6V-53T engine was provided. Table 1 relates the main points of the remaining drivetrain specifications:

Table 1. General Specifications for Hydrostatic Test Platform

Total sprocket stall torque (two sprockets):	16,800 ft-lb
Maximum required vehicle speed:	40 mph
Desired Transmission Efficiency:	75 percent over 75 percent of the speed-torque envelope
Turning Capability:	straight line to spin turn, regeneration of power required

Although these specifications may at first appear to be relatively indefinite in detail, it is the third specification that serves to fully describe the intended performance and efficiency, with the first two providing the limits of the speed-torque envelope.

Figure 1 presents the desired transmission performance relationship for the case of 300 net flywheel horsepower less 30 horsepower used to operate the cooling system. It should be noted that the drivetrain efficiencies are evaluated only from the output side of the engine to the output side of the sprockets; thus eliminating the variability of the track system on the drivetrain evaluation.

The turning capability specification relates one inherent feature of dual path hydrostatic transmissions: the ability to operate each transmission independently from

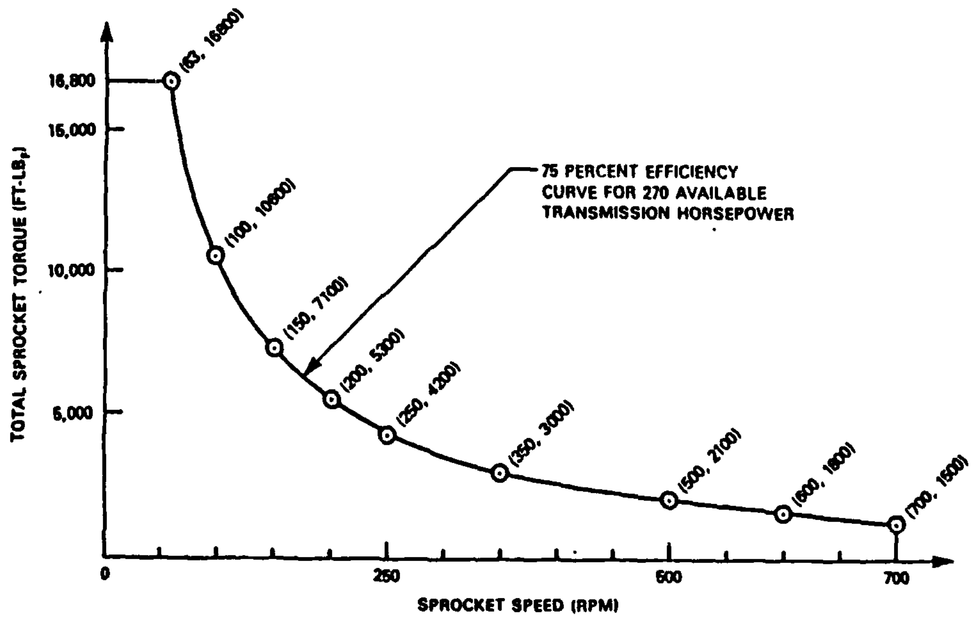


FIGURE 1. 75 PERCENT TRANSMISSION EFFICIENCY CURVE
FOR 270 AVAILABLE TRANSMISSION HORSEPOWER

full forward speed to full reverse speed continuously. This provides the spin turn capability. Regenerating power, however, to make high speed turns is not an obvious feature of this transmission, but is a requirement for effective high-speed operation.

Tracked vehicles have a general tendency to go straight. If powered by only on track, any tracked vehicle will obtain a certain fairly large turn radius when the other track freewheels. If the turn radius is desired to be less than this natural turn, some braking of the inside track is required. This vehicle was designed to require the fully developed engine power plus the power that is fed back through the inside transmission to perform high speed turns. The amount of regenerated power, although not specified, was determined to be approximately equal to the net engine input power during turns at the maximum vehicle speed.

The main components of the hydrostatic test platform are shown in Figure 2. From the operator's point of view, the control of the vehicle is fairly typical of most mobile equipment. The operator elements - the steering wheel, shifter, brake and accelerator pedal - provide electrical signals proportional to the desired mode of operation and are fed into the on-board microcomputer. The microcomputer takes these operator-provided signals, and various status signals obtained from the drivetrain, interprets them in regard to the desired engine and transmission settings, and output voltages that actually control the drivetrain.

As related in this figure, the two hydrostatic pumps are driven off of a gear drive splitter box mounted to the engine. The splitter box also drives an auxiliary pump which is used to power the hydraulically driven fan (not shown). Sprockets are mounted to the final drives which support the hydrostatic motors and separate brake units.

Control of the engine speed and associated output power capability is accomplished via electro-hydraulic governor valve with integral linear actuator. Displacing the governor controls the amount of fuel supplied to the engine. No constant-speed governor is used with this arrangement. The displacements, and thus the speeds of the hydrostatic motors, are controlled via electrohydraulic displacement control valves mounted on each of the two hydrostatic transmissions. Actuation of the brakes and clutches are likewise controlled via electrohydraulic valves.

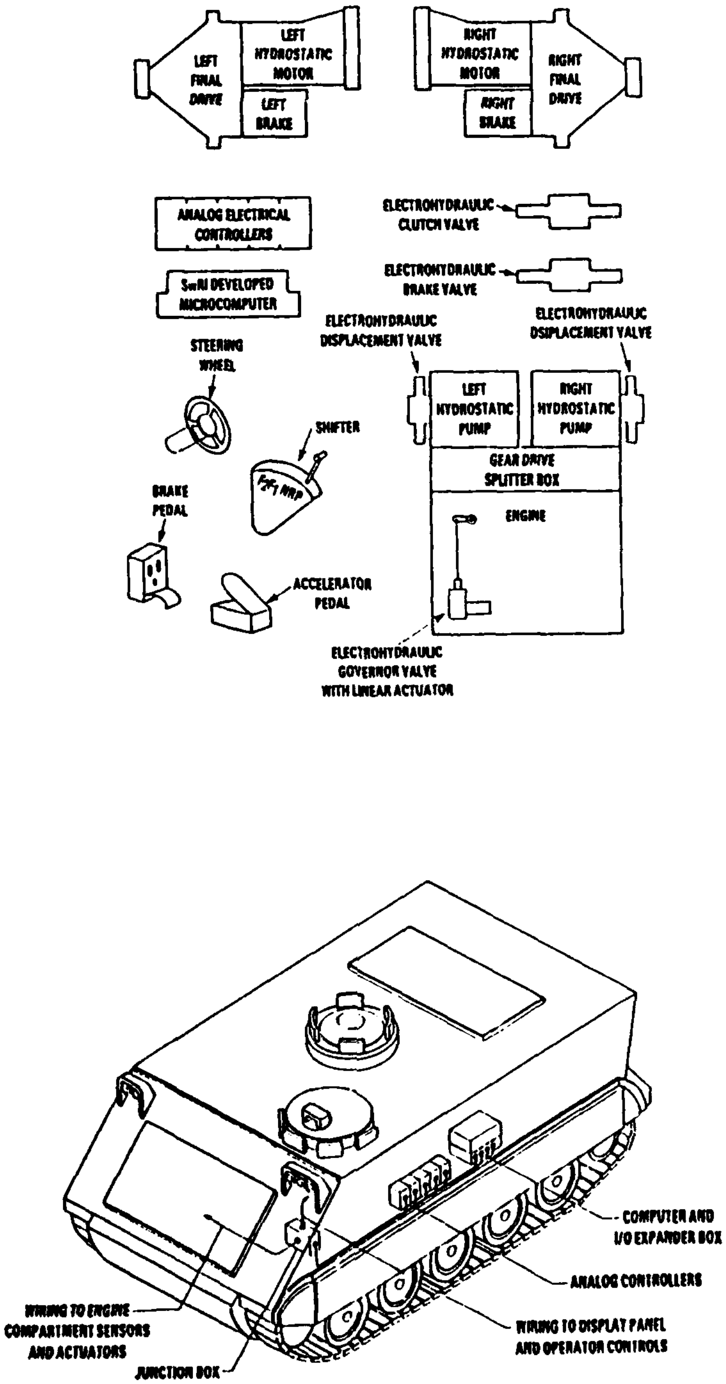


FIGURE 2. MAIN COMPONENTS OF THE HYDROSTATIC TEST PLATFORM

The overall system design is best described in terms of the operational performance groups that are involved. The first group to be discussed includes all of the human operator interfaces that must exist to transform the operator's desires into the machine's performance. Separately described will be the drivetrain components that produce the desired response and the control systems group with its associated input control signals and output command signals.

3. OPERATOR CONTROLS

The operator controls interface design previously shown in Figure 2 are a result of the human engineering requirements of the situation. In this situation the vehicle's overall control has been subdivided into tactical requirements according to the following:

- Vehicle Acceleration and Speed
- Vehicle Deceleration
- Vehicle Director of Travel (forward, reverse)
- Vehicle Direction of Turn (right, left)
- Vehicle Radius of Turn

Utilizing basic human engineering principles, proper operator interface dictates that the tactical requirements be transformed into universally accepted operator controls that are minimized in number and complexity. In this case, it was decided that the vehicle acceleration and speed would best be controlled by use of the commonly found accelerator pedal. Deceleration would be controlled by a brake pedal. Vehicle direction of turn and radius of turn is to be controlled by a steering wheel. Vehicle direction of travel, which includes Park, Reverse, Neutral, Forward 1, and Forward 2, would be controlled by a single direction mode selector.

Figures 3, 4, and 5 present the operational relationships for the accelerator pedal, brake pedal, and steering wheel. How these mechanism displacements are translated to electrical signals which are eventually interpreted by the microcomputer will be discussed in the Electrical/Control System section of this report.

Displacing the accelerator pedal allows the operator to control the vehicle's speed and acceleration rate. If the pedal is displaced at a rate less than the maximum response rate of the vehicle, it will limit the vehicle's acceleration rate. If the pedal is displaced more rapidly than the maximum drivetrain response rate, the control system will limit the response rate of the drivetrain to acceptable values.

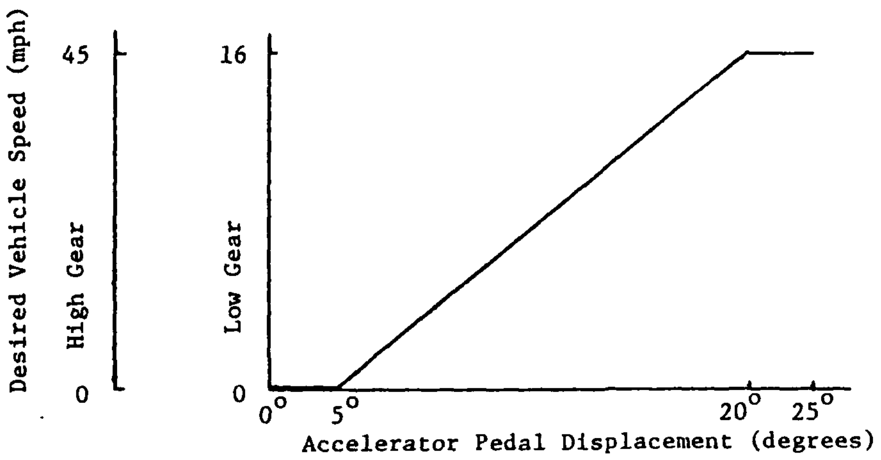


FIGURE 3. RELATIONSHIP BETWEEN ACCELERATOR PEDAL DISPLACEMENT AND DESIRED VEHICLE SPEED

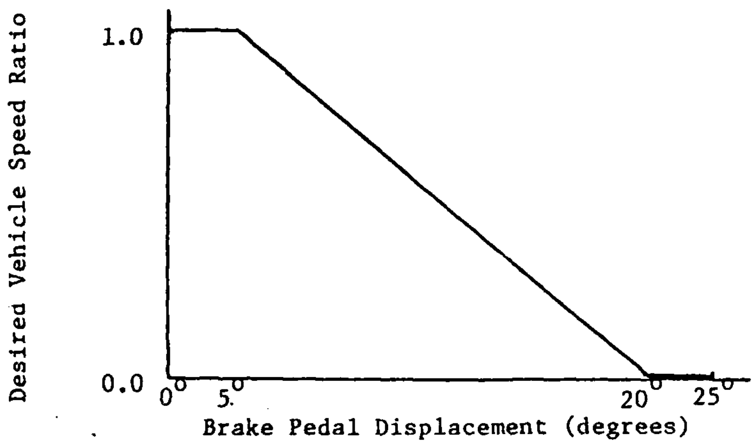


FIGURE 4. RELATIONSHIP BETWEEN BRAKE PEDAL DISPLACEMENT AND DESIRED VEHICLE SPEED RATIO

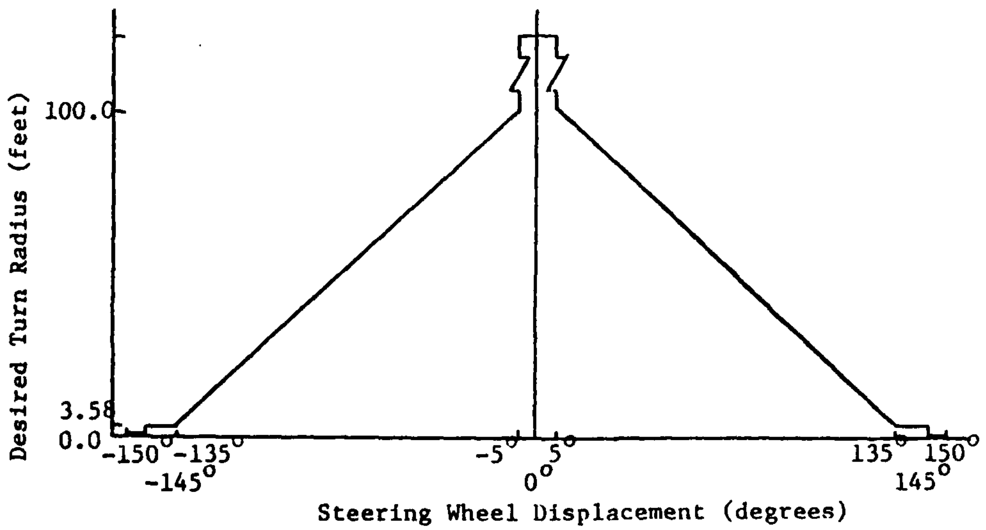


FIGURE 5. RELATIONSHIP BETWEEN STEERING WHEEL DISPLACEMENT AND DESIRED TURN RADIUS

Displacing the brake pedal allows the opertor to control the vehicle's deceleration rate. The Desired Vehicle Speed Ratio obtained from the brake pedal is used as a modifier to the Desired Vehicle Speed value obtained from the accelerator. The control system determines the Desired Vehicle Speed from the accelerator and brake pedal inputs according to the following equation:

Desired Vehicle Speed = Desired Vehicle Speed (from accelerator pedal) x Desired Vehicle Speed Ratio (from brake pedal)

By utilizing this calculation scheme, the brake pedal signal is allowed to override the accelerator pedal. This was done in the interest of safety. If, for example, an operator had both pedals simultaneously displaced, the signal from the brake pedal displacement would override that of the accelerator pedal.

The signal from the steering wheel relates the Desired Turn Direction (DTD) and Desired Turn Radius (DTR). When the steering wheel is in the neutral position, the Desired Turn Radius is infinite. As the steering wheel is turned, a turn radius of 100 feet is first sensed. This value was emperically determined to be the largest turn radius that was noticeable during vehicle operation. Continued displacement of the steering wheel results in a linear decrease in Desired Turn Radius until a value of 3.58 feet is reached, which is equal to the Half Track Gage (HTG) of the vehicle. This turn radius corresponds to a pivot turn around one of the tracks which would be stopped. Continued displacement of the steering wheel results in a Desired Turn Radius of 0.0 feet. This corresponds to a spin turn where one track is turning forward while the other track is turning in reverse (at the same speed).

The only other operator input control device is the transmission selector, which is shown photographically in Figure 6. This mechanism allows Park, Reverse, Neutral, Forward 1 or Forward 2 to be selected. Table 2 relates the switch closure schedule for the shifting mechanism.

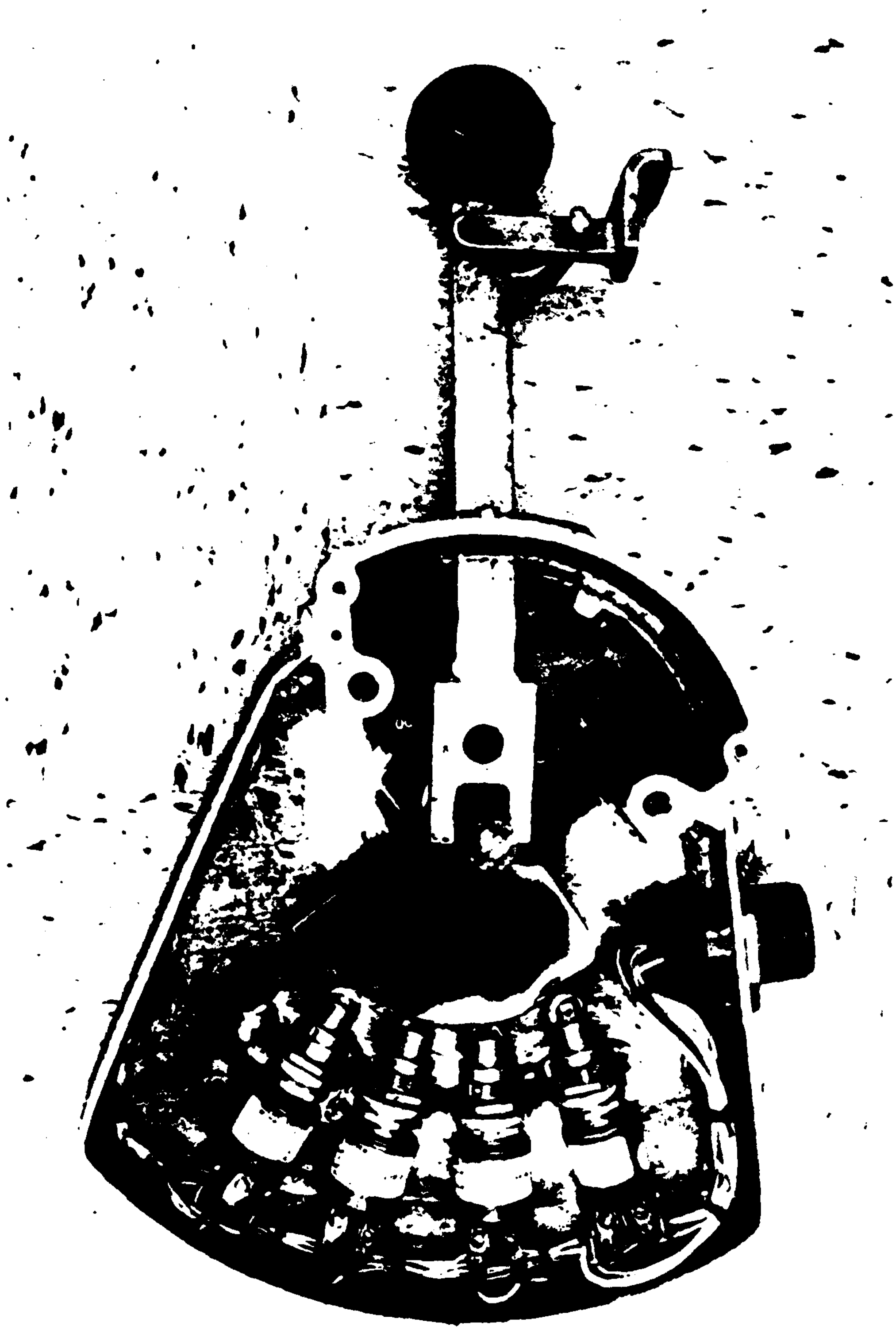


FIGURE 6. ILLUSTRATION OF TRANSMISSION SELECTOR MECHANISM

Table 2. Desired Transmission Setting Versus Number of Switch Closures

Park	4
Reverse	3
Neutral	2
Forward 1	1
Forward 2	0

These operator devices provide the input values to the control system to adjust the operational state of the drivetrain components. The next section of this report will discuss the various drivetrain components that were utilized.

4. DRIVETRAIN COMPONENTS

The RFP stated in part the following operational specifications:

Maximum Land Speed - 40 mph
Maximum Forward Transient Sprocket Torque - 8050 $ft\text{-}lb_f$
Maximum Differential Steering Torque - 8400 $ft\text{-}lb_f$

From these operational specifications it was determined that the sprocket output specifications should be as follows:

Maximum Sprocket Operational Torque - 8400 $ft\text{-}lb_f$
Maximum Forward Sprocket Speed - 700 rpm (40 mph)
Maximum Rearward Sprocket Speed - 275 rpm (15.71 mph)

Translating these sprocket output specifications into hydrostatic motor specifications requires a detailed knowledge of the sprocket reduction which occurs in the final drives. The historical development of the final drive selection should be quickly reviewed for reference purposes.

During the time of the preparation of the response to the RFP, Southwest Research Institute (SwRI) reviewed the operational specifications as outlined in the RFP and analyzed every identifiable hydrostatic line of equipment that might fulfill those specifications. It was obvious that two basic approaches were feasible for this application. As was indicated in the RFP the use of multiple hydrostatic drive motors married to a single reduction final drive was a possible option as was the use of a multiple speed final drive. SwRI contacted the major United States manufacturers of wheel mounted final drive components and was informed that no multiple speed final drives were presently available. This was disconcerting in light of the perceived improvement in overall transmission efficiency which would be afforded by the application of a multiple speed final drive. Thus, SwRI proceeded to outline a transmission design that utilized two hydrostatic motors per final drive and proposed the incorporation of a basic microcomputer to control the entire drivetrain.

Shortly after contract award, a company by the name of Funk Manufacturing contacted SwRI and related that they had prototyped several two-speed final drives. A reevaluation of our proposed design was made in light of the availability of these components, and it was determined that an improvement of 7 to 10 percent in the overall efficiency of the transmission could be obtained by the incorporation of these components. The program was then directed toward the application of those components.

The review of hydrostatic components which was performed during the preparation of the proposal indicated that superior hydrostatic motor performance was available in a bent axis design as compared to swash plate motor components. In particular, two manufacturers were identified as possible sources of bent axis hydrostatic motor components. The manufacturers are Linde Hydraulics, Inc., and Rexroth, Inc. Both offer a wide line of components with specific corner horsepower to weight ratios of from 2.13 to 3.65.

To determine the best motor for this application is an iterative process. To meet the maximum sprocket speed specification the final drive gear ratio is found by taking the maximum motor operating speed and dividing by the maximum sprocket speed. To determine whether or not the maximum sprocket output torque specification is met the maximum motor torque is multipled by the final drive gear ratio. This process is further complicated by the possible incorporation, as in this project, of a two-speed final drive.

It was determined that a single hydrostatic motor in combination with a two-speed final drive would provide the specified output torque and speed. The design that was applied during this program is not fully optimized because of the inability to obtain the optimized final drive gear ratios which might be desired; however, the final drives which were obtained are sufficiently close that the overall system will suffer only a 1.0 to 2.0 percent decrease in efficiency.

The hydrostatic motor which was chosen for this application is a Linde BMV 186 hydrostatic motor. Information regarding this motor is provided as Figure 7. It has the following operational specifications:

Maximum Displacement per Revolution - 11.36 in^3
Minimum Displacement per Revolution - 3.37 in^3
Maximum Rotational Speed (without flushing) - 3000 rpm
Maximum Output Torque (at 6000 psi) - 812 $ft\text{-}lb_f$

From these motor operational specifications it is possible to derive the optimum theoretical final drive gear ratios as follows:

$$\text{Optimum High Speed Gear Ratio} = \frac{3000 \text{ rpm}}{700 \text{ rpm}} = 4.29$$

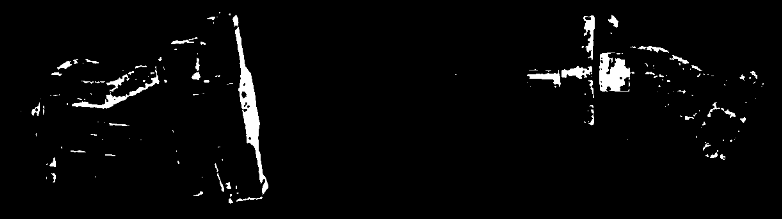
$$\text{Optimum Low Speed Gear Ratio} = \frac{8400 \text{ ft-lb}}{812 \text{ ft-lb}} = 10.34$$

Because of the short time frame for this demonstration program, it was not possible to obtain these optimal theoretical final drive gear ratios. The available gear ratios and the corresponding sprocket output speed and torque are illustrated in Table 2. As shown in this table the second and third options meet the operational requirements; however, it was felt that the second option was superior because it limited the sprocket speed to a reasonable value above the specified speed which allows more overlap of the speed torque curves between low and high gear.

As has been mentioned, the final drives applied in this design are manufactured by Funk Manufacturing of Coffeyville, Kansas. These units were not designed as a dedicated application for this vehicle but were designed for wide range future possible industrial and military applications. The designs applied in this program are illustrated

motors

	variable displacement						fixed displacement					
	BENT AXIS OPEN AND CLOSED LOOP						BENT AXIS OPEN AND CLOSED LOOP					
model	50	75	105	140	186	260	35	50	75	105	140	186
displacement cubic inches	3.06	4.57	6.40	8.51	11.36	15.86	2.13	3.06	4.57	6.40	8.51	11.36
maximum rpm open loop at maximum displacement 28° Without Flushing (28°)	3600	3300	3000	2700	2400	2100	3900	3600	3300	3000	2700	2400
minimum displacement (8°) Without Flushing (8°)	4600	4200	3800	3400	3000	2600	–	–	–	–	–	–
With Flushing (28°)	4000	3700	3400	3100	2800	2500	4300	4000	3700	3400	3100	2800
With Flushing (8°)	5500	5000	4500	4000	3500	2900	–	–	–	–	–	–
maximum rpm, closed loop	4000	3700	3400	3100	2800	2500	4300	4000	3700	3400	3100	2800
maximum system pressure, psi (intermittent)	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
maximum continuous pressure psi (100% duty cycle)	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
control options/remote hydraulic	*	*	*	*	*	*	–	–	–	–	–	–
maximum torque (ft. lbs.) tilt head angle 28° 1000	32	46	68	101	115	160	22	32	46	68	101	115
2000 psi	68	101	144	194	259	360	47	68	101	144	194	259
3000 psi	111	173	236	310	410	570	77	111	173	236	310	410
3600 psi	132	196	276	368	489	680	92	132	196	276	368	489
5000 psi	194	288	410	540	715	990	135	194	288	410	540	715
6000 psi	220	328	461	612	812	1130	154	220	328	461	612	812
dry weight lbs.	51	75	93	147	165	180	33	37	60	71	104	126



Linde linde hydraulics corporation

FIGURE 7. ILLUSTRATION AND SPECIFICATIONS FOR LINDE BMV 186 HYDROSTATIC MOTOR

Table 3. Optimal Final Drive Gear Ratios and Their Corresponding Sprocket Output Speed and Torque Using Linde BMV 186 Components

Available Final Drive Gear Ratio	Sprocket Output Torque (ft-lb$_f$)	Sprocket Output Speed (rpm)
Low, 10.187	8272	294
High, 3.96	3216	757
Low, 10.877	8832	276
High, 4.10	3329	731
Low, 10.59	8599	283.29
High, 3.95	3207	760

in Figures 8 and 9. Figure 8 illustrates the power path options for low and high gear. Figure 9 illustrates the mounting positions for the hydrostatic motor and the service/park brake. Figure 8 also indicates the power path for the service/park brake.

Aside from the non-optimal, but acceptable, final drive gear ratios, the application of these specific final drives is problematic because of their associated weight. Each unit weighs approximately 509 pounds, and is a result of Funk Manufacturing's efforts to design a highly adaptable configuration. As a dedicated design, it is estimated that the weight of 509 pounds could be reduced by half, which would result in a weight of approximately 250 pounds. This is the approximate weight of the new two-speed final drives that are being procured for application in the Automotive Test Rig (ATR) vehicle. This will be more acceptable from the viewpoint of overall vehicle integration.

It was noted that the final drives have an input location for a service/park brake assembly. The service brake represents the single largest operational compromise of the vehicle design. The reason for this is that there is not much room to install a substantial service brake in this location. The limitation is in the diameter of the brake which can be applied. Figure 10 illustrates the service/park brake which will be used in this application. Although quite suitable for the park brake, as a service brake it will be somewhat anemic because of its limited stopping torque of 6200 in-lb_f.

Having described the final drives and hydrostatic motors, the description of the drivetrain next focuses on the hydrostatic pumps. Since bent axis motor components have been chosen, it might seem logical that bent axis pump components might also be chosen. Indeed, bent axis pump components would have been chosen except for a number of problems associated with them. The overriding problem associated with bent axis pumps is their relative inability to take a high amount of torsional vibration during their operation. If such vibrations are encountered, failure of the connecting link between the bearing plate and the piston head occurs because these are the transmission members that carry the rotary forces. When bent axis pumps are attached to an engine, as in this design, through a splitter box, the torsional vibrations of the engine are directly transmitted into the pump. Thus engine mounted bent axis

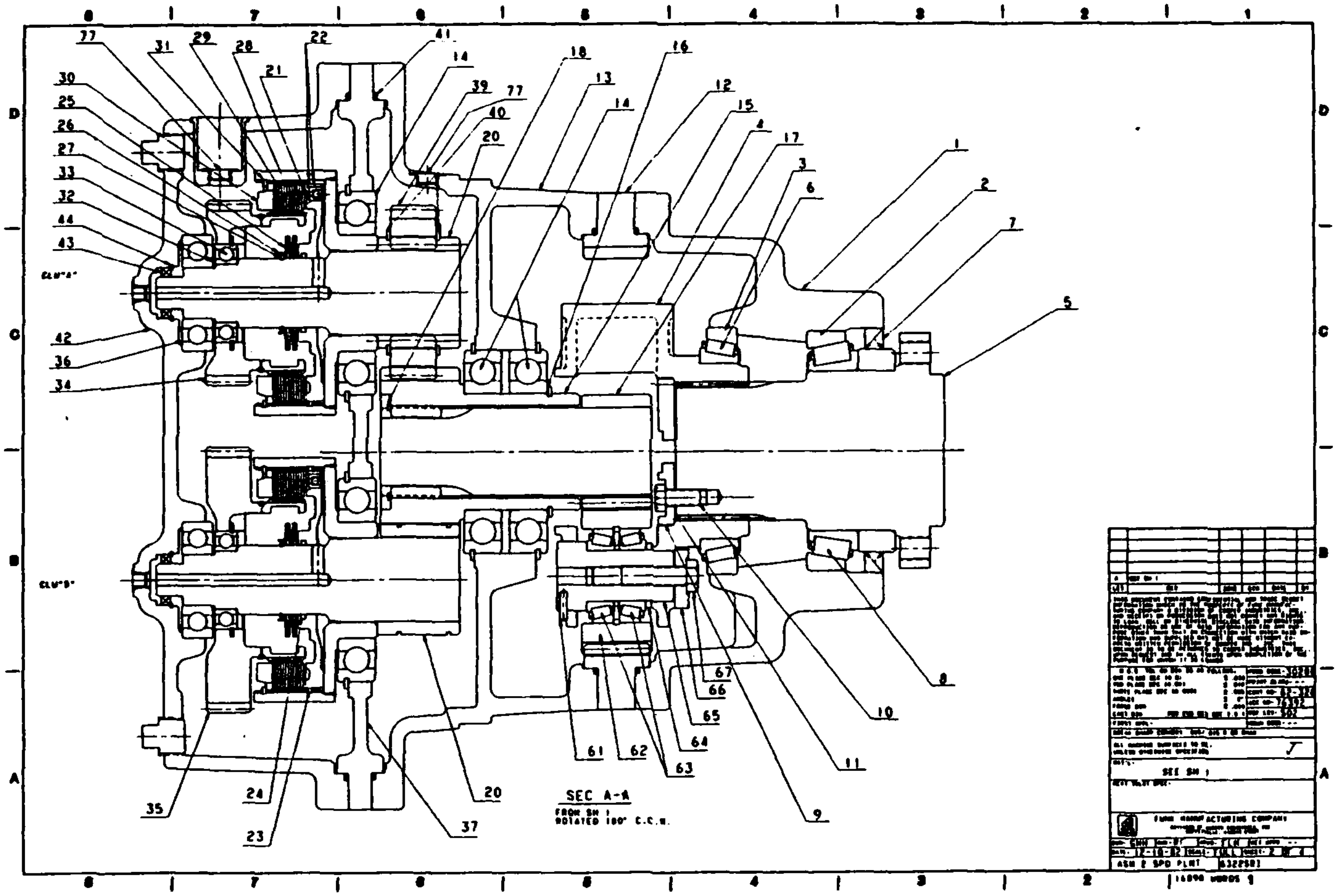


FIGURE 8. CROSS SECTIONAL VIEW OF FUNK TWO-SPEED FINAL DRIVE

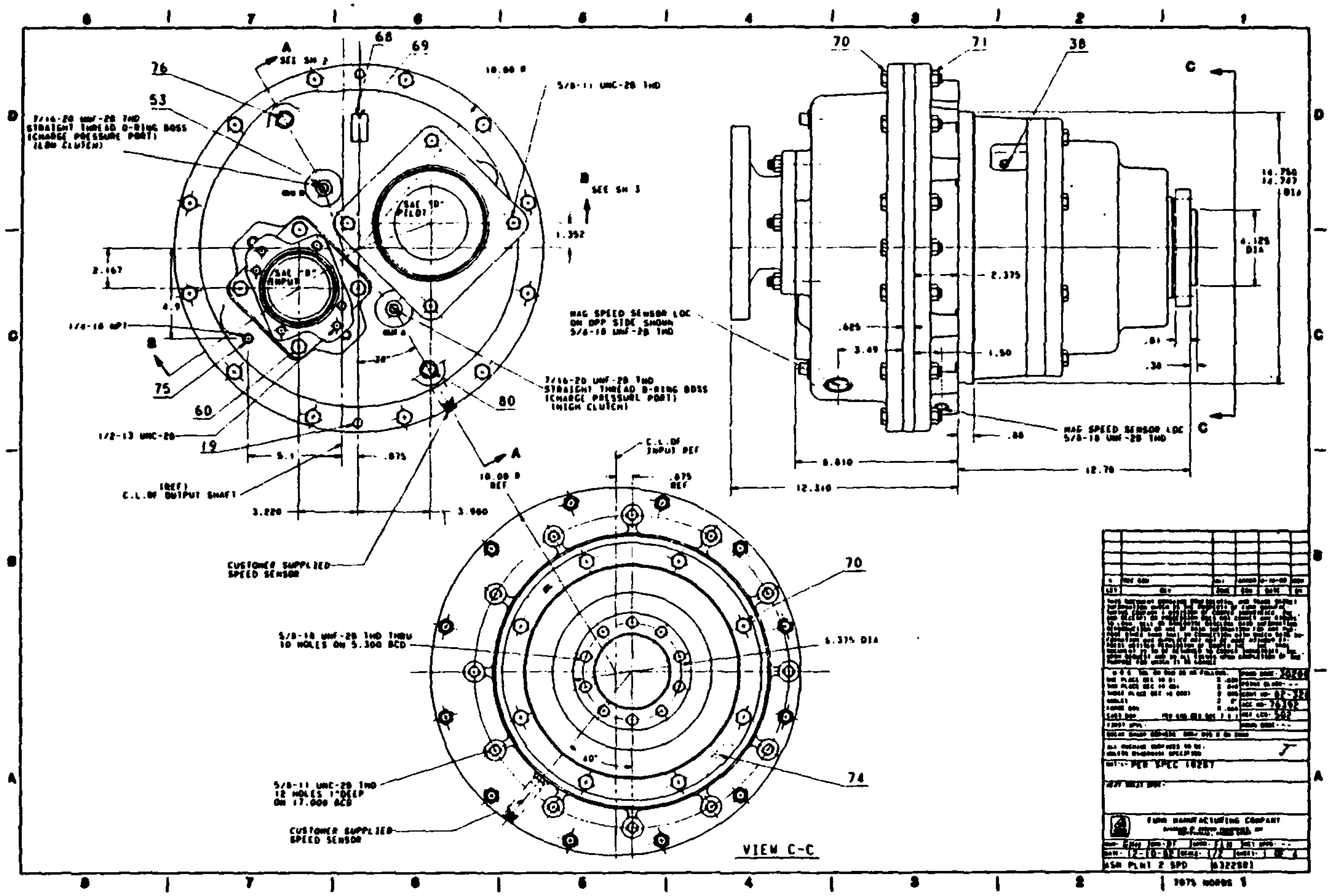
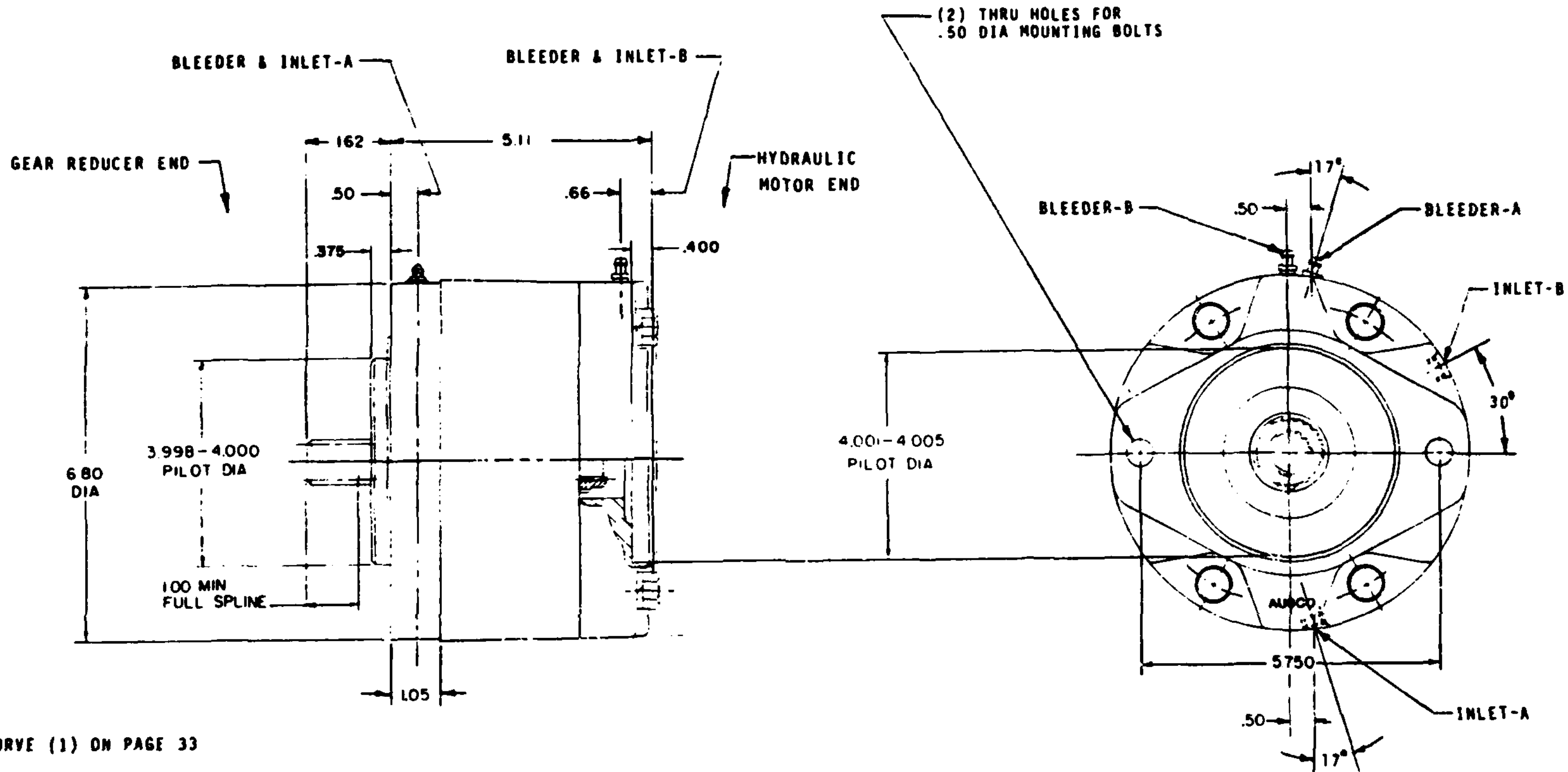


FIGURE 9. VIEW OF FUNK TWO-SPEED FINAL DRIVE SHOWING HYDROSTATIC MOTOR AND BRAKE INPUTS



a-SEE CURVE (1) ON PAGE 33

OPERATING MEDIUM	PETROLEUM	PETROLEUM
DISPLACE. RELEASE (MIN/WORN(MAX)	———	1.5/3.0
(CU IN.) ENGAGEMENT(MIN)	0.25	———
EXTERNAL: GEAR REDUCER END MAJOR DIA	13T 16/32 .853-.875	
INTERNAL: HYD MOTOR END FLAT ROOT SIDE FIT, 30° P.A. BRAKE SHAFT SPLINE	13T 16/32	
MAXIMUM RECOMMENDED WORKING PRESSURE(PSI)	1500	3000
RELEASE HYD PRESSURE(PSI)	(1)a	150
RATED TORQUE (LB IN.)		2400
PISTON	SERVICE	FAILSAFE
BRAKE PART NO.	34800	

FITTING POSITION:
INLET & BLEEDER-A: SERVICE BRAKE
INLET & BLEEDER-B: FAILSAFE BRAKE

INLET SIZE:
.250 TUBING OD
STRAIGHT THREAD O-RING GASKET BOSS
(.438-20 UNF-2B)

SAE 'B' MOUNT FAILSAFE BRAKE WITH SERVICE BRAKE

FIGURE 10. AUSCO SERVICE/PARK BRAKE APPLIED TO THE FINAL DRIVE

pumps would seem to have failure problems and this is actually the case based on manufacturers' information.

The use of swash plate pumps in this application presents no real problem and is in fact the industry norm. Although the swash plate pumps do suffer slightly from a decrease in efficiency, their normal operation limits the time spent at the lower efficiencies. When swash plate pumps operate at moderate output flows, their efficiencies are comparable to bent axis pumps. Only when these pumps operate at high pressures and low flow do they become relatively less efficient than bent axis pumps, and in this condition the amount of power consumed is relatively small so that the effect of the inefficiency is further decreased.

Sizing the pump becomes a function of providing sufficient flow to allow the motors to operate at their required speed. In this case the maximum pump displacement can be found as follows:

Motor Displacement at Maximum Output Speed - 3.41 in^3/rev
Motor Maximum Output Speed - 3000 rpm

$$\text{Required Pump Output Flow} = \frac{(3000)(3.41)}{231} = 44.29 \text{ gpm}$$

Since the maximum pump speed should be limited to a value of approximately 2600 rpm, the required maximum pump displacement is found as:

$$\text{Maximum Pump Displacement} = \frac{(44.29)(231)}{2600} = 3.93 \text{ in}^3/\text{rev}$$

To allow for the motors to operate at full speed at greater than their minimum displacement per revolution requires extra pump capacity. Additionally, to allow for a respectable overlap between low and high gear in the final drives requires additional capacity. From the results of the calculated required pump capacity with the realization that some additional capacity is needed, a review of Linde hydrostatic pumps indicates that their BPV 100 pump, a 6.12 cubic inch per revolution pump, was applicable. Their BPV 70 pump, a 4.32 cubic inch per revolution pump, would also have worked but was thought to be somewhat marginal. The BPV 100 pump has been chosen for this program because of the additional required capacity and is illustrated in Figure 11.

The final member of the drivetrain to be specified is the splitter box. Here the requirement is to provide two hydrostatic pump mounts and one auxiliary pump mount. Several options for this piece of equipment exist and a model manufactured by Funk Manufacturing, Inc., was chosen in an attempt to obtain the greatest overall cooperation from them in this venture. Figure 12 illustrates this splitter box.

The drivetrain member which was not a design option was the use of a Detroit Diesel 6V-53T engine. This engine is described in Figure 13. This engine was applied to this design because of its availability, power output, and compact size.

Adjustments to the drivetrain components were made through the actuation of electrohydraulic control valves. The transmissions were adjusted via proportional values illustrated in Figure 14. These values provide a hydraulic control pressure proportional to the applied voltage. The displacement of the pumps and motors is controlled by this control pressure valve. Figure 15 relates the control pressure and component displacement as a function of applied voltage.

Many problems were encountered during the course of this project relative to these values. These problems were not in regard to the operating principle of the valve, but rather were associated with the implementation of the valve in the vehicle. Two problems were encountered: one associated with the plugging of the 0.030 inch orifices, and the other associated with the initial ball design instead of the cone design eventually utilized to provide a variable restriction in the return-to-tank line.

Linde | piston pumps

variable displacement

		BENT AXIS OPEN AND CLOSED LOOP		AXIAL PISTON CLOSED LOOP				
model		140	186	35	50	70	100	200
displacement cubic inches		8.53	11.35	2.13	3.10	4.32	6.12	12.2
ximum rpm .pen loop	flooded inlet	1600	1450	–	–	–	–	–
	pressurized inlet (10 psi max.)	1800	1600	–	–	–	–	–
maximum rpm closed loop		2400	2200	3400	3200	3000	2800	2600
maximum system pressure psi (intermittent)		5000	5000	6000	6000	6000	6000	6000
maximum continuous pressure psi (100% duty cycle)		3000	3000	3600	3600	3600	3600	3600
control options	remote hydraulic	*	*	*	*	*	*	*
	power limiter	*	*	–	–	–	–	–
	pressure compensator	*	*	–	–	–	–	–
	lever servo	*	*	*	*	*	*	*
	electric hydraulic servo	–	–	*	*	*	*	*
	torque control	*	*	*	*	*	*	*
	automotive hydraulic	–	–	*	*	*	*	*
performance @ 1800 rpm or maximum permissible speed flooded inlet	1000 psi gpm	64	86	16	23	32	46	92
	1000 psi hp	44	58	11	16	21	30	60
	3000 psi gpm	63	84	15	23	32	45	90
	3000 psi hp	130	173	33	45	61	90	180
	5000 psi gpm	61	82	15	22	31	44	8P
	5000 psi hp	216	287	54	79	111	158	315
dry weight lbs.		390	456	68	77	97	130	304

FIGURE 11. ILLUSTRATION AND SPECIFICATIONS FOR LINDE BPV 100 HYDROSTATIC PUMP

SPECIFICATIONS

*RATINGS

Input Torque (Max.): 1250 lbs/ft.
Output Torque (Max.): 950 lbs/ft. per pump pad
Input or Output speed (Max.): 3000 R.P.M.
Horsepower (Max.): 475 H.P. (360 H.P. Max. per pump pad)

PUMP ROTATION

Anti-Enginewise

OIL

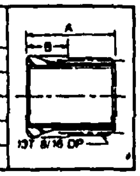
Any oil which meets EP gear lubrication Spec MIL-L-2105C or API classification GL-5.

GEAR RATIOS

Ratio	Gear Group
1:1	4028806
.647:1 Inc.	4028935
.741:1 Inc.	4028457
.787:1 Inc.	4028456
.909:1 Inc.	4028845
.954:1 Inc.	4028455
1.048:1 Red.	4028458
1.100:1 Red.	4028844
1.400:1 Red.	4028460
1.545:1 Red.	4028846

FUNK PUMP ADAPTER SLEEVES

Part No.	SAE Size	A Dim.	B Dim.	Internal Spline or Key Shaft
4028055	B	1.81	.75	7/8-13T 16/32 P.
4028056	C	2.00	.937	1 1/4-14T 12/24 P.
4028271		2.00	.93	1 3/8-21T 16/32 P.
4028145	C	1.87	.81	1 1/4-14T 12/24 P.
4028303	B	2.00	.93	7/8 x 3/16 Key & 1/4 Key



PUMP ADAPTER PLATES

Part No.	Pump Size	Bolts Required	Bolt Size
4028004	S.A.E. A	2	3/8-16
4028005	S.A.E. B	2 or 4	1/2-13
4028006	S.A.E. C	2 or 4	1/2-13
4028007	S.A.E. D	4	3/4-10

*The above ratings are based on gear and bearing life using a 1:1 ratio at 2500 RPM for a 2000 hour B-10 life. Actual usage of the units may be limited by drive lines on independent input models, clutch ratings on clutch models (See table, Page 39), pump mounting limitations and gear ratios.

COVER-FLYWHEEL HOUSING

Part No.	SAE Size	A	B	Bolts Required
4028009	1	20.875	20.125	12-7/16-14
4028010	2	18.375	17.625	12-3/8-16
4028011	3	16.875	16.125	12-3/8-16
4028012	4	15.000	14.250	12-3/8-16
4028013	5	13.125	12.375	8-3/8-16

CLUTCH COVER HOUSING

Part No.	SAE Size	A	B	Bolts Required
*4028196	1	20.875	20.125	12-7/16-14
†4028318	1	20.875	20.125	12-7/16-14
4028190	1	20.875	20.125	12-7/16-14
4028191	2	18.375	17.625	12-3/8-16
4028192	3	16.875	16.125	12-3/8-16
4028193	4	15.000	14.250	12-3/8-16

*Special Housing (9.625 deep) to be used with SP211
†Special Housing (9.625 deep) to be used with SP114

PUMP DRIVE CLUTCH DATA

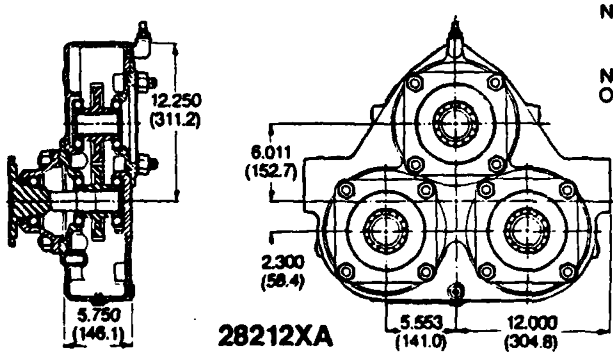
Nominal Clutch Size	Clutch Number	*Working Torque	C Dim.	D Dim.	E Dim. Pilot Brg. Dia.	F Dim.	G Dim.	No. Holes	Hole Size
8"	T.D. C-108	228	10.375	9.625	2.4409	3 11/16	2 7/16	6	13/32
10"	T.D. C-110	328	12.375	11.625	2.8346	3 11/16	2 1/8	8	13/32
11 1/2"	T.D. C-111	387	13.875	13.125	2.8346	3 11/16	1 9/16	8	13/32
11 1/2"	T.D. S.P. 211	910	13.875	13.125	2.8346	3 11/16	1 9/16	8	13/32
14"	T.D. S.P. 114	810	18.375	17.250	3.1496	3 11/16	1	8	17/32

DRIVE PLATE ASSEMBLY

Part No.	Nominal Clutch Size	C	D	E	F	G	No. Holes	Hole Size
4028080	8	10.375	9.625	2.047	3 11/16	2 7/16	6	13/32
4028081	8	10.375	9.625	2.43	3 11/16	2 7/16	6	13/32
4028082	10	12.375	11.625	2.43	3 11/16	2 1/8	8	13/32
4028083	10	12.375	11.625	2.83	3 11/16	2 1/8	8	13/32
4028084	11 1/2	13.875	13.125	2.43	3 11/16	1 9/16	8	13/32
4028085	11 1/2	13.875	13.125	2.83	3 11/16	1 9/16	8	13/32
4028136	11 1/2	13.875	13.125	2.83	3 11/16	2 1/8	8	13/32
4028086	14	18.375	17.250	2.83	3 11/16	1	8	17/32
4028087	14	18.375	17.250	3.15	3 11/16	1	8	17/32

NOTE: Application subject to approval by Funk Sales and/or Engineering Dept. All data and specifications subject to change without notice or obligation.

NOTE: DIPSTICKS AND PTO SHAFTS SHOWN ARE OPTIONAL EQUIPMENT.



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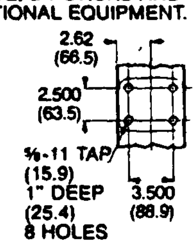
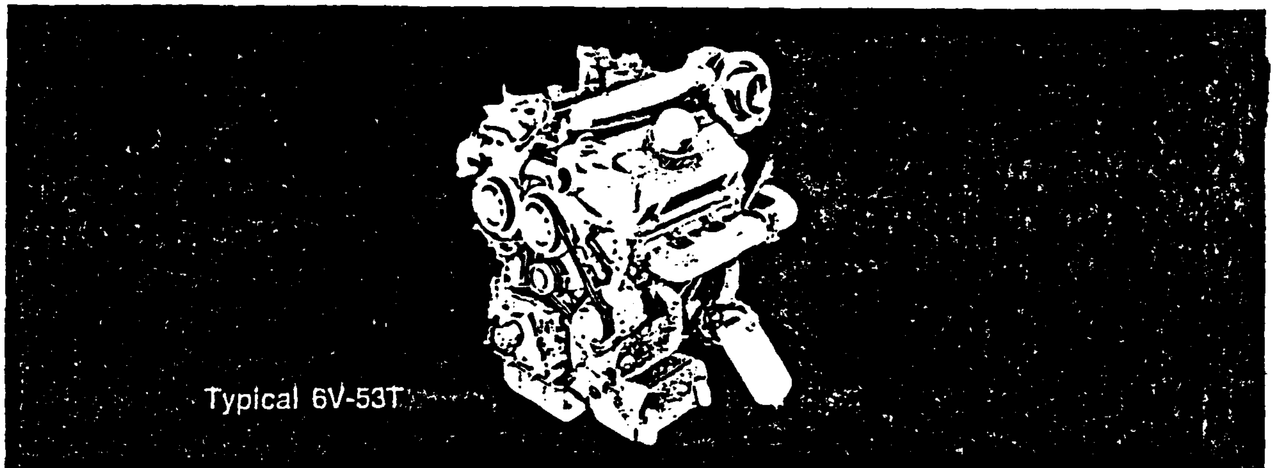


FIGURE 12. FUNK MODEL 28212XA SPLITTER BOX

Detroit Diesel Engines

commercial engines for military applications

6V-53T
300 hp



specifications

Engine Type	Two Cycle	Two Cycle	Two Cycle
Number of Cylinders	6	6	6
Bore and Stroke	3.875 in x 4.5 in (98 mm x 114 mm)	3.875 in x 4.5 in (98 mm x 114 mm)	3.875 in x 4.5 in (98 mm x 114 mm)
Displacement	318 cu. in (5.22 litres)	318 cu. in (5.22 litres)	318 cu. in (5.22 litres)
Rated Gross Power: 60°F (15.6°C) Air Inlet Temperature and 29.92 in. Hg (101.31 kPa) Barometer (Dry)	260 BHP (194 kW) @ 2800 RPM	280 BHP (209 kW) @ 2800 RPM	300 BHP (224 kW) @ 2800 RPM
Torque: 60°F (15.6°C) Air Inlet Temperature and 29.92 in. Hg (101.31 kPa) Barometer (Dry)	557 lb ft (755 N•m) @ 1800 RPM	606 lb ft (822 N•m) @ 2000 RPM	638 lb ft (865 N•m) @ 2100 RPM
Compression Ratio	17 to 1	17 to 1	17 to 1
Fuel Capability	Diesel #2 through CITE	Diesel #2 through CITE	Diesel #2 through CITE
Fuel Consumption at Idle	2.4 lbs/h (1.09 kg/h)	2.4 lbs/h (1.09 kg/h)	2.4 lbs/h (1.09 kg/h)
BMEP @ 2800 RPM	116 psi (800 kPa)	124 psi (855 kPa)	133 psi (917 kPa)
Air Required for Scavenging and Combustion @ 2800 RPM	1140 CFM (32.3 m³/min)	1190 CFM (33.7 m³/min)	1250 CFM (35.4 m³/min)
Exhaust Gas Flow @ 2800 RPM	2734 CFM (77.4 m³/min)	2915 CFM (82.6 m³/min)	3131 CFM (88.7 m³/min)
Rotation Mass Movement of Inertia	820 lb-in² (.24 kg•m²)	820 lb-in² (.24 kg•m²)	820 lb-in² (.24 kg•m²)
Volume Envelope (Basic Engine)	34.8 cu ft (987.1 litres)*	34.8 cu ft (987.1 litres)*	34.8 cu ft (987.1 litres)*
Horsepower per Cubic Foot	7.5 (.197 kW/litre)	8.0 (.212 kW/litre)	8.6 (.227 kW/litre)
Pounds Per Horsepower	5.19 (3.15 kg/kW)	4.82 (2.93 kg/kW)	4.50 (2.73 kg/kW)
Net Weight (Dry)	1350 lbs (612 kg)	1350 lbs (612 kg)	1350 lbs (612 kg)

*Turbocharger location will vary these values.

FIGURE 13. DETROIT DIESEL 6V-53T ENGINE ILLUSTRATION

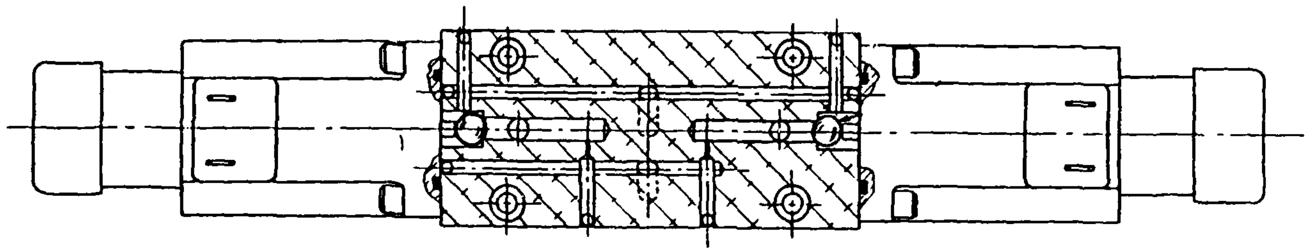


FIGURE 14. TRANSMISSION ELECTRO-HYDRAULIC CONTROL VALVE

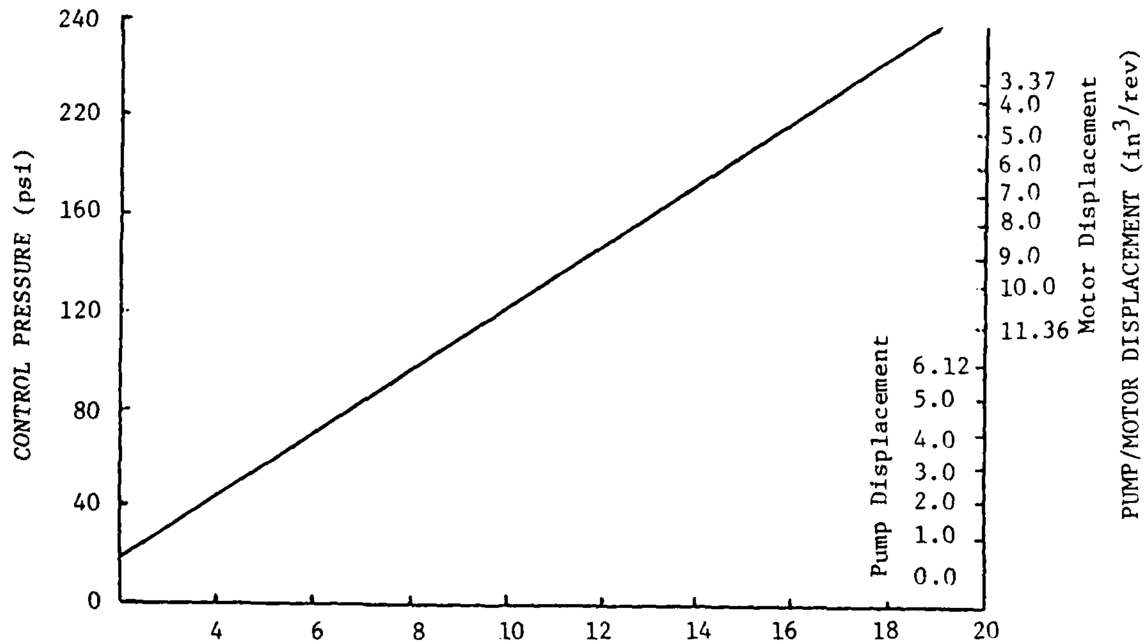


FIGURE 15. CONTROL PRESSURE AND TRANSMISSION COMPONENT DISPLACEMENT AS A FUNCTION OF C NTROL VOLTAGE

Normally, a 0.030 inch orifice in a hydraulic system would be considered relatively small and prone to plugging, and this is the case for this application. Proper function of the valve was assured, however, by adequate prefiltration of the oil before entering the valve.

The problem associated with the variable orifice ball mechanism appears to have been related to the oil used in the vehicle. This oil, MIL-SPEC-83282, has a low viscosity and valve oscillations were noted before switching to the cone-type valve illustrated in Figure 14.

Adjustments to the engine governor position were made via an electro-hydraulic valve with integral linear actuator illustrated in Figure 16. This device provided control pressure to actuate a spring loaded hydraulic linear actuator. The relationship between applied control voltage to actuate displacement is illustrated in Figure 17.

Control of the brake pressure was provided via two proportional electro-hydraulic valves housed in a single valve body. This valve is illustrated in Figure 18. Its actuation was very similar to that of the transmission valve and the governor valve. All of these valves were provided by Electro Hydraulics, Inc.

Actuating the high and low clutches was made via three-position, four-way electrohydaulic valves. This descrete value allowed actuation of either the high or low clutch, but would not allow simultaneous actuation of both valves.

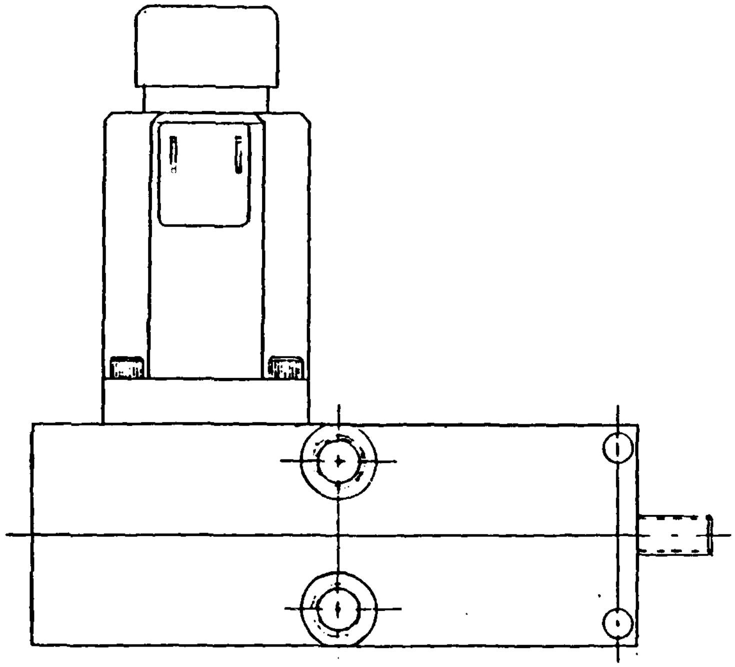


FIGURE 16. ENGINE GOVERNOR DISPLACEMENT MECHANISM

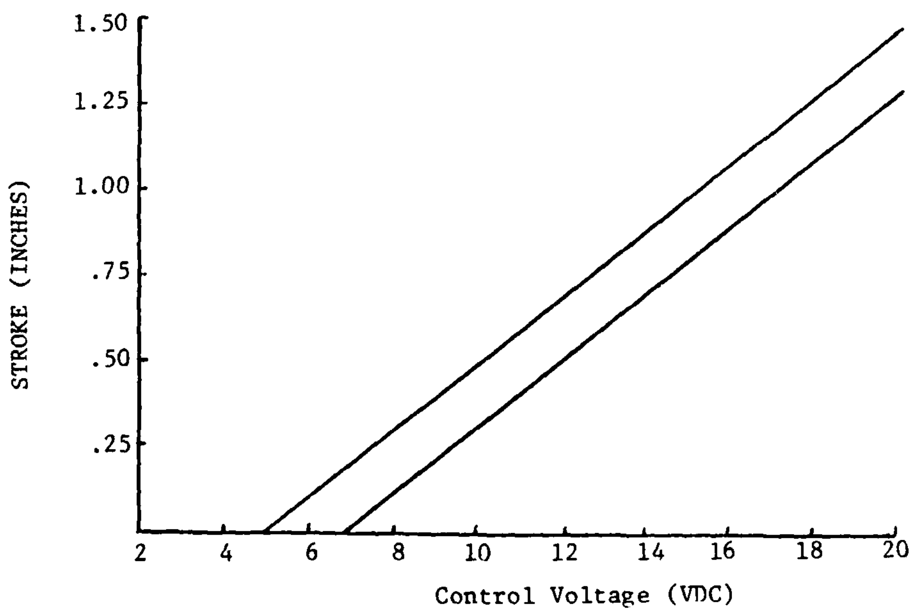


FIGURE 17. RELATIONSHIP BETWEEN GOVERNOR VALVE STOKE AND CONTROL VALVE VOLTAGE

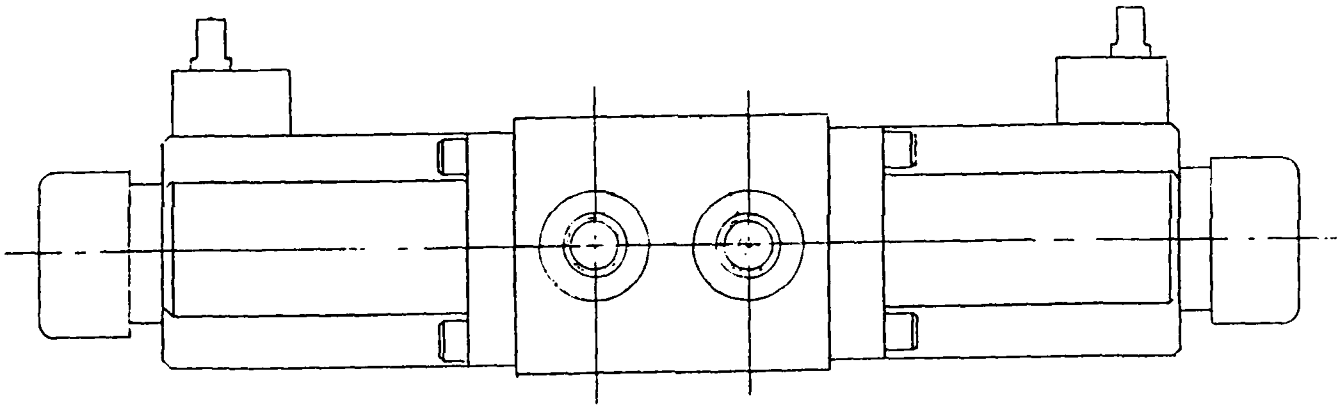


FIGURE 18. ILLUSTRATION OF ELECTROHYDRAULIC BRAKE VALVE

5. DRIVETRAIN EFFICIENCY

The drivetrain efficiency analysis must begin with a review of the drivetrain operation. As designed, the drivetrain is integrally controlled by the microcomputer. It is desired that the engine run at its most efficient speed to provide the required output power. To determine the required output power, the output motor torques are obtained at any one point in time and these values are multiplied by the desired motor speeds (as derived from the accelerator pedal). This estimate of the required power is then compared against the engine power-speed map to determine the optimum engine speed setting to provide the required output power. Once the engine speed has been determined and is in the process of adjustment, the hydrostatic pumps and motors are likewise adjusted. From a standing start to any velocity the general sequence of events will be to increase the engine speed and simultaneously increase the displacement of the pumps until their maximum displacement is obtained and then to decrease the displacement of the motors until the desired motor speeds or a power limitation are reached. With this scheme the settings of the drivetrain components can be specified and their efficiencies evaluated.

5.1 Engine Efficiency

Figure 19 illustrates the amount of fuel that is consumed by the engine at certain power and speed settings. This information is a reprint of manufacturers' information. As can be seen from this illustration, choosing the most efficient engine speed setting for power levels below 150 hp is a most risky speculation.

To determine the actual fuel usage relationship of the engine used in this project, an independent dynamometer test was performed at SwRI. The results of that test are presented in Figure 20. From the format of this engine performance map it is fairly easy to derive the relationship for desired engine speed versus required engine power.

Referring to Figure 20, if 100 horsepower were required, 1600 rpm might be the most efficient engine speed at which to operate, and, in fact, this was the rationale

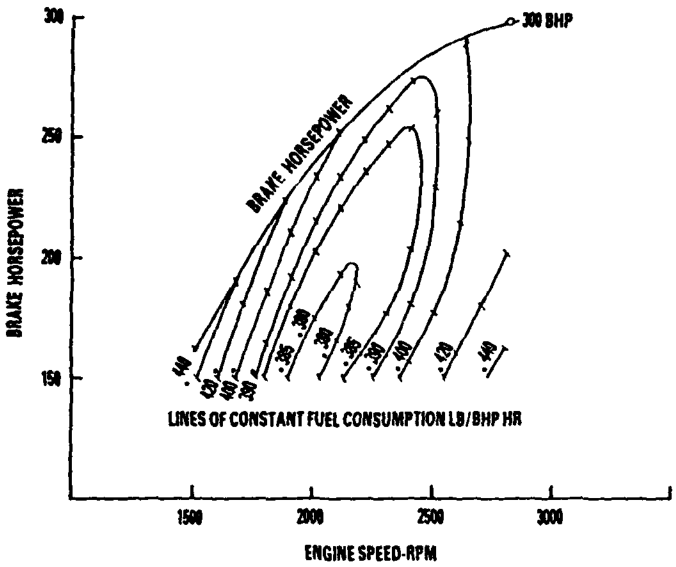


FIGURE 19. FUEL CONSUMPTION RATES AT VARIOUS POWER AND SPEED LEVELS FOR DETROIT DIESEL 6V-53T ENGINE, FROM MANUFACTURERS DATA

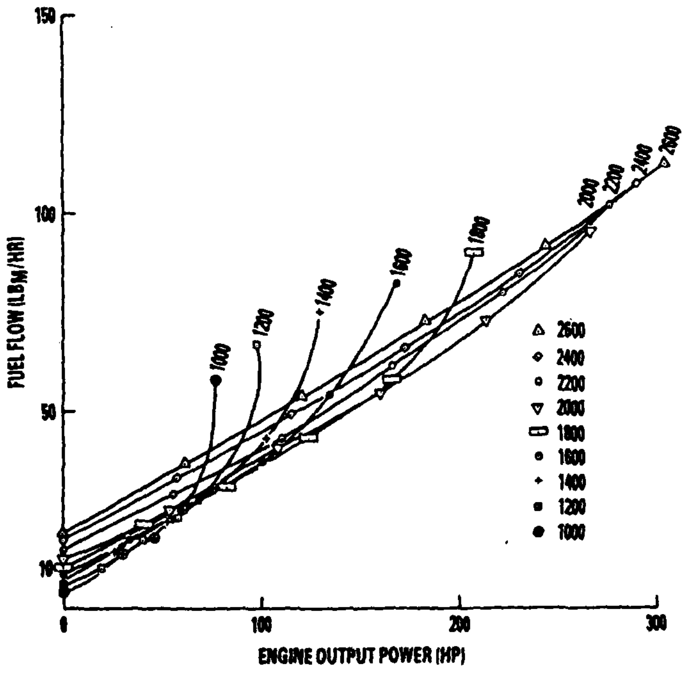


FIGURE 20. FUEL CONSUMPTION RATES VERSUS OUTPUT POWER FOR VARIOUS ENGINE SPEEDS FOR DETROIT DIESEL 6V-53T ENGINE, FROM SwRI DYNO TEST RESULTS

that was used during the initial checkout of the control logic. It should be apparent that if 100 horsepower were being consumed at an engine speed of 1600 rpm and more power was desired, the engine could not easily accelerate to provide the additional power. During such operation, the engine would emit great clouds of black smoke as the governor would go to full rack to try to accelerate the engine. It was quickly realized that for any particular power requirement the engine would have to be operated at a higher than optimal engine speed to assure that there was sufficient power reserve before reaching the smoke threshold to accelerate the engine so that larger and larger amounts of power could be produced. Figure 21 relates the ideal engine speed versus required power relationship that was derived from Figure 20.

It also became apparent during the course of this project that hydrostatic transmissions do not like to operate at high motor speeds with low pump speeds. In fact, it is impossible to obtain maximum motor speed of 3000 rpm if the pump speed is not at some mid-range value. If the system had 100 percent volumetric efficiency the minimum pump speed to obtain 3000 rpm at the motor with its displacement set at minimum would be:

$$\text{Minimum Pump Speed} = \frac{(3000 \text{ rpm})(3.37 \text{in} \;\; /\text{rev})}{6.12 \text{ in}^3/\text{rev}} = 1652 \text{ rpm}$$

It is through this combination of desired motor speed and power requirements that the desired engine speed was eventually determined. This relationship is given as

$$\begin{pmatrix}\text{Desired}\\\text{Engine}\\\text{Speed}\\\text{(rpm)}\end{pmatrix} = 1100 \text{ rpm} + (.3666)\begin{pmatrix}\text{Temporary}\\\text{High}\\\text{Motor}\\\text{Speed}\end{pmatrix} + (8.4)\begin{pmatrix}\text{Total}\\\text{Required}\\\text{Engine}\\\text{Power}\end{pmatrix} - (.00185)\begin{pmatrix}\text{Temporary}\\\text{High}\\\text{Motor}\\\text{Speed}\end{pmatrix}\begin{pmatrix}\text{Total}\\\text{Required}\\\text{Engine}\\\text{Power}\end{pmatrix}$$

This relationship is graphically presented in Figure 22.

In this equation the value of Temporary High Motor Speed is determined as the higher of the two desired motor speeds that result when the vehicle makes a turn. During a turn the desired vehicle speed is converted to an equivalent desired motor

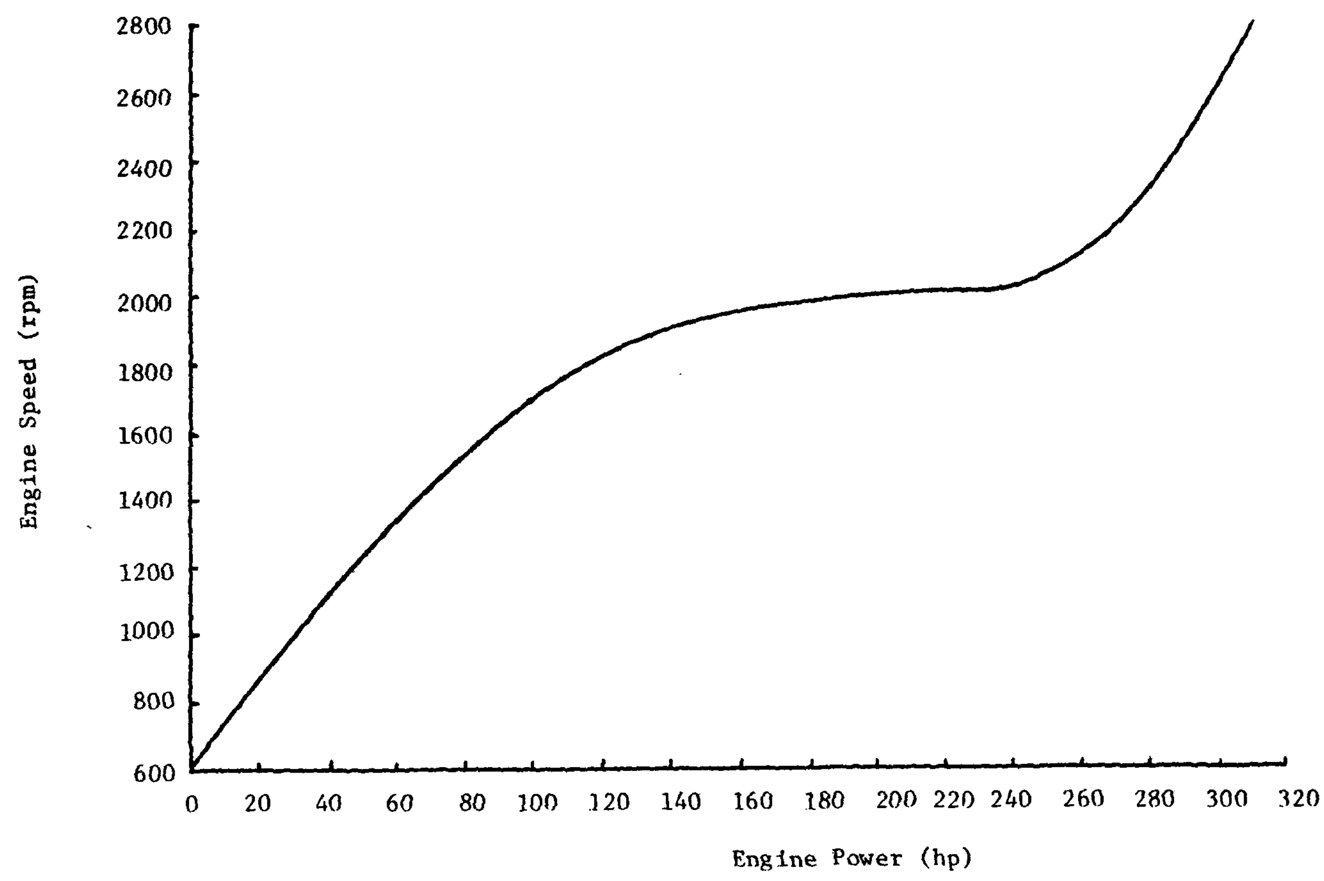


FIGURE 21. OPTIMAL DESIRED ENGINE SPEED AS A FUNCTION OF TOTAL REQUIRED ENGINE POWER

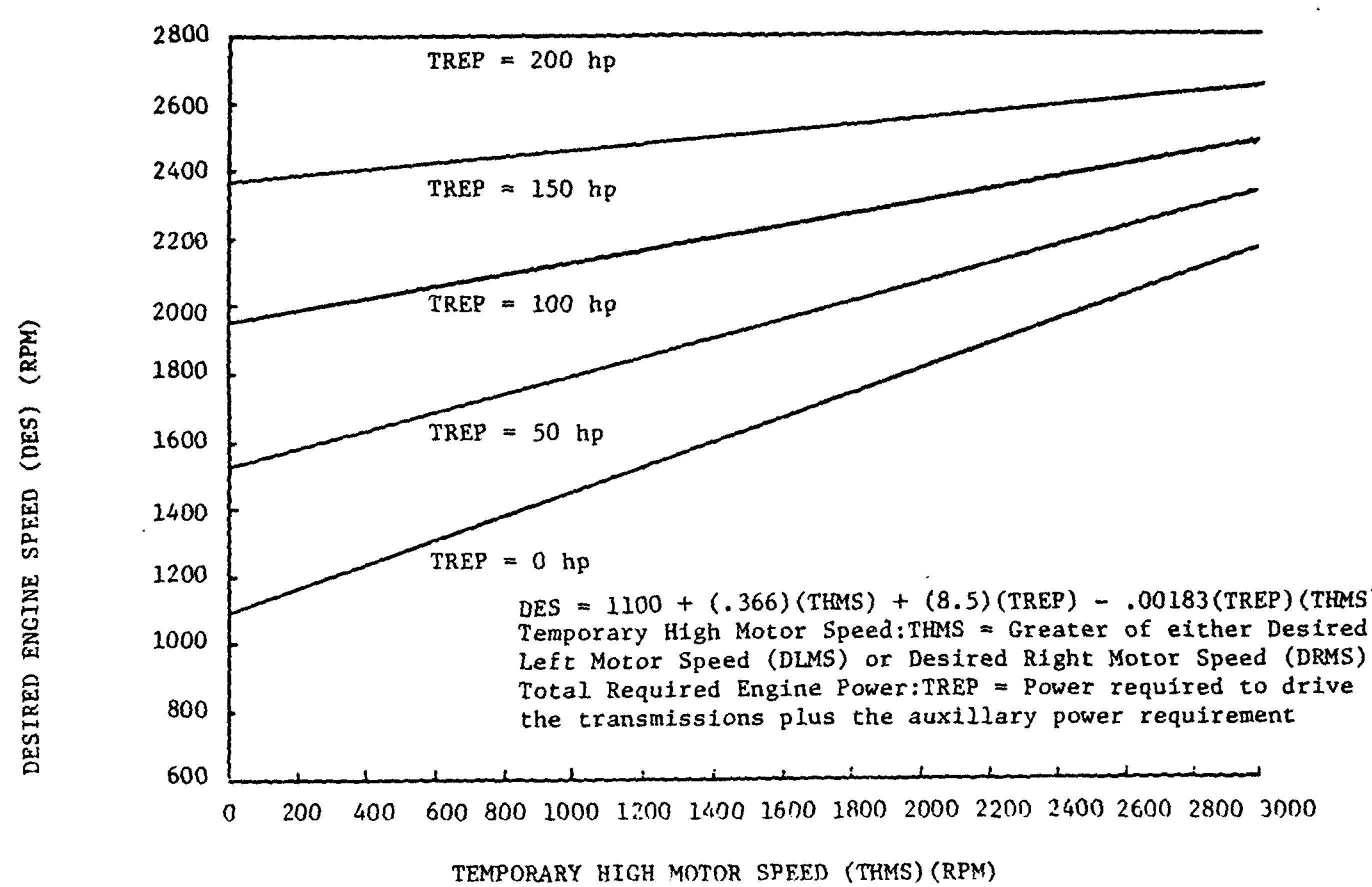


FIGURE 22. DESIRED ENGINE SPEED AS A FUNCTION OF TEMPORARY HIGH MOTOR SPEED AT VARIOUS TOTAL REQUIRED ENGINE POWER LEVELS

speed and that value is applied to the outside motor. Since, during a turn, the inside motor speed is always slower than the outside motor speed, the Temporary High Motor Speed Value is always associated with the higher (outside) motor speed.

5.2 Transmission Efficiency by Computer Model

The efficiency of the drivetrain also is easily dependent on the efficiency of the transmission. For this vehicle, it has already been related that the hydrostatic pumps and motors that were used were the Linde BPV 100 series pumps and the Linde BMV 186 series motors. Information was obtained from Linde Hydraulics, Inc., regarding the efficiency relationships of these units. The general efficiency relationships that were provided are presented in Table 4.

These efficiency equations were used to evaluate the overall efficiency of two drivetrain options originally considered for this project. One drivetrain configuration consisted of a single reduction final drive used in combination with large hydrostatic pumps and two hydrostatic moors used with each final drive, while the other configuration used two-speed final drives in combination with smaller hydrostatic components as related in Table 5.

The efficiency of each option was evaluated via computer model of the entire drivetrain system using the previously described equations to model the hydrostatic components and taking into account the losses due to the hydrostatic charge pump circuit as well as the losses in the gear drive splitter box and the final drive components. Figure 23 relates the modeled efficiency of the drivetrain from the input to the splitter box to the output of the final drives for the single reduction final drive with a double hydrostatic motor input. This efficiency relationship is compared to the modeled efficiency of the drivetrain using two-speed final drives and a single hydrostatic motor input as related in Figure 24. Appendix A contains the computer program that was written to evaluate these efficiencies as well as summary data sheets from runs used to develop these efficiency curves.

Table 4. Volumetric and Mechanical Efficiencies as a Function of Speed, Pressure and Displacement per Revolution for Linde Components

$$PVEFF(I) = .98 - \left[\frac{(0.012345)[(Data\ [1])](2000)}{(PDISP[I])(Data\ [3])}\right]^2 - \left[\frac{(0.0123)(SPRES[I])[(Data\ [1])](2000)}{(1450)(PDISP[I])(Data\ [3])}\right]^2 - \left[\frac{(.01)(SPRES[I])}{1450}\right]$$

$$PMEFF(I) = 1.0 - \left[\frac{(0.033)[(Data\ [1])](5000)}{(PDISP[I])(SPRES[I])}\right]$$

$$MVEFF(I) = .98 - \left[\frac{(0.012345)[(Data\ [2])](2000)}{(DISPM[I])(Data\ [3])}\right]^2 - \left[\frac{(0.0123)(SPRES[I])[(Data\ [2])](2000)}{(1450)(DISPM[I])(Data\ [3])}\right]^2 - \left[\frac{(0.1)(SPRES[I])}{1450}\right]$$

$$MMEFF = 1.0 - \left[\frac{(0.025)(5000)[(Data\ [2])]}{(SPRES[I])(DISPM[I])}\right]$$

PVEFF(I) = Pump Volumetric Efficiency for Variable Range
Data [1] = Pump Maximum Displacement
PDISP(I) = Pump Displacement at Point of Investigation
Data [3] = Pump/Motor RPM
SPRES(I) = Pressure at Point of Investigation
PMEFF(I) = Pump Mechanical Efficiency for Variable Range
DISPM(I) = Motor Displacement at Point of Investigation
Data [2] = Motor Maximum Displacement
MMEFF(I) = Motor Mechanical Efficiency at Point of Investigation
MVEFF(I) = Motor Volumetric Efficiency at Point of Investigation

Table 5. Hydrostatic Test Platform Development Options

1. Incorporate a single-reduction final drive with a double motor input.

2. Incorporate a two-speed final drive with a single motor input.

	OPTION 1	OPTION 2
Hydrostatic Pump	2 Linde BPV 200 12.24 in^3/rev 6000 psi 2600 rpm	2 Linde BPV 100 6.12 in^3/rev 6000 psi 2800 rpm
Hydrostatic Motor	4 Linde BMV 260 15.88 in^3/rev 1130 ft-lb_f 2600 rpm	2 Linde BMV 186 11.36 in^3/rev 812 ft-lb_f 3000 rpm
Final Drive	Single Reduction 3.71 Ratio	Funk Two-Speed 10.877 ratio in Low 4.10 ratio in High

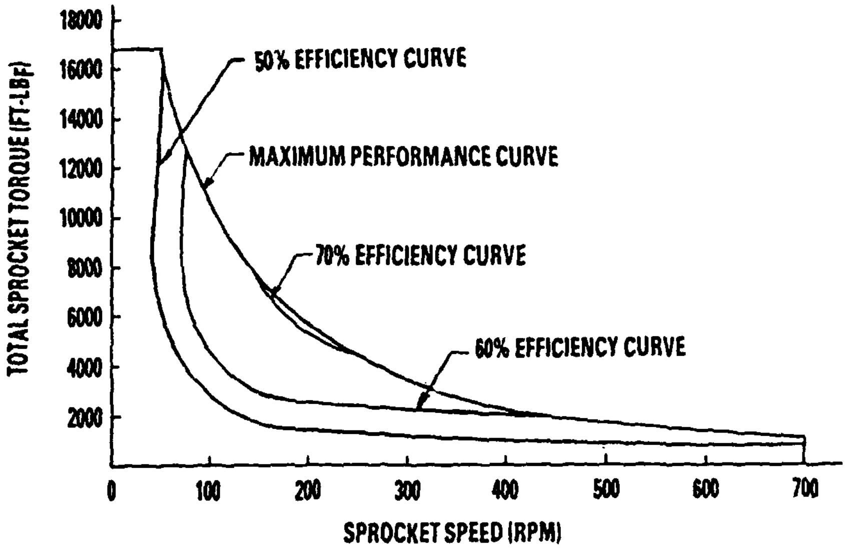


FIGURE 23. MODELED PERFORMANCE OF HTP VEHICLE WITH SINGLE REDUCTION FINAL DRIVE

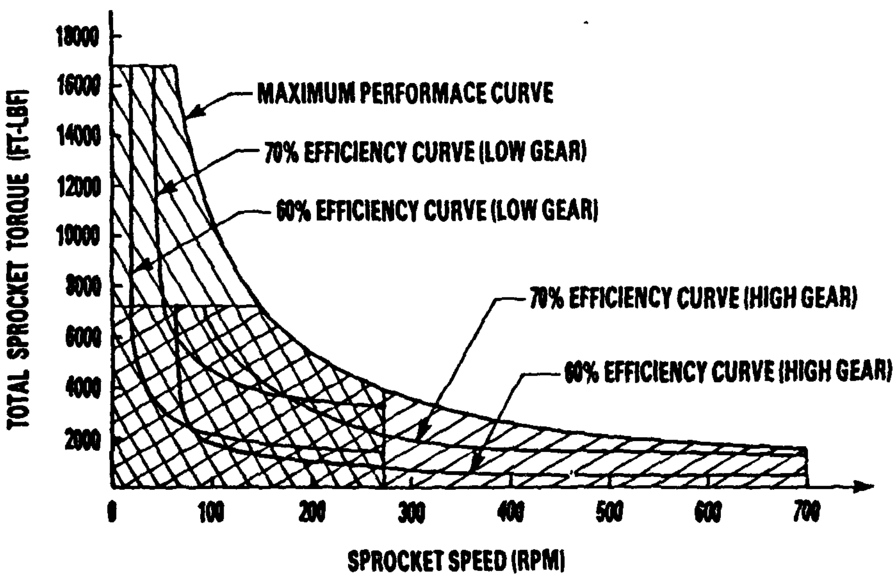


FIGURE 24. MODELED PERFROMANCE OF HTP VEHICLE WITH TWO-SPEED FINAL DRIVE

A comparison of Figures 23 and 24 indicates that the two-speed final drive option was considered to be between 5 and 17 percent more efficient at transmitting near maximum available engine power and was, in general, approximately 12 percent more efficient at transmitting partial engine power to he output sprocket. The basic reason for this difference is that inefficiencies of hydrostatic components, when operated at high pressures and low flows or high flows and low pressure, is compounded by the use of larger components in the case of the single reduction final drive. It was for this reason that two-speed final drives were used on this vehicle.

5.3 Transmission Efficiency From Whole Vehicle Dynamometer Testing

To determine the actual efficiency of the transmission, a whole vehicle dynamometer test was performed as pictorially described in Figure 25. In general, the dynamometer output speed and torque values were monitored relative to the engine output power. The auxiliary pump power was subtracted from the engine power and the overall transmission efficiency was determined as the ratio of dynamometer power to net transmission input power.

While this dynamometer test arrangement would be ideal for determining the overall transmission efficiency, a number of problems were discovered that reduce the accuracy of the test results. These problems included the lack of sufficient low speed torque capability in the dynamometers to adequately determine the sprocket output power in low gear, a lack of absolute confidence in the determination of the engine output power, and a concern that a substantial amount of power was being inadvertently consumed by the final drives and brakes during most of the testing.

The problem associated with the inability to obtain high sprocket torques at low sprocket speeds is related to the use of eddy-current dynamometers for this test. Although the dynamometers used were rated at 1200 hp each, this rating is effective for speeds in excess of 800 rpm. At lower sprocket speeds the power rating is reduced. As a result, only sprocket speeds in excess of 100 rpm were tested. Since low gear sprocket speeds vary from 0 rpm to 265 rpm and high gear sprocket speeds vary from 0 rpm to 700 rpm, the range of test prints was accordingly limited.

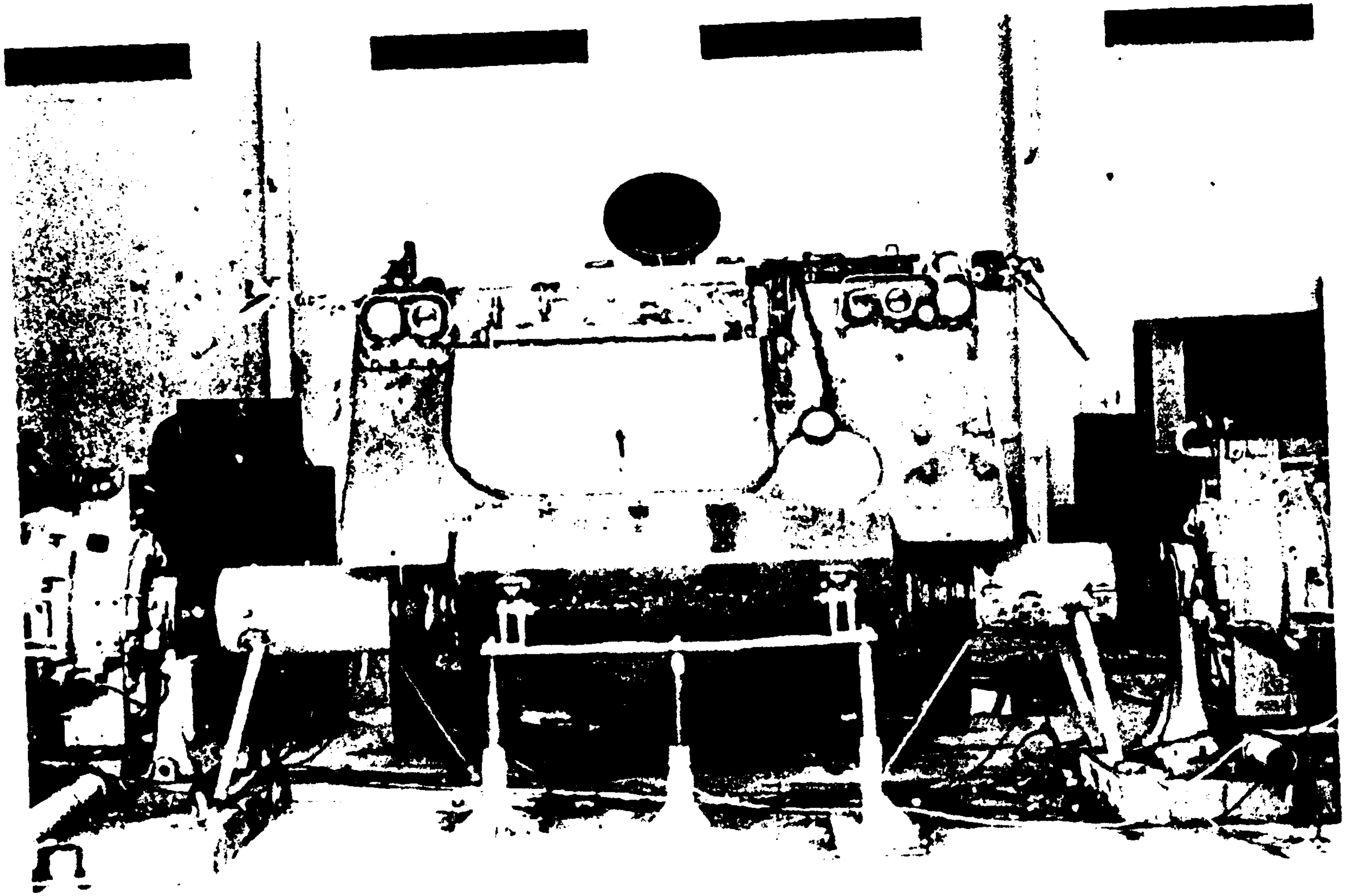


FIGURE 25. WHOLE VEHICLE TEST SET-UP AT SwRI

Accurately determining the engine output power also turned out to be problematic because there was not a sufficient amount of space in the engine compartment to incorporate the use of an in-line torque transducer. To estimate the output power for each test, the engine fuel usage data presented as Figure 19 was used. During each test, the fuel usage rate and engine speed were recorded. The engine output horsepower was obtained by cross-matching the fuel usage rate to the engine speed and reading the output power. Future tests of the efficiency oi this transmission system should include a more accurate method of determining engine output power.

The single largest concern pertaining to the results of the dynamometer tests is the bias induced because of the improper operation of the final drives and brakes. During the course of the testing, numerous failures of critical items in the final drives and brakes were experienced. Clutches were seized because of hydrodynamic actuation of both the low and high clutches during high-speed operation. Additionally, bearing failures occured at two different times as a result of oil starvation and three brake failures occurred as a result of improper support of the brake shaft as provided by the factory. All failures were progressive and had an indeterminant effect on the tests that were taking place.

The test data that was obtained is presented in Appendix B. Corrections to the test data were made to partially compensate for the losses that were incurred as a result of the previously mentioned failures. The resulting dynamometer efficiency data is presented as Figure 26.

A comparison of this dynamometer test data to the modeled test data (Figure 24) reveals two basic findings. First, the efficiency of the transmission under dynamometer test conditions is lower than the efficiency as predicted from the computer model. Second, the dynamometer test data is incomplete because of an inability to adequately load the transmissions at low speed as was previously related and because of an insufficient amount of time available to perform a comprehensive matrix of test conditions.

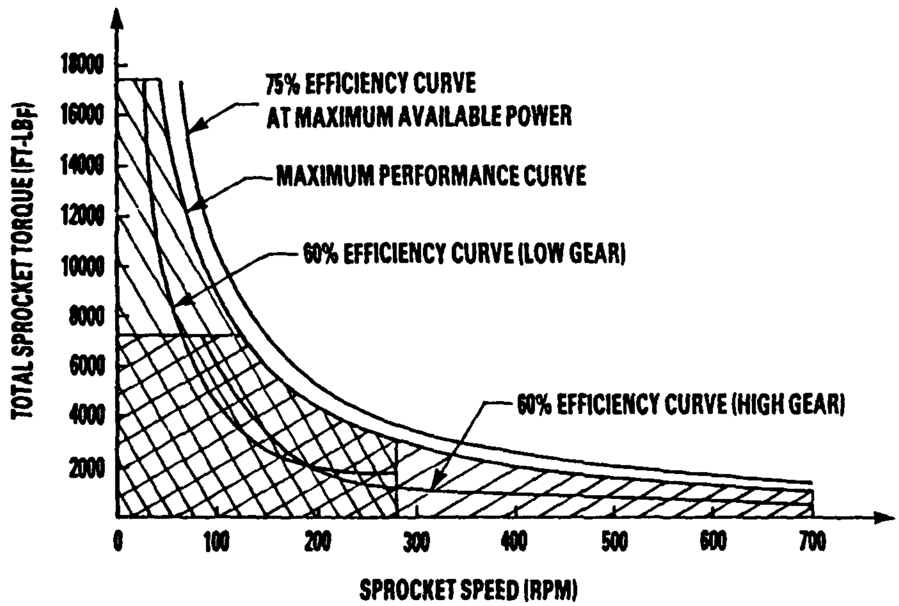


FIGURE 26. HTP EFFICIENCY FROM DYNOMOMETER TEST RESULTS

Several attempts have been made to determine why the dyno test results show the transmission to be less effective than expected, and the lack of firm conclusions indicated that additional dynamometer testing should be performed. However, several likely sources of the inefficiency problem have been identified. These include the power consumed by the final drives, even when they are operating properly, the power consumed by the cooling fan, improper sequencing of the pump and motor displacements, and power losses associated with slightly smaller than optimum main hydraulic hoses.

Figure 27 relates the power consumed by both final drives as a function of sprocket speed. This data was obained by measuring the deceleration rate of the dynamometers after they had been operated at a steady 700 rpm.

5.4 Transmission Efficiency from Transmission Component Dynamometer Testing

To determine the actual transmission efficiency, a series of component dynamometer tests have been performed. The test setup is shown in Figure 28. In these tests a diesel engine was used as the pump input power device and a mechanical dynamometer was used as the power absorbing device. By using this dynamometer the transmission was loaded to stall torque over its entire speed envelope.

Dynamometer tests were performed on used hydrostatic components taken from the vehicle after one year of field testing. These components were inspected by Linde personnel and were found to be worn in excess of the number of hours obtained from the field test activities. This condition is noteworthy because of the debris subjected to these components from the whole vehicle dynamometer failures previously related and because of the hydraulic fluid used in this test vehicle.

The hydraulic fluid used throughout the project was a MIL-SPEC-83282 fire resistant hydraulic fluid. This fluid has a considerably lower viscosity than other hydraulic fluids, especially at elevated temperatures. The viscosity versus temperature relationshiop for this fluid is shown in Figure 29. This low viscosity can generally be related to lower component volumetric efficiencies.

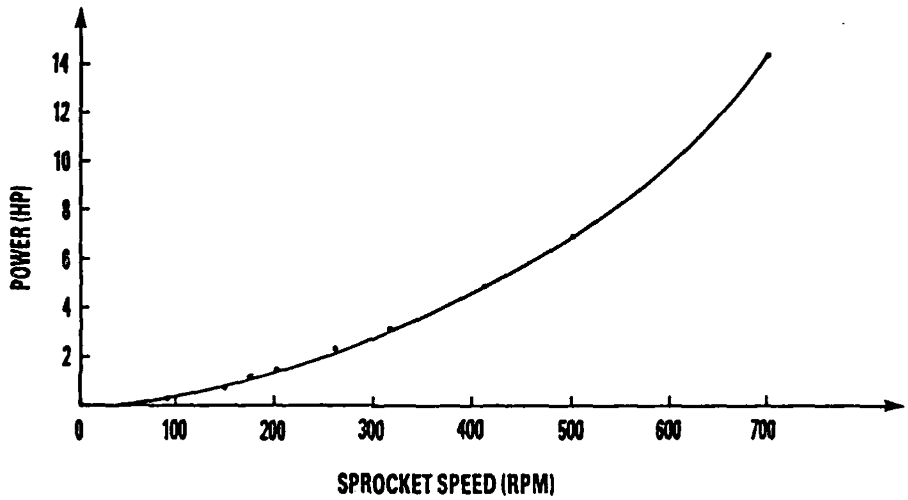


FIGURE 27. FINAL DRIVE POWER CONSUMPTION VERSUS SPROCKET SPEED

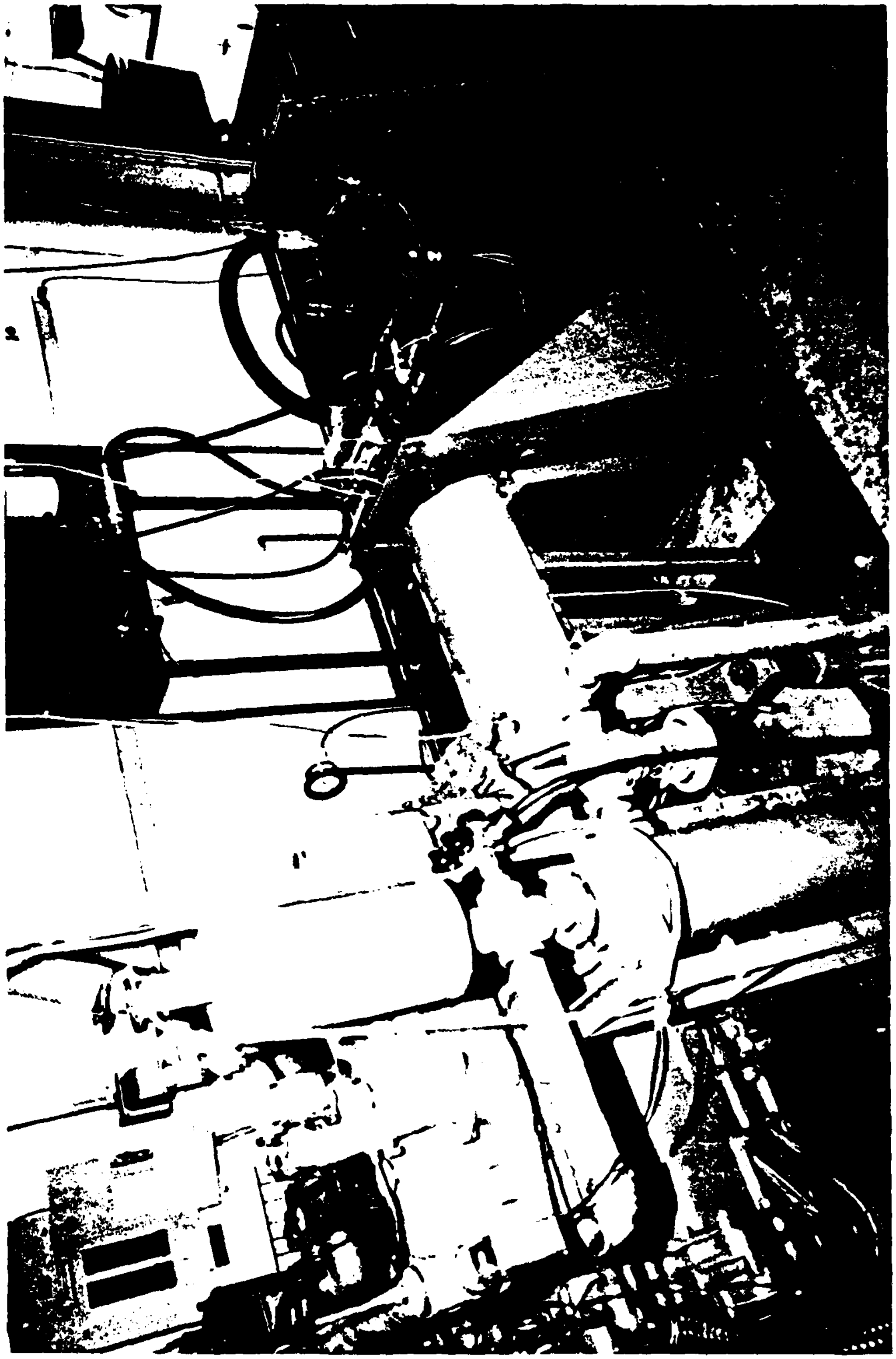


FIGURE 28. TRANSMISSION TEST SET-UP AT SwRI

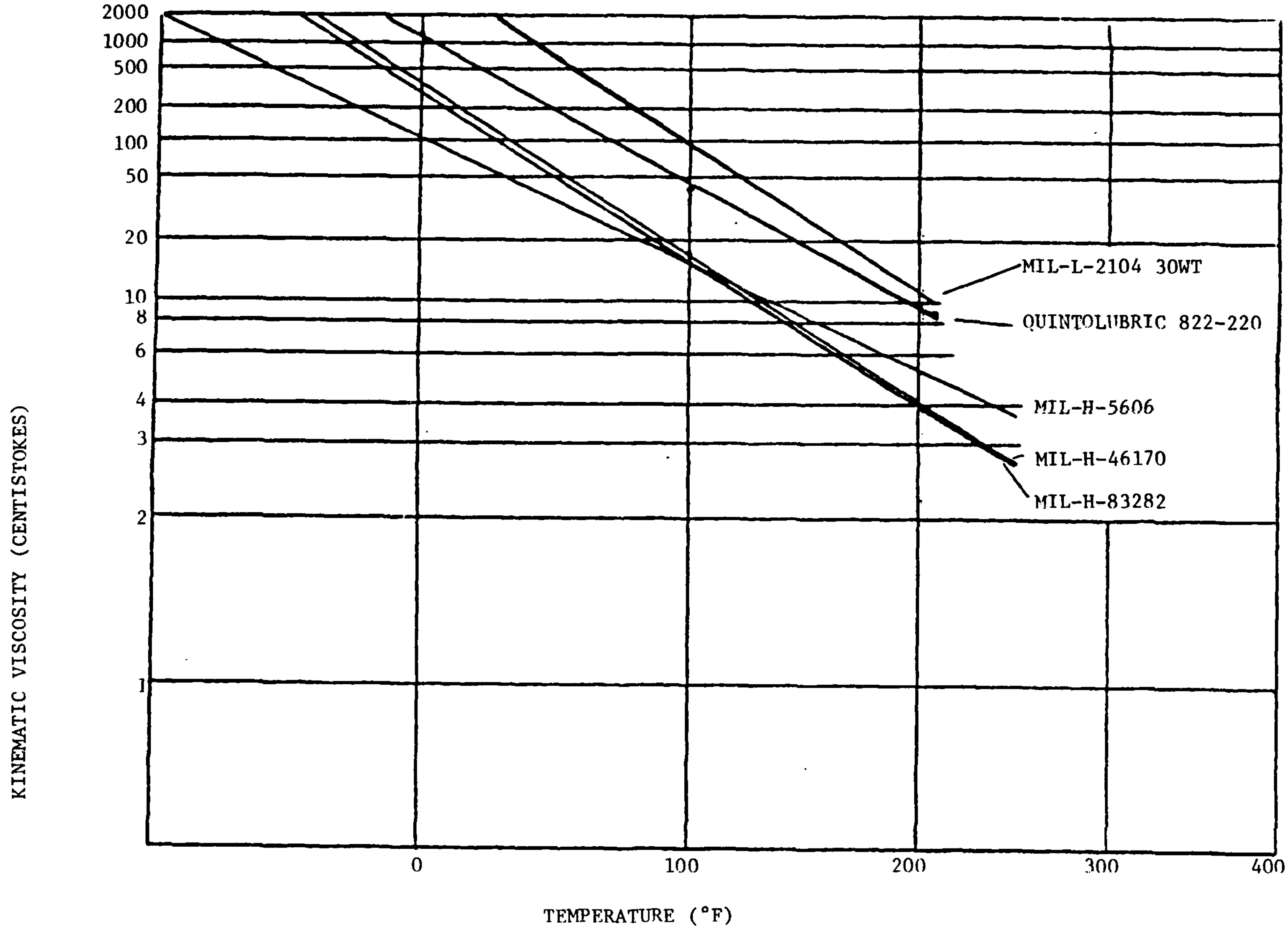


FIGURE 29. VISCOSITY VERSUS TEMPERATURE RELATIONSHIP OF HYDRAULIC FLUIDS

The dynamometer tests were thus performed to determine the transmission efficiency under the conditions of worn components and less than ideal hydraulic fluid. Tests were performed at pump inlet speeds which varied between 1000 and 2800 rpm. The motor torques were varied between 0 and 800 ft-lb_f. The other control variable was transmission control voltage which varied between 0 and 24 VDCA (volts direct current average). The test results are presented in Figures 30 through 39 to relate motor speed versus control pressure at various motor torque values at different engine speeds. Figures 40 through 49 illustrates this same data but in the form of overall transmission efficiency versus motor output speed at various motor torque values at different engine speeds. The pump input speed for these tests is equal to the engine speed. Finally, all the data is summarized in Figure 50, which relates the sprocket torque versus sprocket speed relationships that could be derived from this data with lines of constant efficiency indicated. Computer prints of the actual data obtained is contained in Appendix C.

These figures relate lower efficiency values than were predicted from the modeled analysis. The reasons for this are twofold: (1) the transmission components were of a worn condition, and (2) the low hydraulic oil viscosity produces more internal leakage which reduces efficiency.

In order to determine the efficiency potential of these transmission components, additional tests are planned under separate contract from DTNSRDC to AAI Corporation with SwRI performing subcontract tasks to retest new transmission components. The final results of these tests will be presented in the report under Contract No. N00167-84-C-0022, but preliminary efficiencies of 82 percent have been obtained at motor speeds of 1700 rpm and 300 ft-lb_f torque.

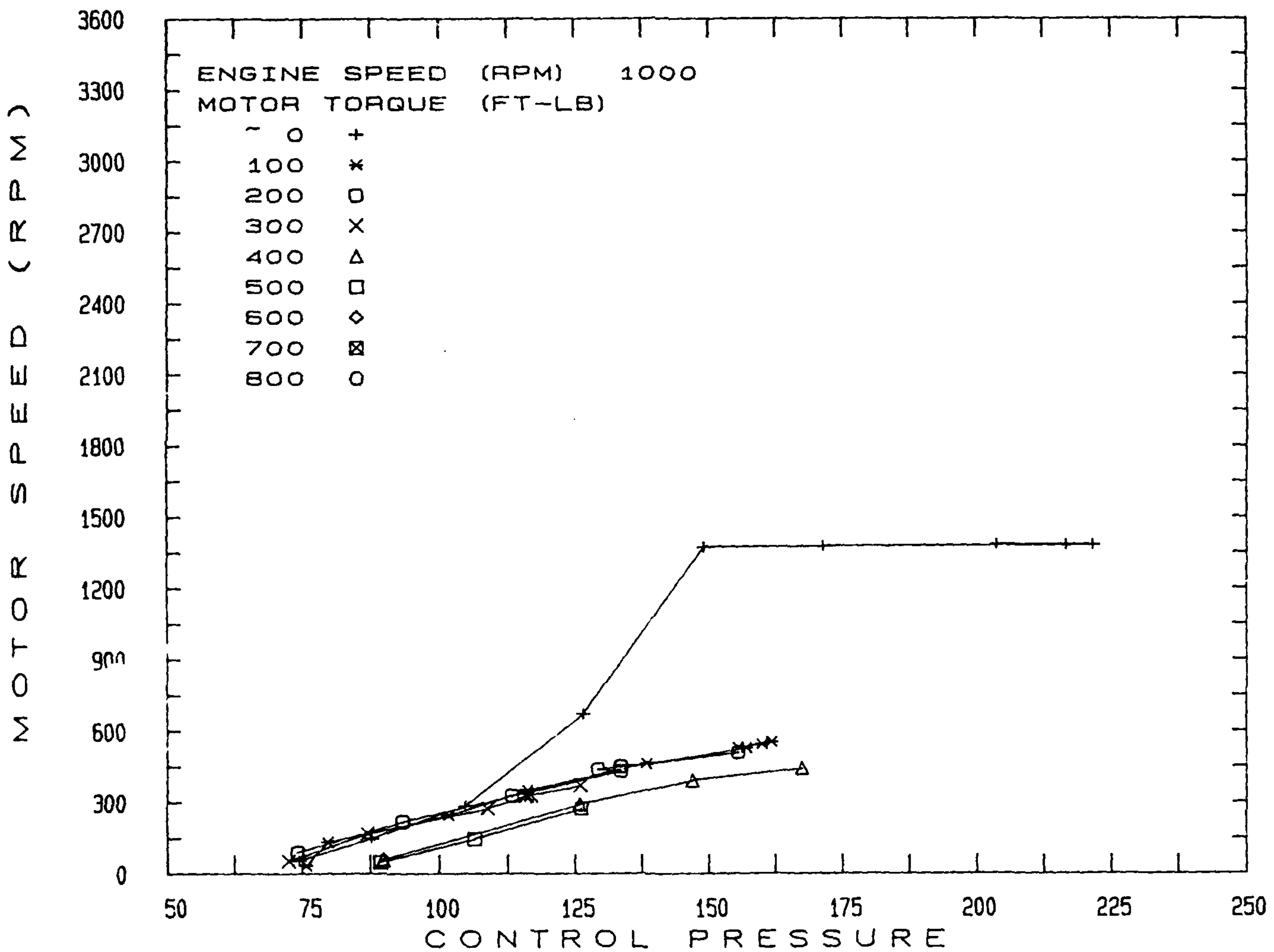


FIGURE 30. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1000 RPM.

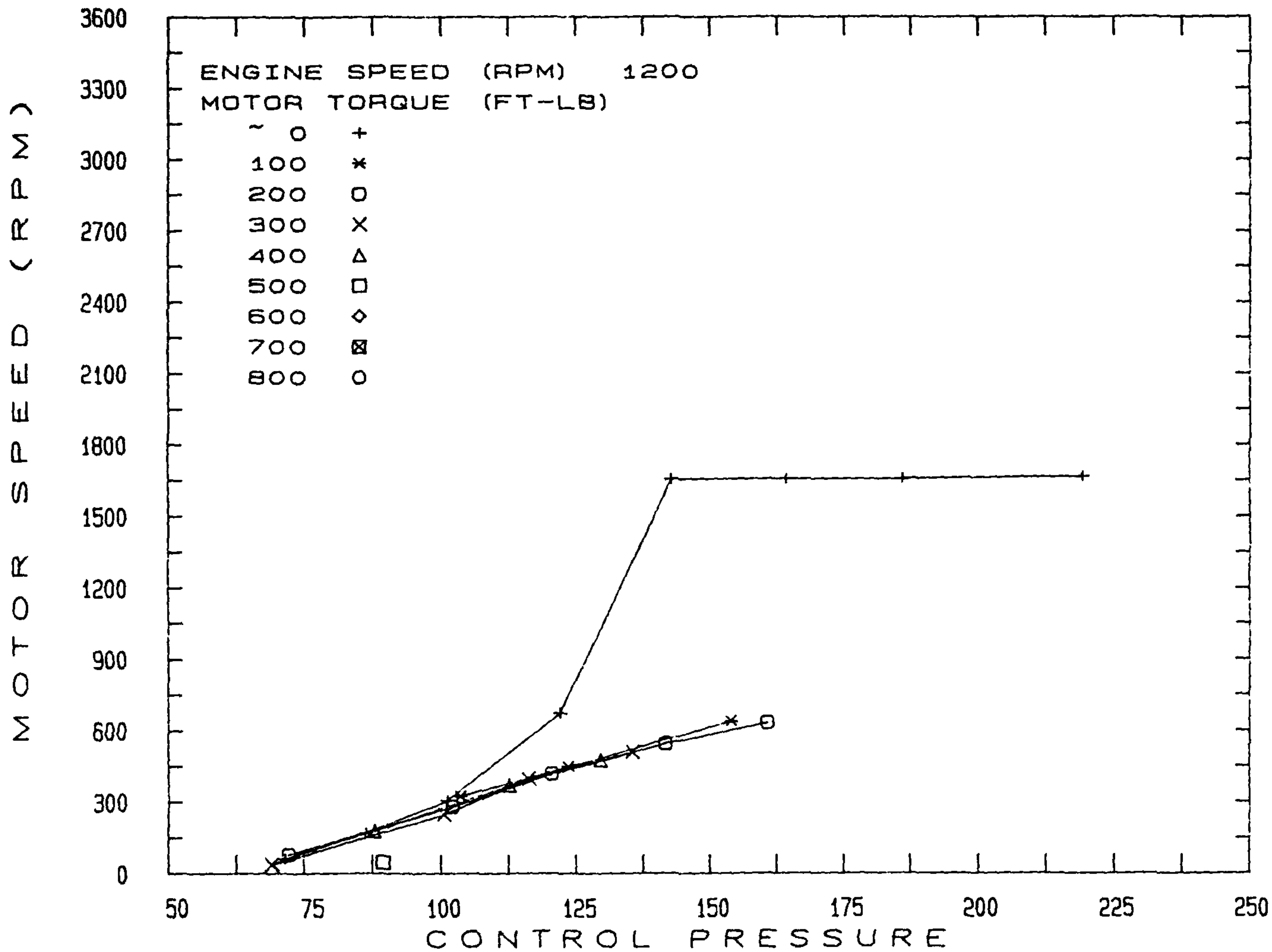


FIGURE 31. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1200 RPM.

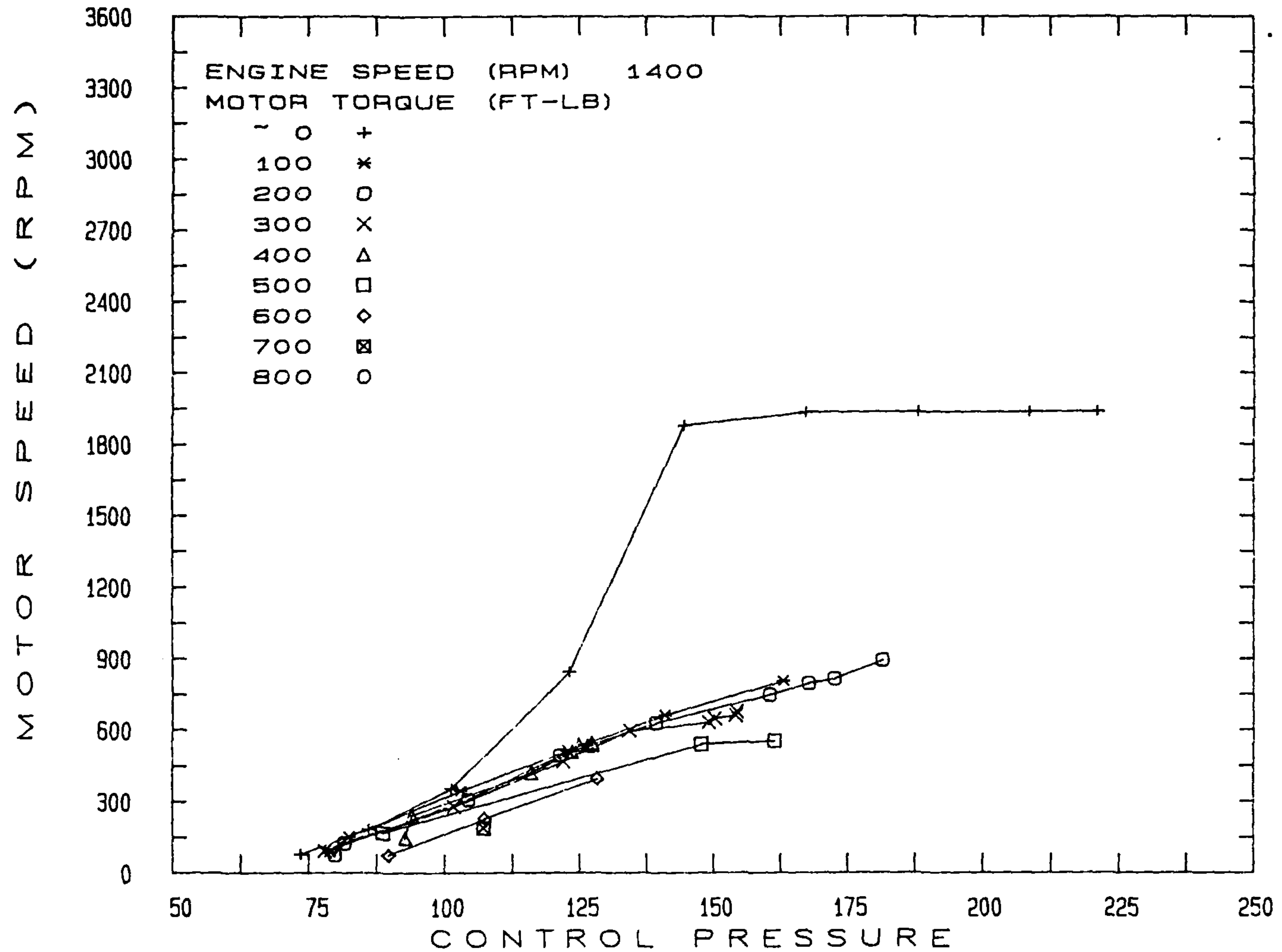


FIGURE 32. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1400 RPM.

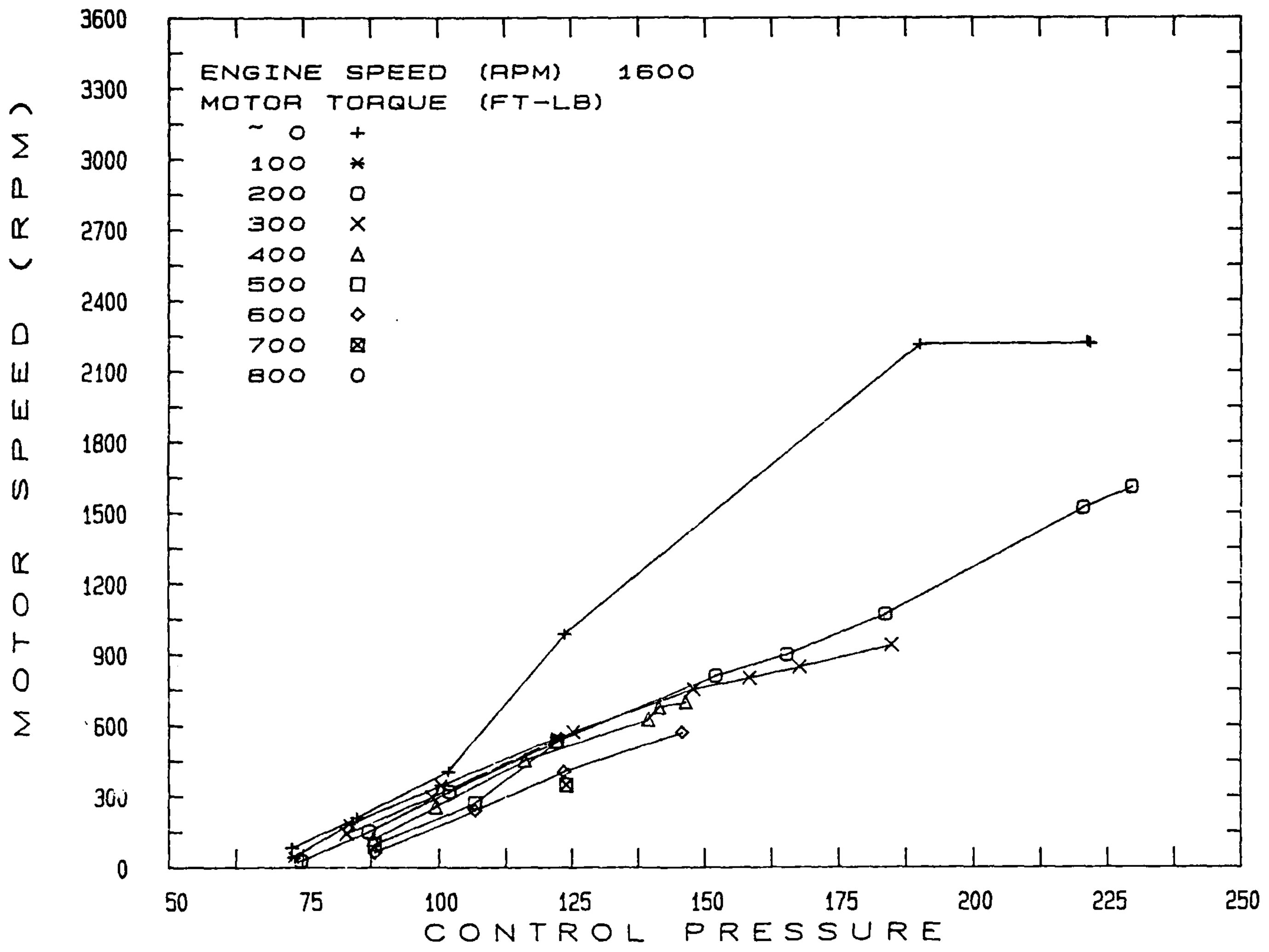


FIGURE 33. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1600 RPM.

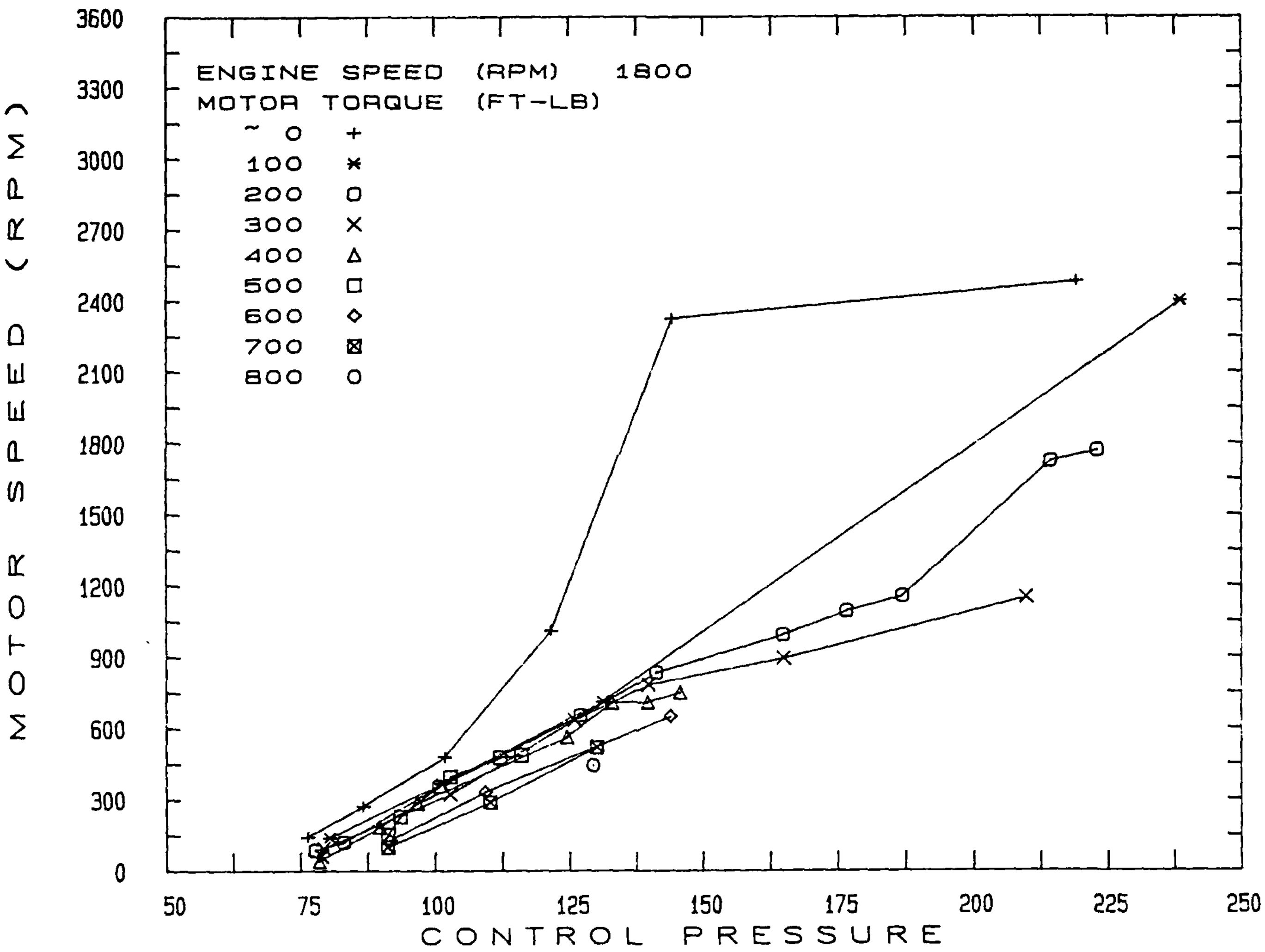


FIGURE 34. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1800 RPM.

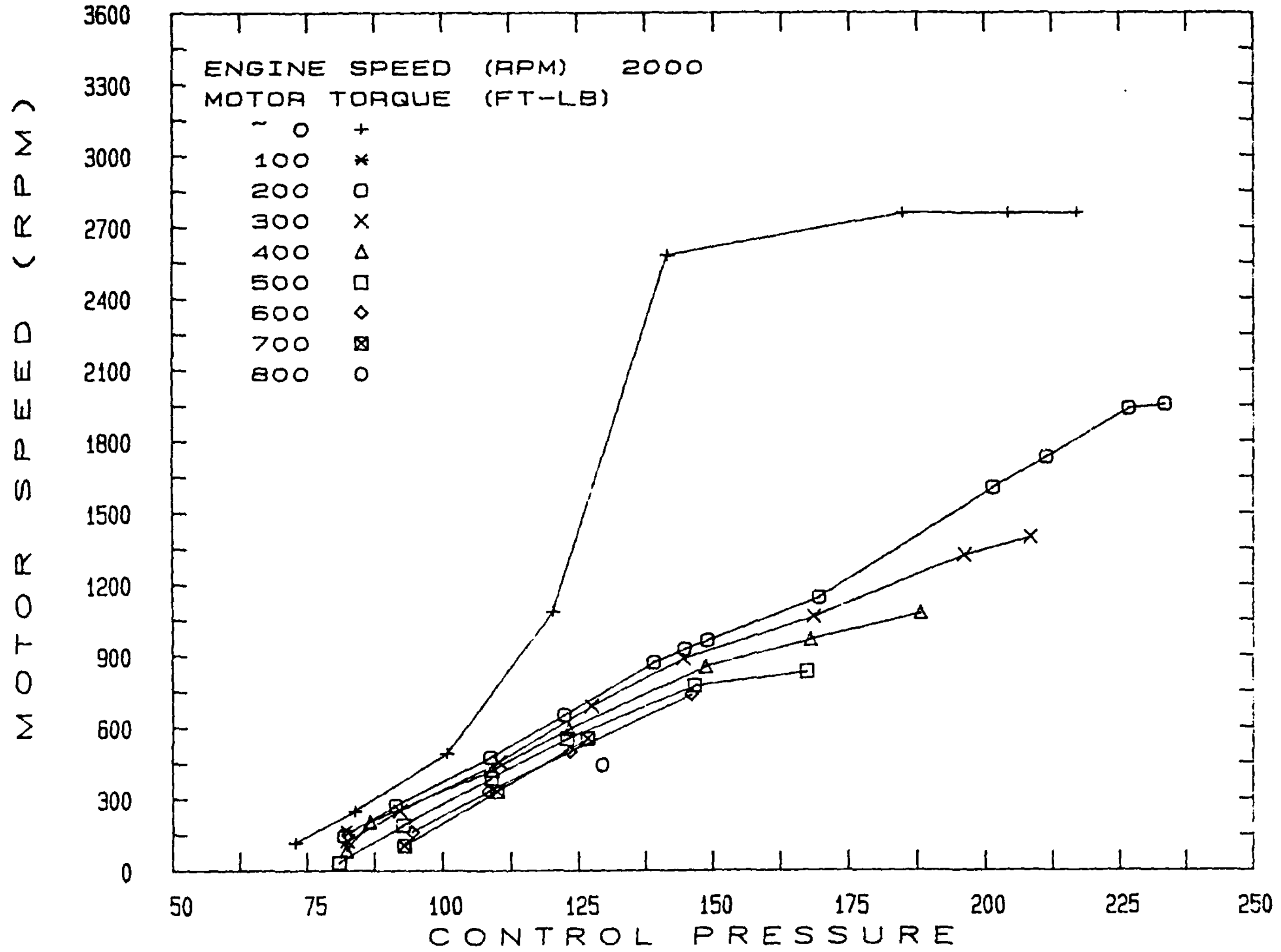


FIGURE 35. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2000 RPM.

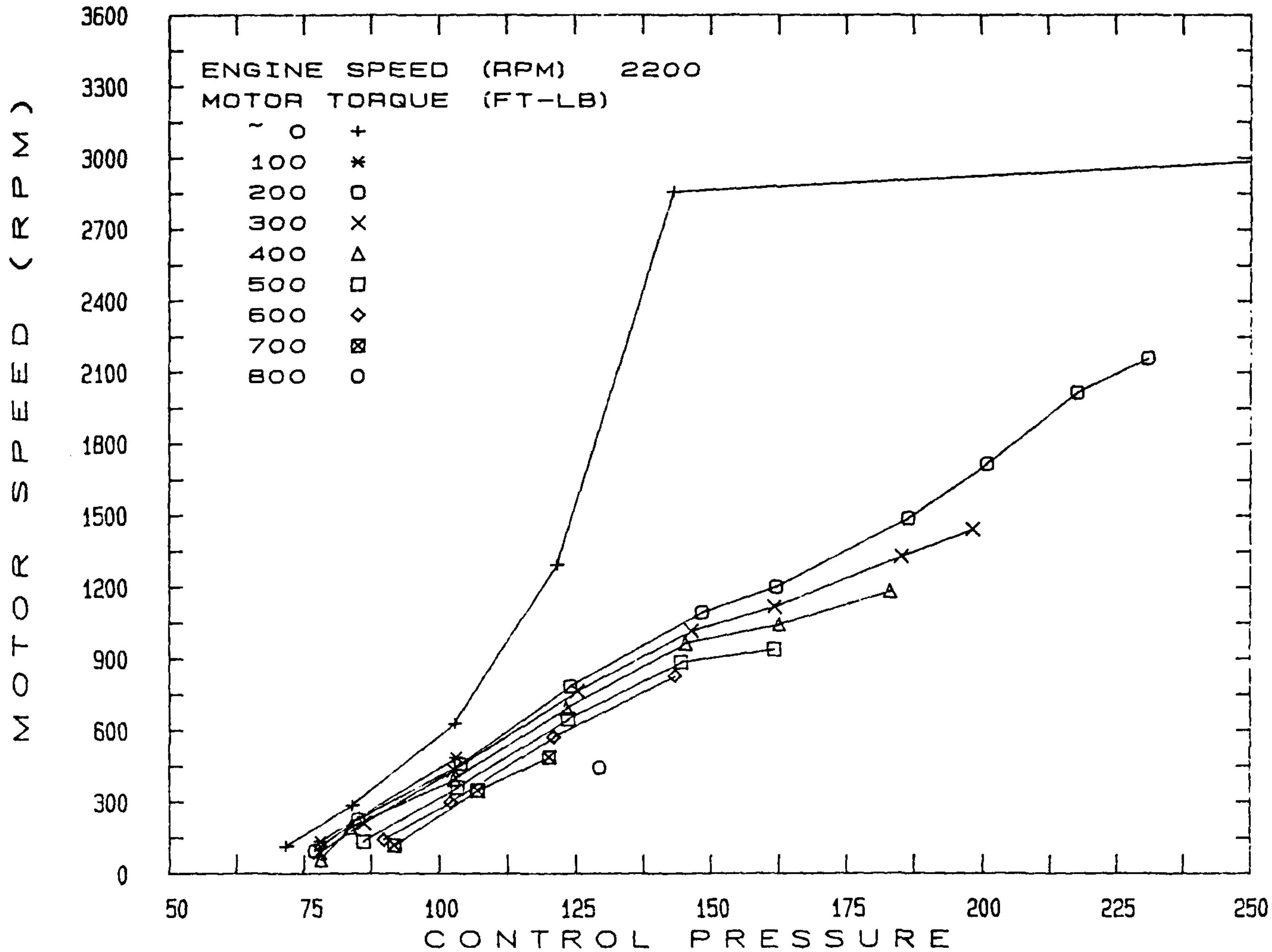


FIGURE 36. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2200 RPM.

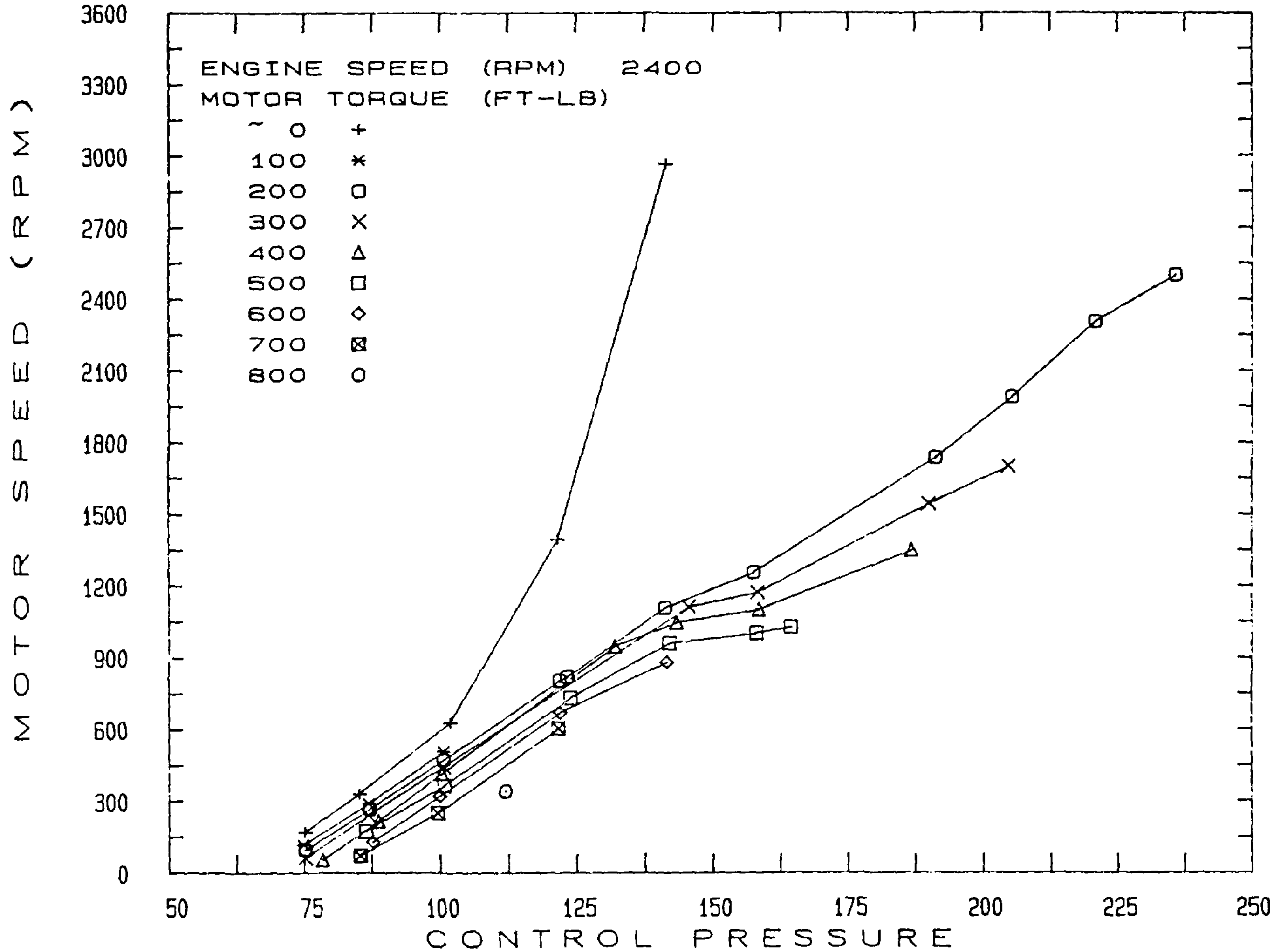


FIGURE 37. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2400 RPM.

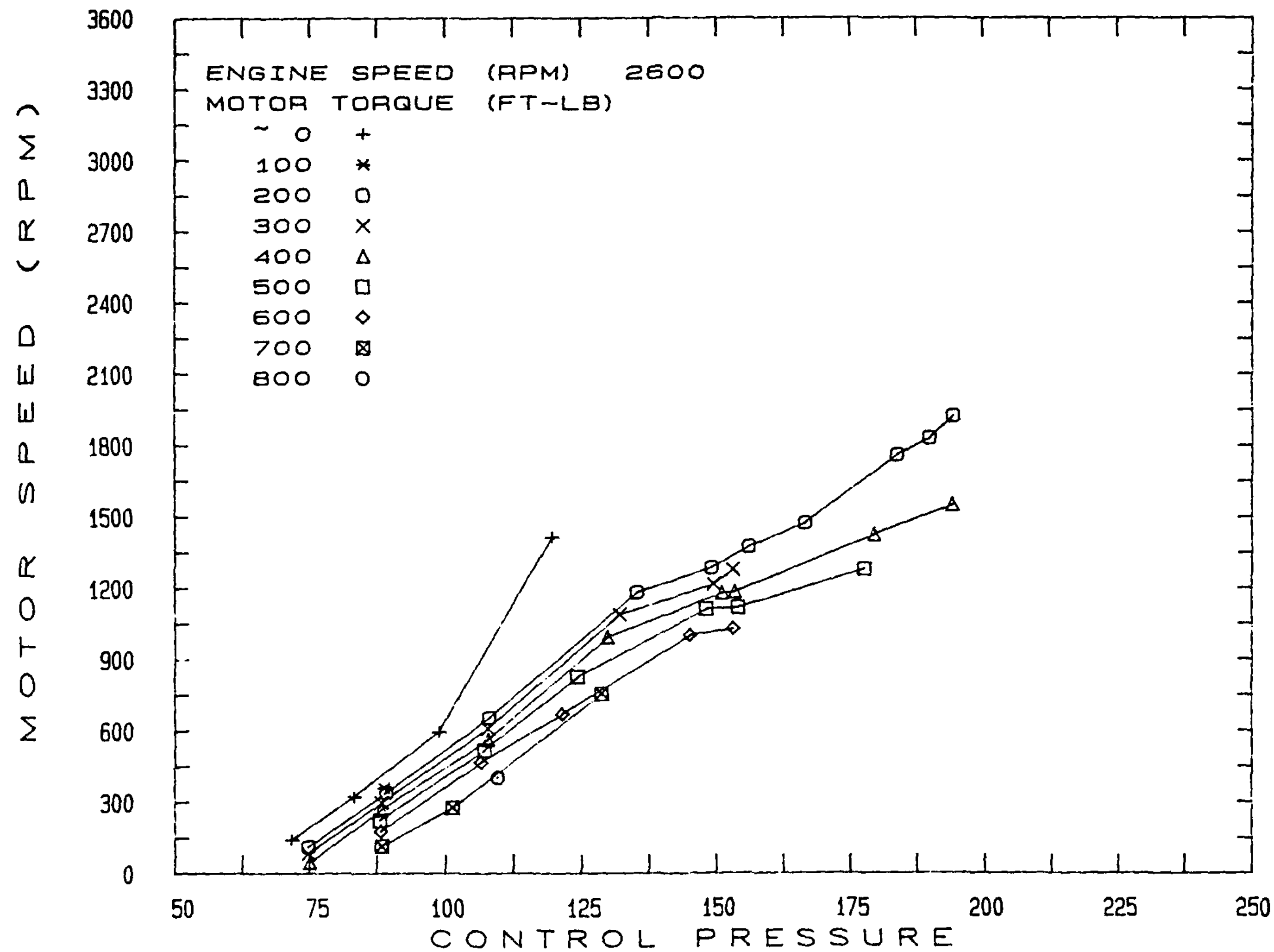


FIGURE 38. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2600 RPM.

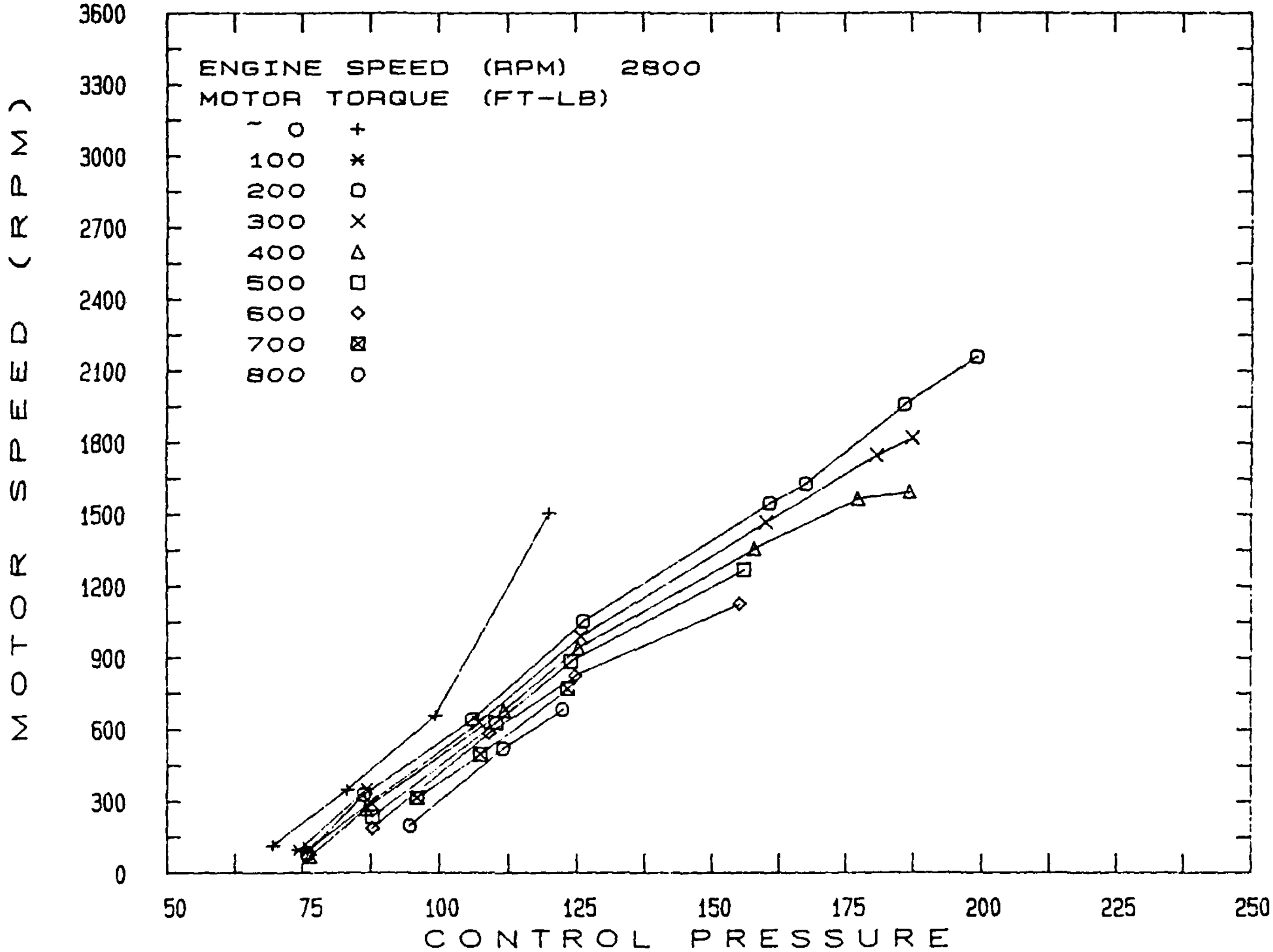


FIGURE 39. TRANSMISSION MOTOR SPEED VERSUS CONTROL PRESSURE FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2800 RPM.

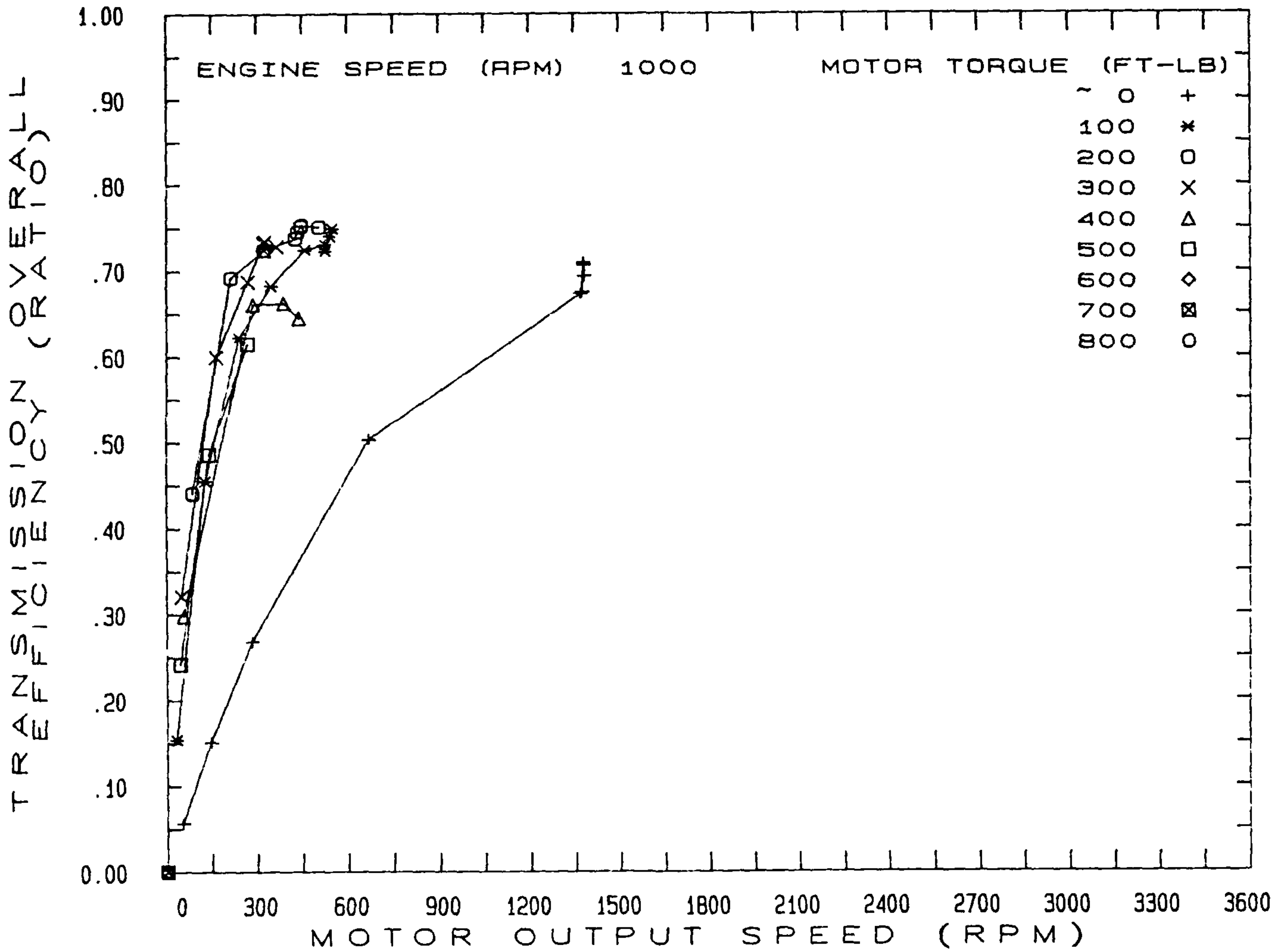


FIGURE 40. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1000 RPM.

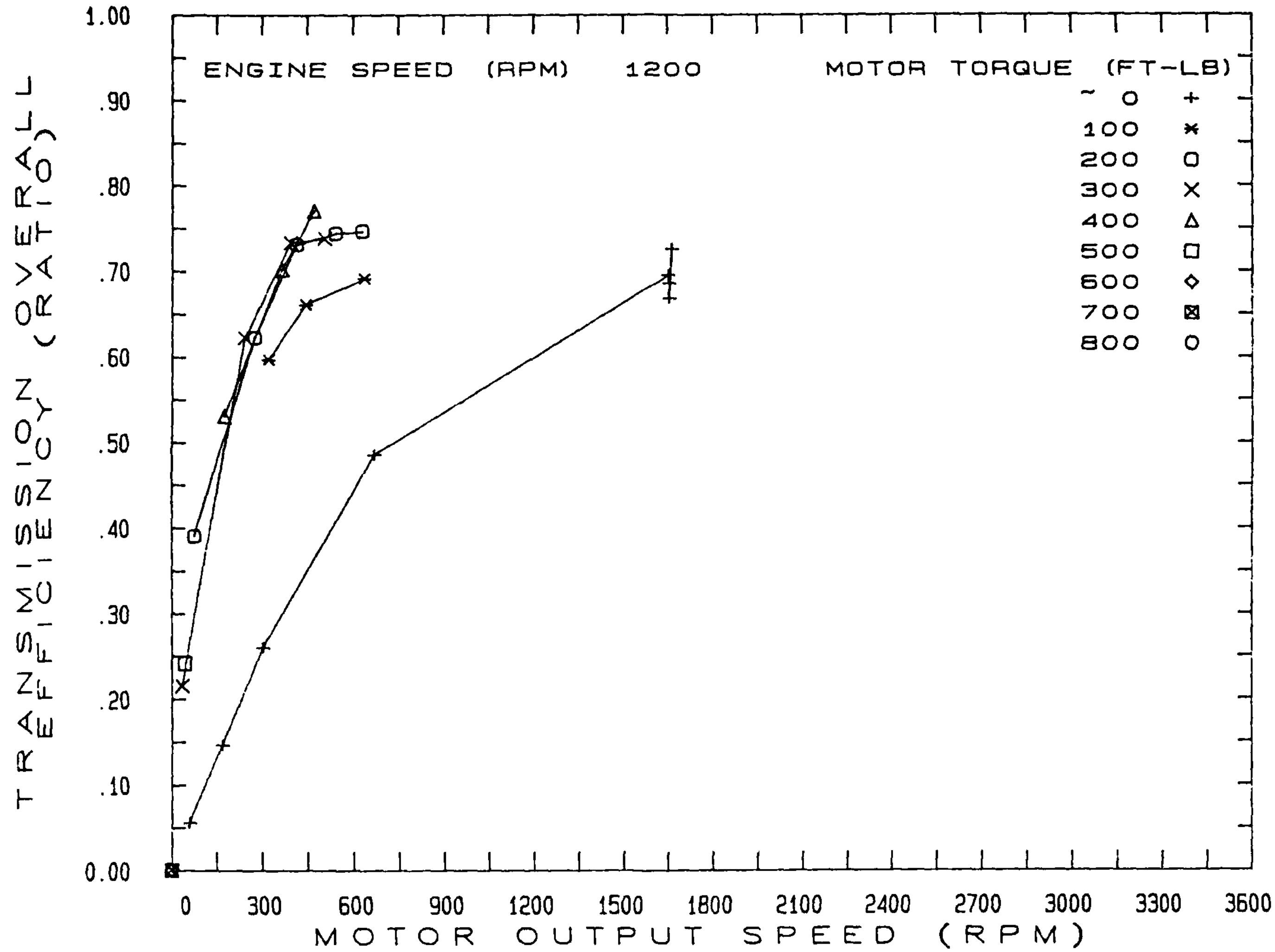


FIGURE 41. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1200 RPM.

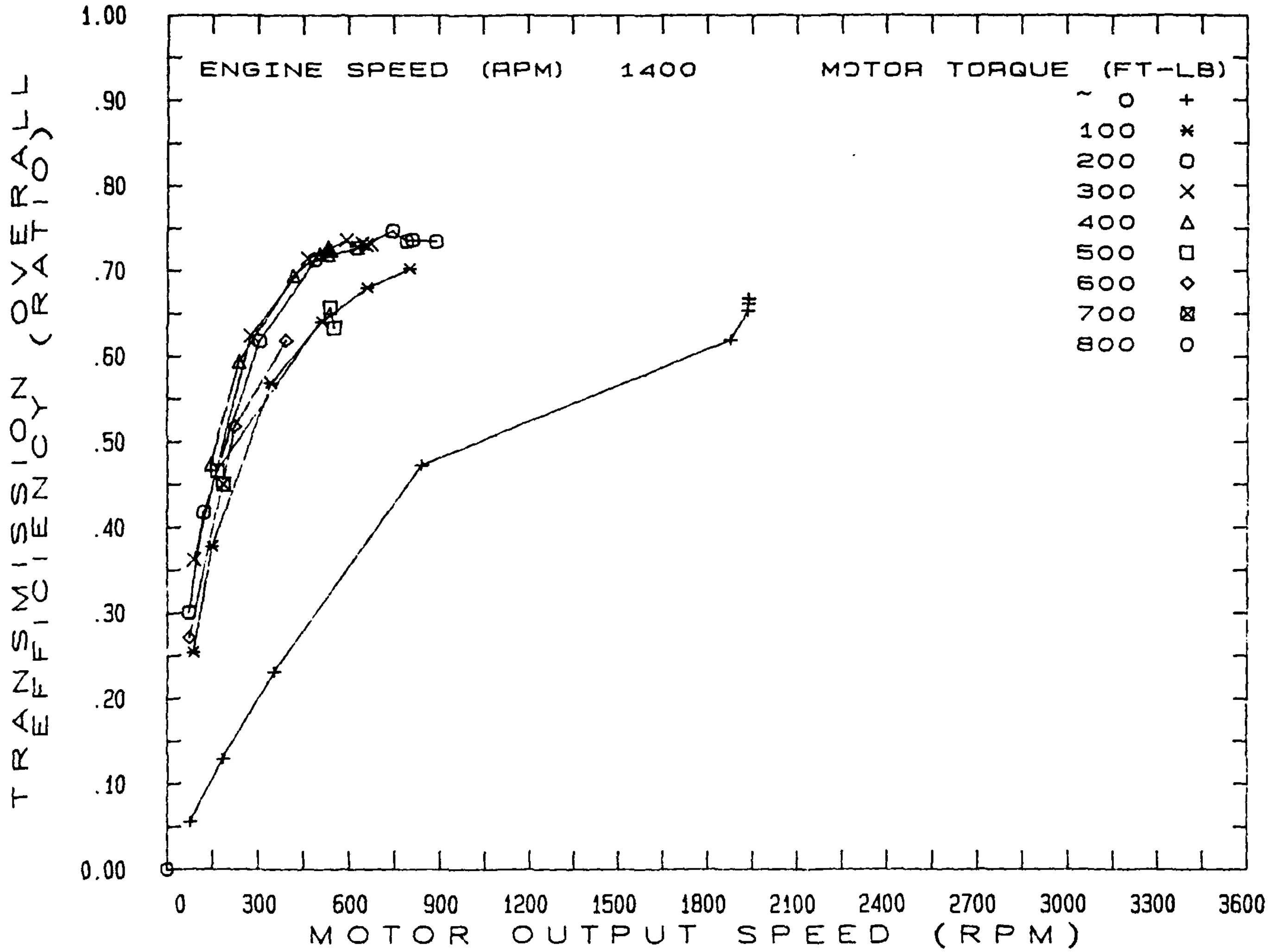


FIGURE 42. TRANSMISSION ONVEALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1400 RPM.

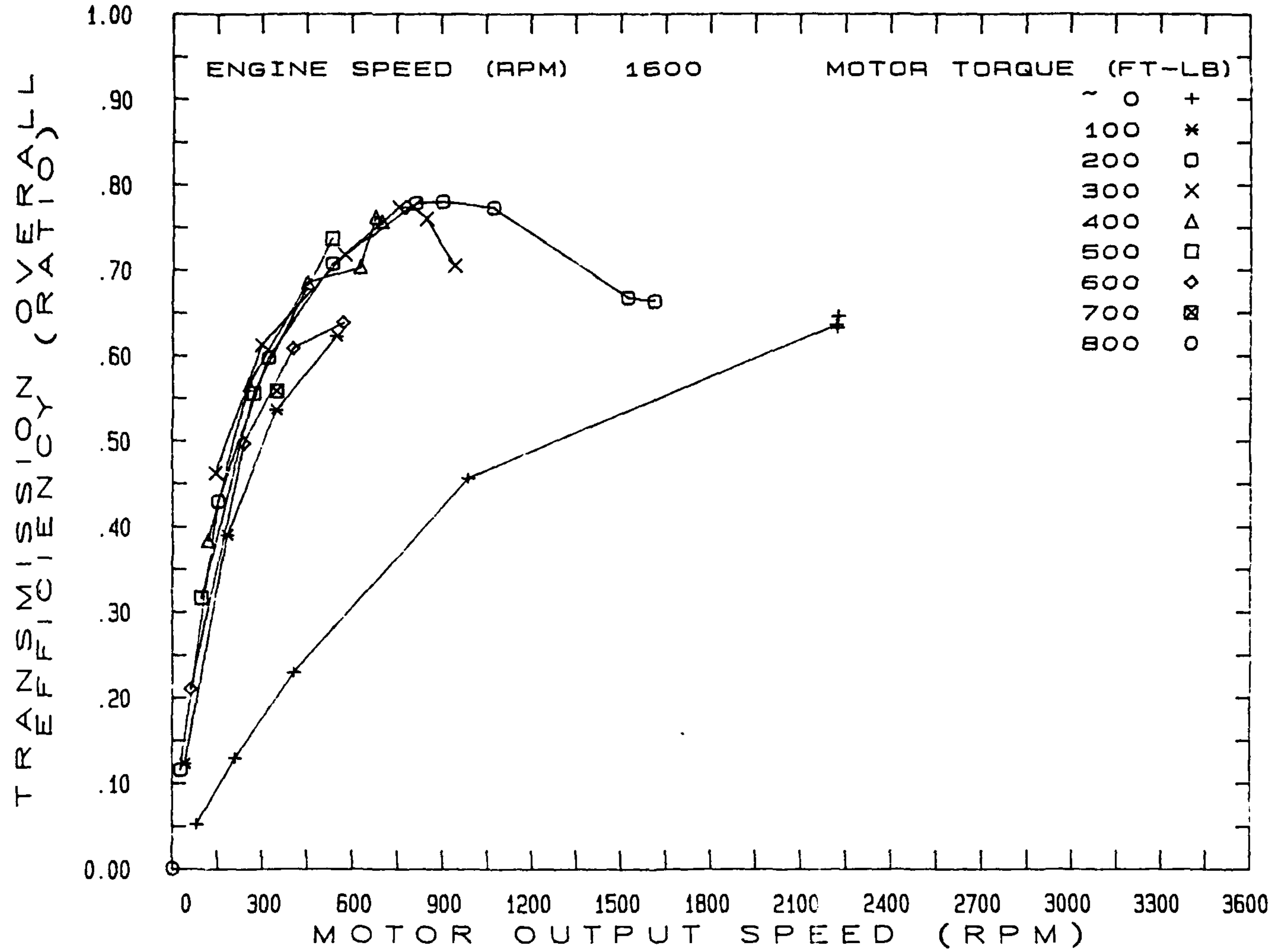


FIGURE 43. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1600 RPM.

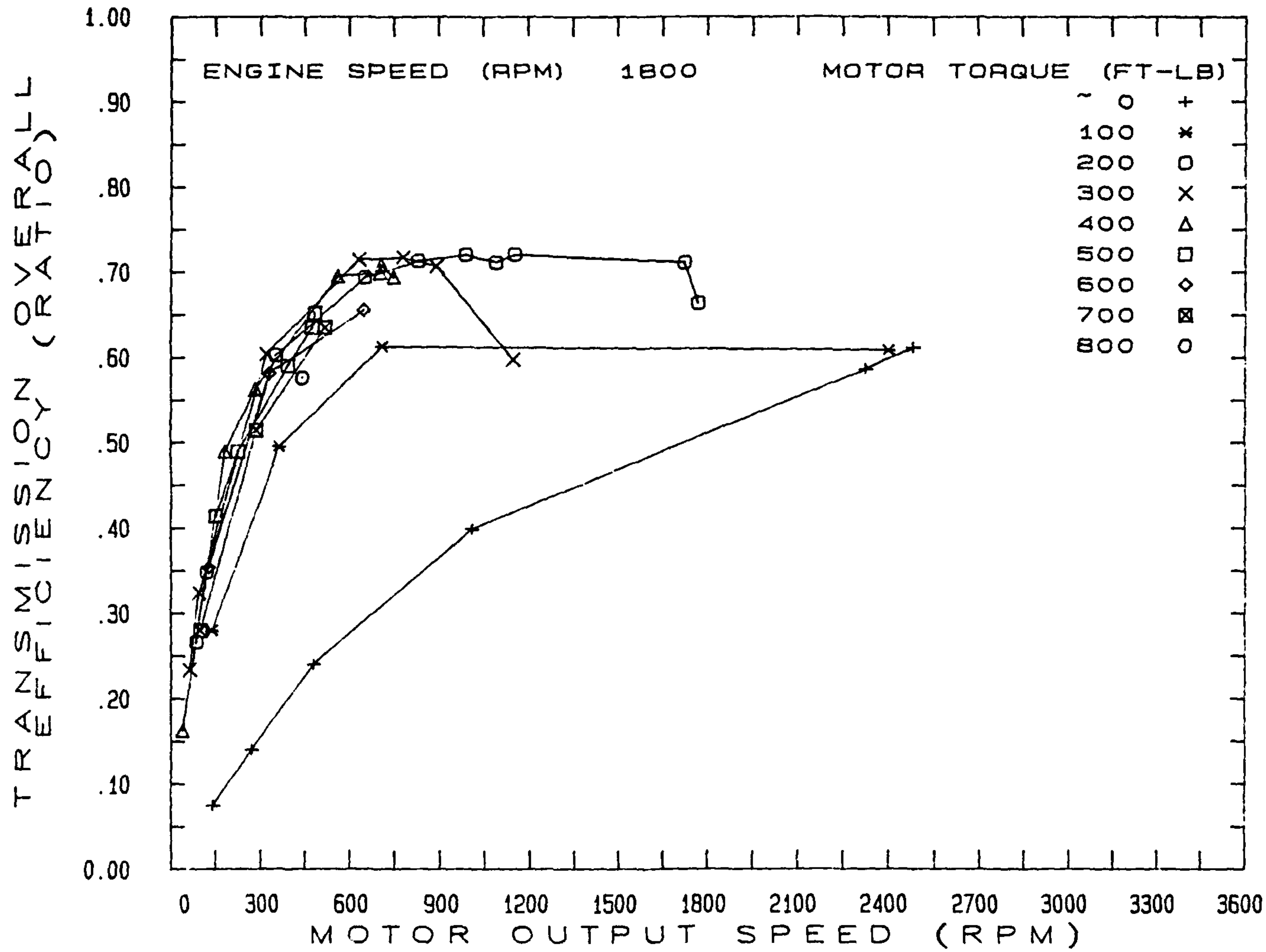


FIGURE 44. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 1800 RPM.

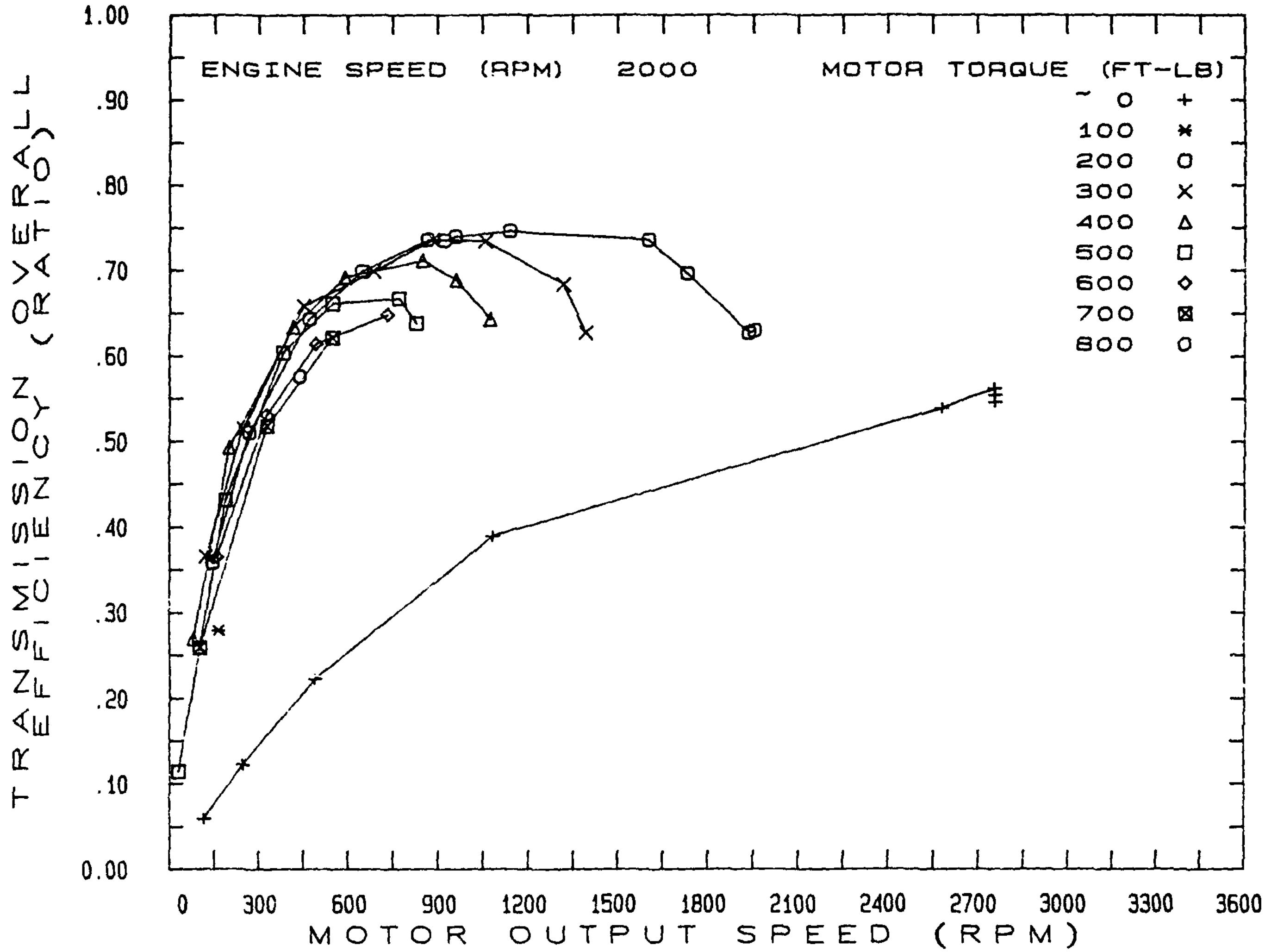


FIGURE 45. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2000 ROM.

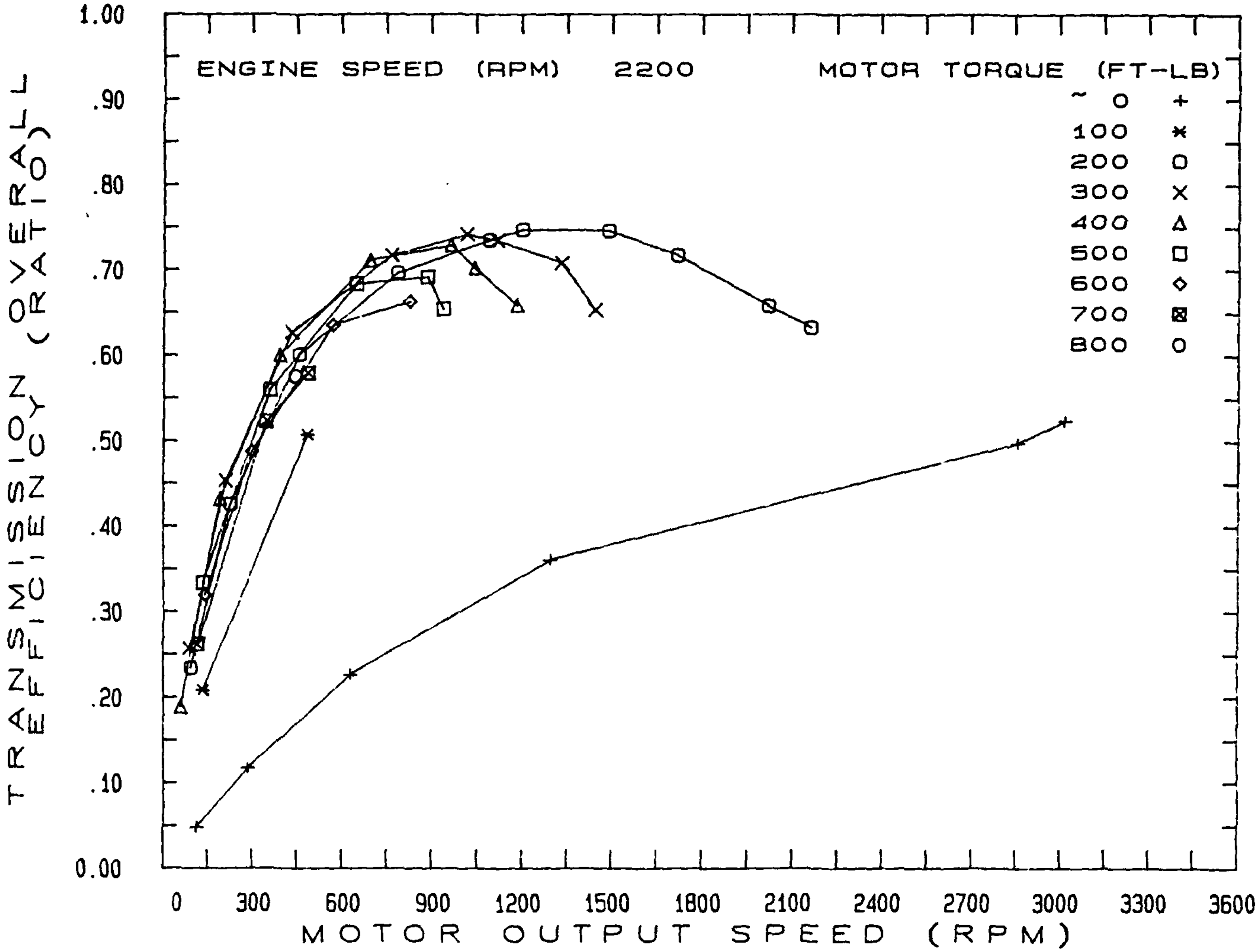


FIGURE 46. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2200 RPM.

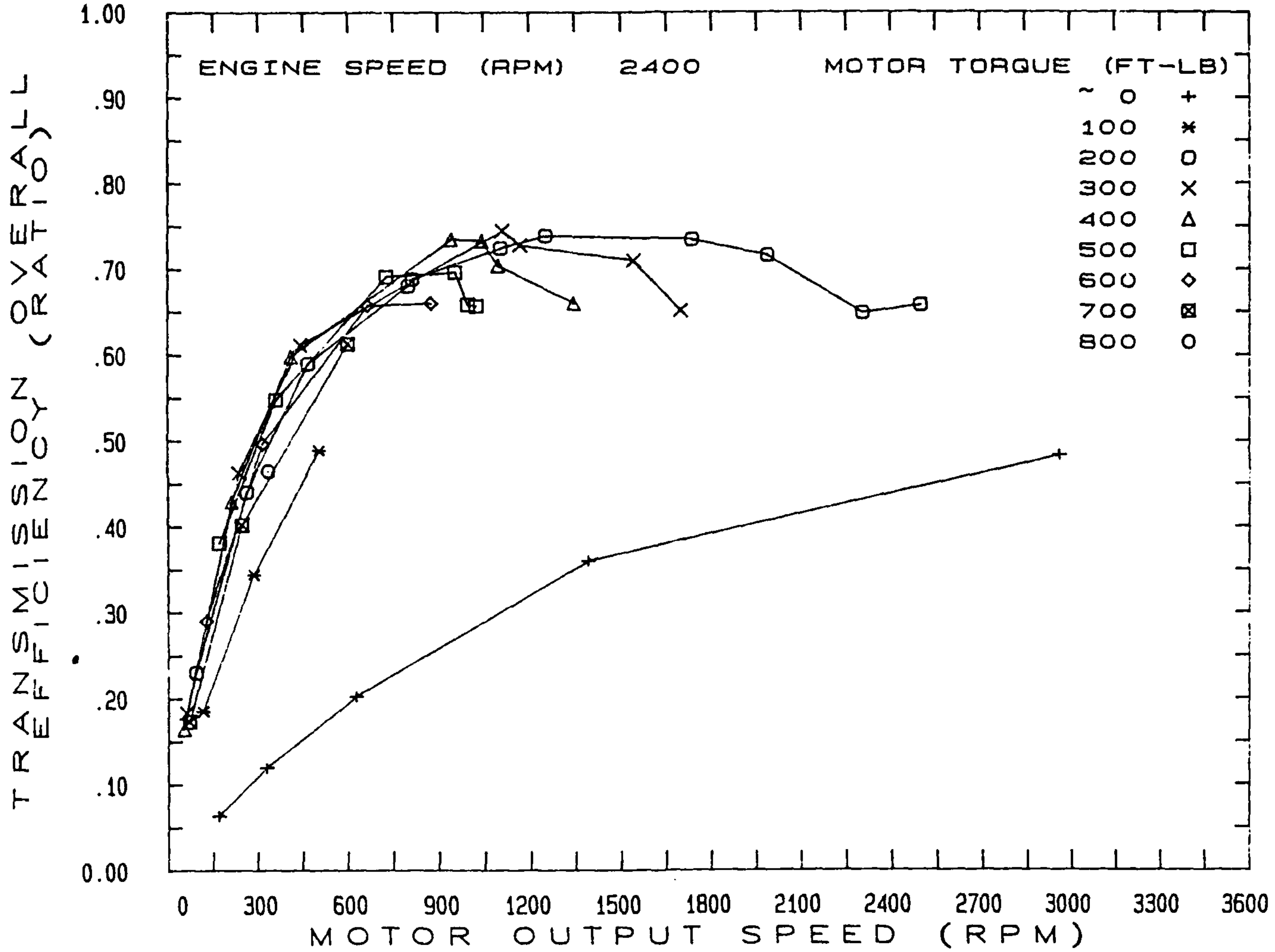


FIGURE 47. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2400 RPM.

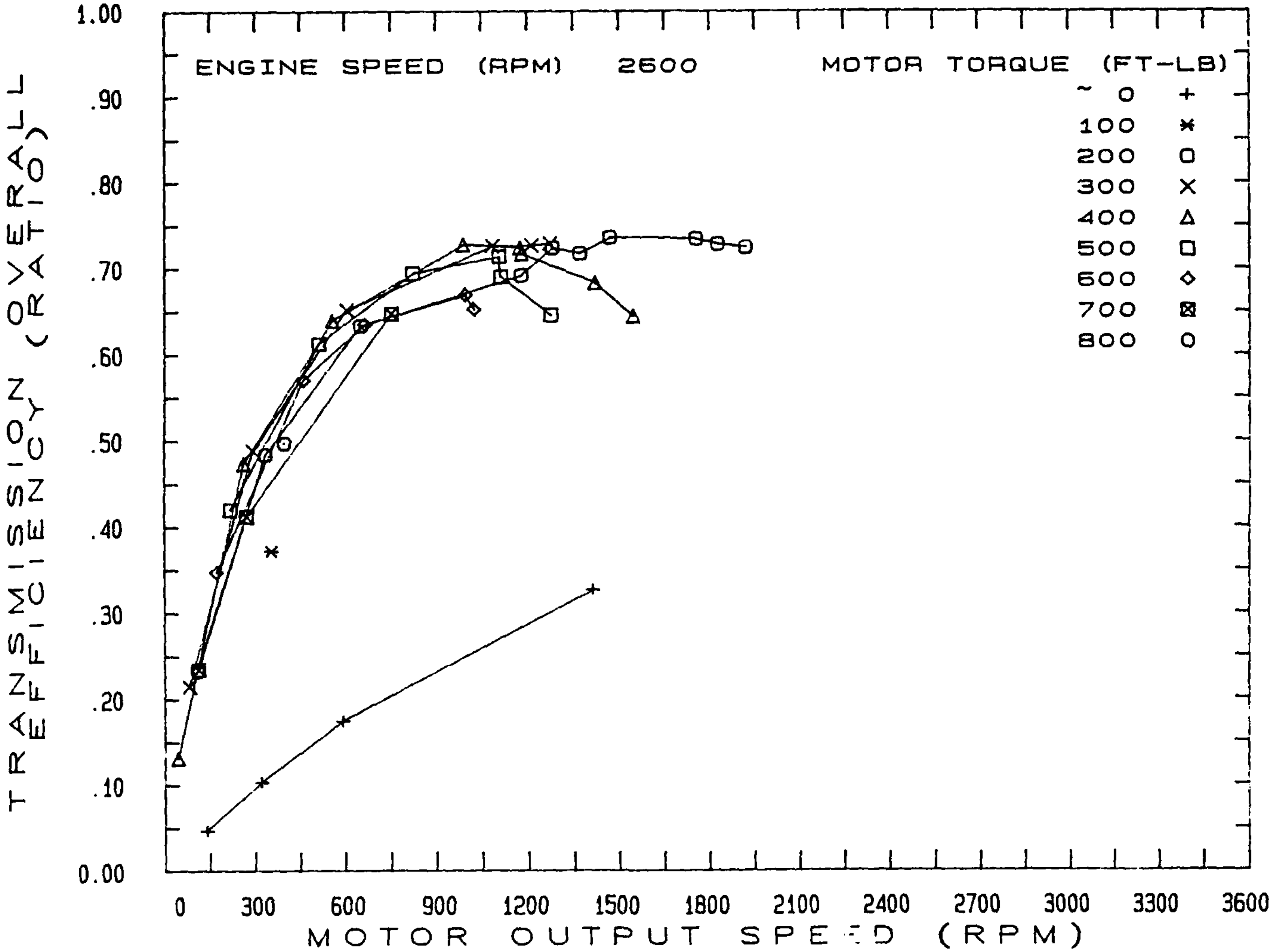


FIGURE 48. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2600 RPM.

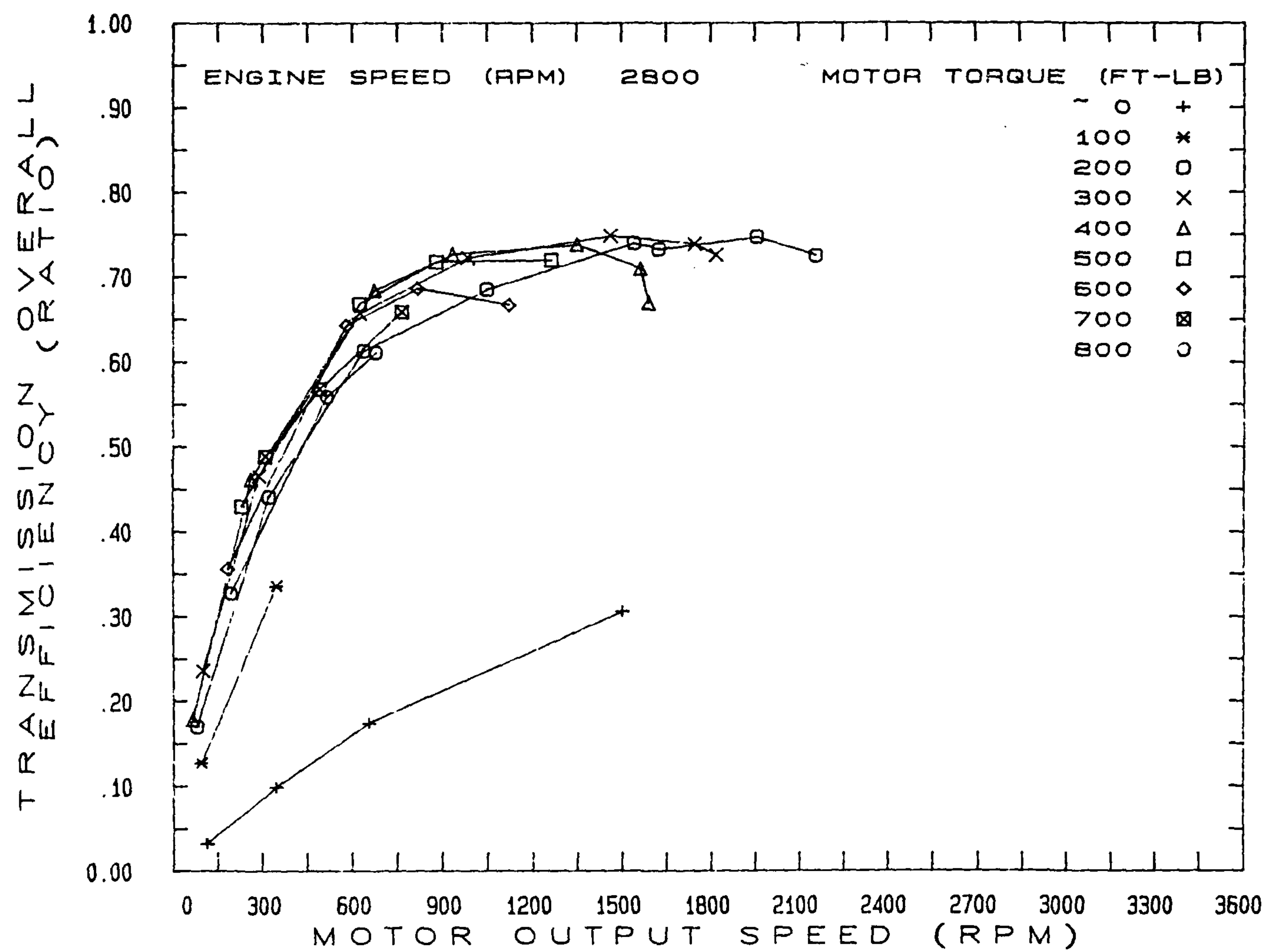


FIGURE 49. TRANSMISSION OVERALL EFFICIENCY VERSUS MOTOR OUTPUT SPEED FOR VARIOUS MOTOR TORQUES AT AN ENGINE SPEED OF 2800 RPM.

Note: Transmission Performance Curves Were Generated From Dynamometer Data In Appendix C. Sprocket Speed Torque Are Obtained By Taking Motor Values And Converting Them To Sprocket Values By The Final Drive Gear Ratio. Maximum Pump Input Power Is Limited To 135 Horsepower To Each Of The Two Pumps.

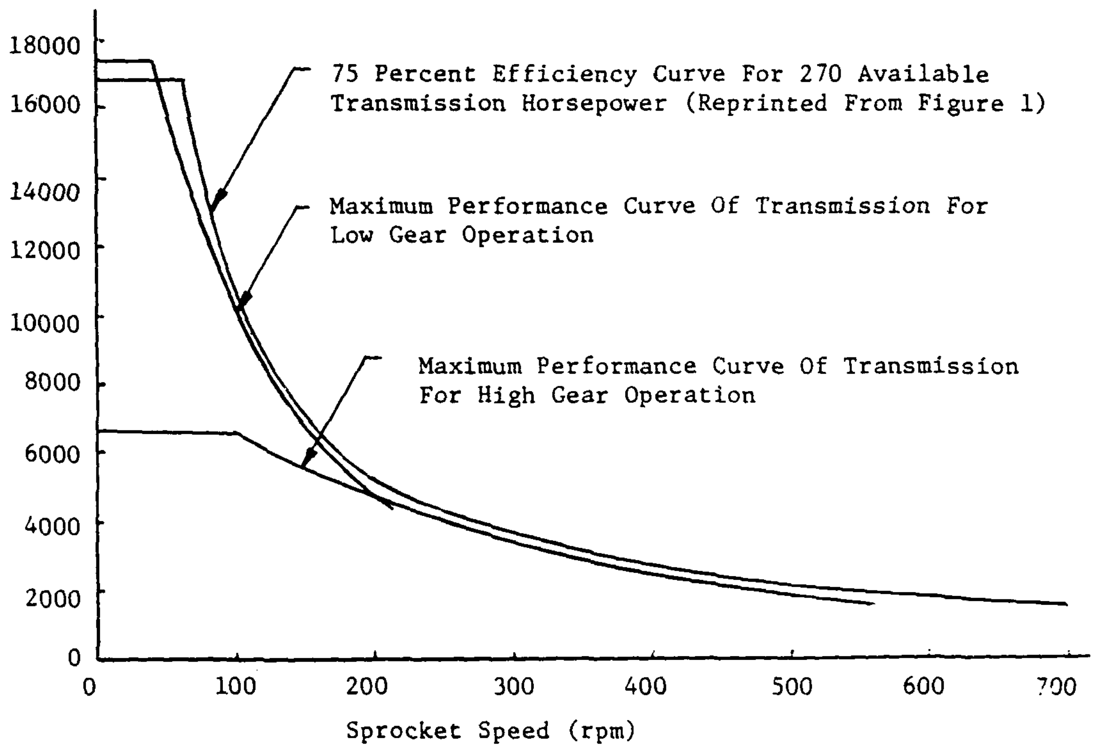


FIGURE 50. TOTAL SPROCKET TORQUE VERSUS MOTOR SPEED CAPABILITY FROM DYNAMOMOTER TEST RESULTS

6. ELECTRICAL/CONTROL SYSTEM DESIGN

6.1 Control System Objectives

The goal of the control system is to take advantage of the continuously variable gear ratio of the hydrostatic drivetrain to create a vehicle which is quite maneuverable while maintaining fuel efficiency. Specifically, the control system is required to:

- safely implement driver commands;
- smoothly adjust pump and motor displacements;
- operate engine for optimum efficiency;
- perform self-diagnostics;
- automatically take emergency actions if a system fails;
- inform driver of component or system failures.

An additional constraint is that the system would be designed in such a manner that would allow manual operation in the event of a computer failure.

6.2 Original Approach

While the drivetrain was originally designed to be computer controlled, the microcomputer was not designed into the primary feedback control loop. Rather, the microcomputer was to function as a system supervisor, sensing operator commands and vehicle parameters, processing signals, and determining optimum states of the driveline. The actual control of the hydrostatic pumps and motors, diesel engine, and service brakes was to be performed by stand-alone analog electrical controllers (AECs). The original control system layout is illustrated in Figure 51.

The control system was designed with the microcomputer outside the feedback control loop for two primary reasons:

- performing an analog control function with a digital computer was thought to be a time-consuming task. There were initial concerns

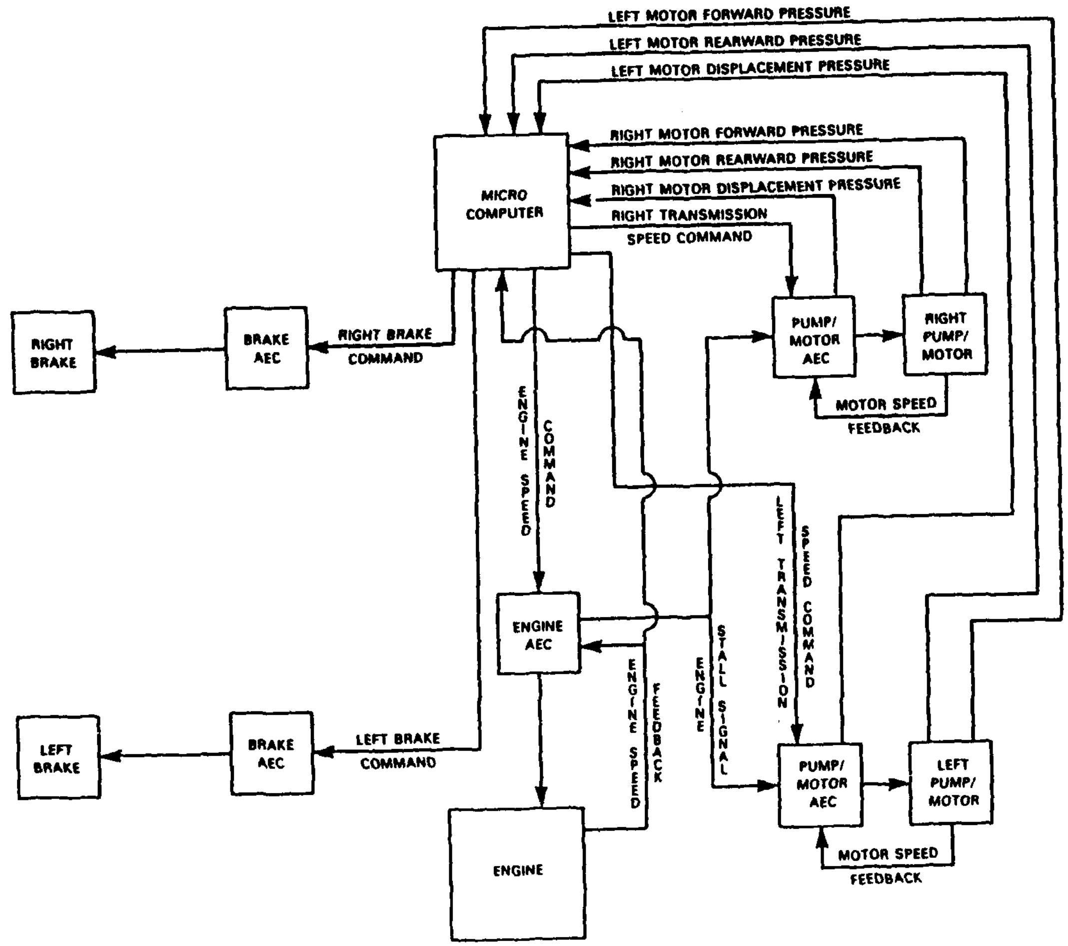


FIGURE 51. ORIGINAL CONTROL SYSTEM LAYOUT

regarding the execution speed of the microcomputer which would be chosen. By off-loading the analog job, the microcomputer would have more execution time available for system performance evaluation and self-testing.

- Overall system reliability would be increased by making the control system somewhat redundant. With the control responsibilities split between the microcomputer and a manual backup system, the impact of an unrecoverable computer failure would not be as severe. Stand-alone analog electrical controllers would facilitate switching from computer to manual control. Additionally, the AECs selected for the control task were supposed to be equipped with ilt-in engine anti-stall. This feature was to prevent the engine from stalling when hydrostatic motor loads were excessive.

6.3 Problems Encountered in the Original Control System Design

The control system described above was conceptually designed, developed, and implemented in hardware. During the vehicle field test phase, certain limitations of the control system became apparent. The first problem noticed was that the response of the hydrostatic drivetrain to operator commands was very sluggish. The second problem was that the anti-stall built into the AECs responded so slowly to track loading that the engine would stall. Both problems were traced to the AECs. Attempting to adjust the controllers to increase their response only resulted in controller instability, causing oscillation of the drivetrain. The inability to effectively adjust controller response rate was traced to the basic design of the AECs. Internally, the AECs created a system error signal which was proportional to the difference between command and feedback signals. Next the error signal was integrated over time and a change in control signal was produced proportional to the integrated error.

This is not a widely accepted method of achieving accurate control. Most closed-loop control algorithms primarily utilize proportional and derivative terms to affect primary control and utilize integrative terms to make final fine adjustments to the control signal. This is known as PID (Proportional Integral Derivative) control.

However, the AECs which were purchased as recommended control system hardware devices to be used with the Linde hydrostatic transmissions utilized only the integral error term to affect control. The net result was an unacceptable control system design.

Three plausible solutions to the control system problem were investigated:

- redesign the AECs including proportional and possibly derivative elements in the feedback control loop;
- implement the function of the feedback control loop in software in the microcomputer;
- implement an open loop control function in the software of the microcomputer.

The first alternative, modifying the analog controllers, would have initially been the quickest approach. However, since the result of this effort would retain an analog device with only the possibility of success, this approach was not pursued. The second approach, implementing a closed loop controller in the microcomputer, was believed the be the correct choice for a long-term solution. However, the proper development of this approach would require considerable modeling and simulation for which there was neither time nor funding. The most appealing path to pursue was determined to be the development of a digital, open loop control algorithm to be implemented in the microcomputer. Details of the final embodiment of the control system are discussed in the following section.

6.4 Final Embodiment of the Electrical/Control System Design

The control system design finally incorporated into the vehicle is shown in Figure 52. This is similar to the original control system design shown in Figure 51 with the deletion of the transmission AECs as primary feedback control devices. This change is illustrated by the routing of the motor and sprocket speed feedback signals to the microcomputer rather than to the AECs.

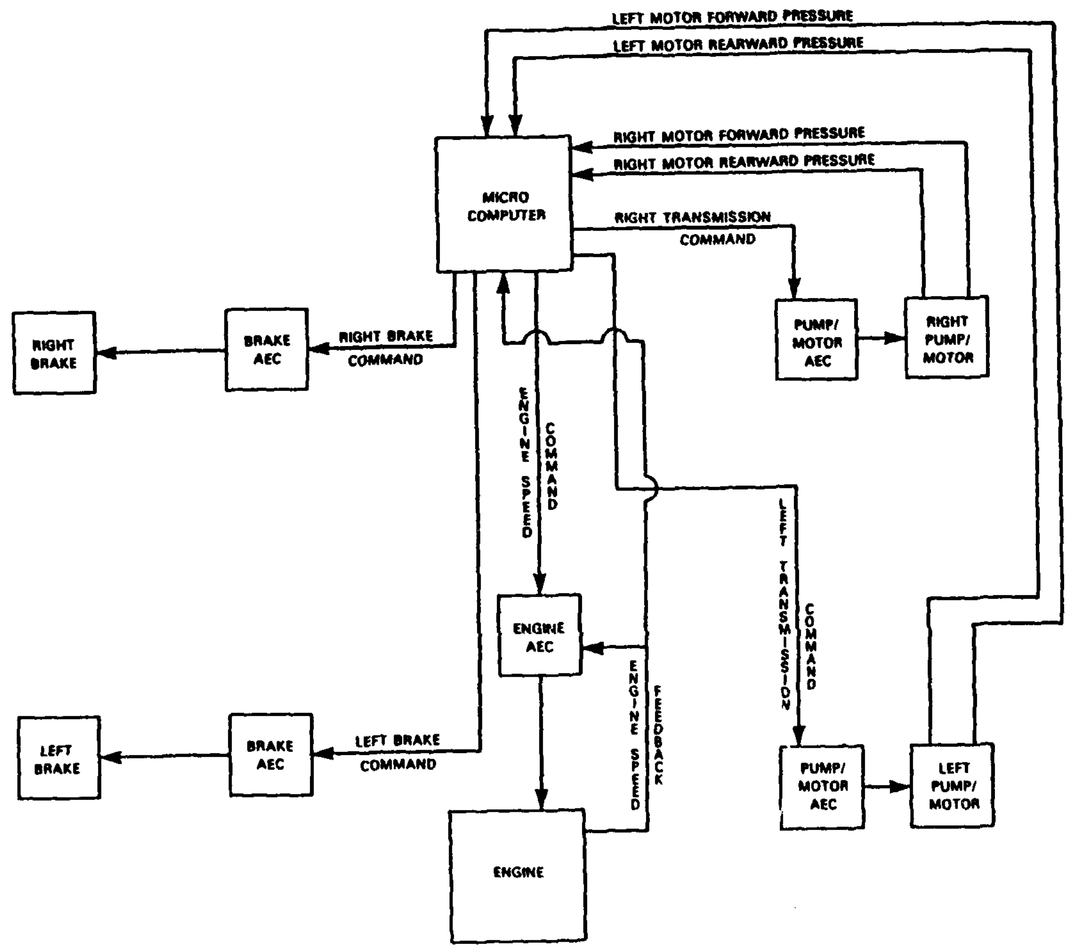


FIGURE 52. FINAL EMBODYMENT OF CONTROL SYSTEM DESIGN

The engine AEC was maintained because the engine speed command signal changed more slowly and the engine AEC was able to provide marginally adequate control of the engine speed. The brake AECs were also maintained because they were originally designed as open-loop control devices and were found to be satisfactory in their operation.

The overall control system, then, operated in the following manner:

- Operator input signals were obtained as indicators of the desired state of the vehicle's drivetrain settings.

- Vehicle feedback signals were obtained to describe the actual state of the vehicle's drivetrain components.

- The microcomputer performed calculations on the operator input signals and drivetrain feedback signals and made adjustments to the control devices accordingly.

Figure 53 pictorially illustrates the components of the electrical system, Table 6 relates manufactuere information relative to these major electrical components, and Figure 54 presents the electrical system wiring diagram. The following discussions will relate in detail the operation of the electrical/control system.

6.4.1 Microcomputer Input/Output (I/O) Devices

The SC-1 microcomputer used in this project is pictorially illustrated in Figure 55. Of particular interest is the kind and location of the Input/Output (I/O) capability which is shown in Figure 56.

The Frequency-to-Voltage (F/V) converters were built to convert the frequency signals obtained from the magnetic pickups on the engine, two motors, and two sprockets to voltage signals. Each of the two cards was built to process four frequency signals. Each card, however, was built with only one F/V converter chip. The F/V cards were designed to operated through a sampling scheme such that the frequency from the

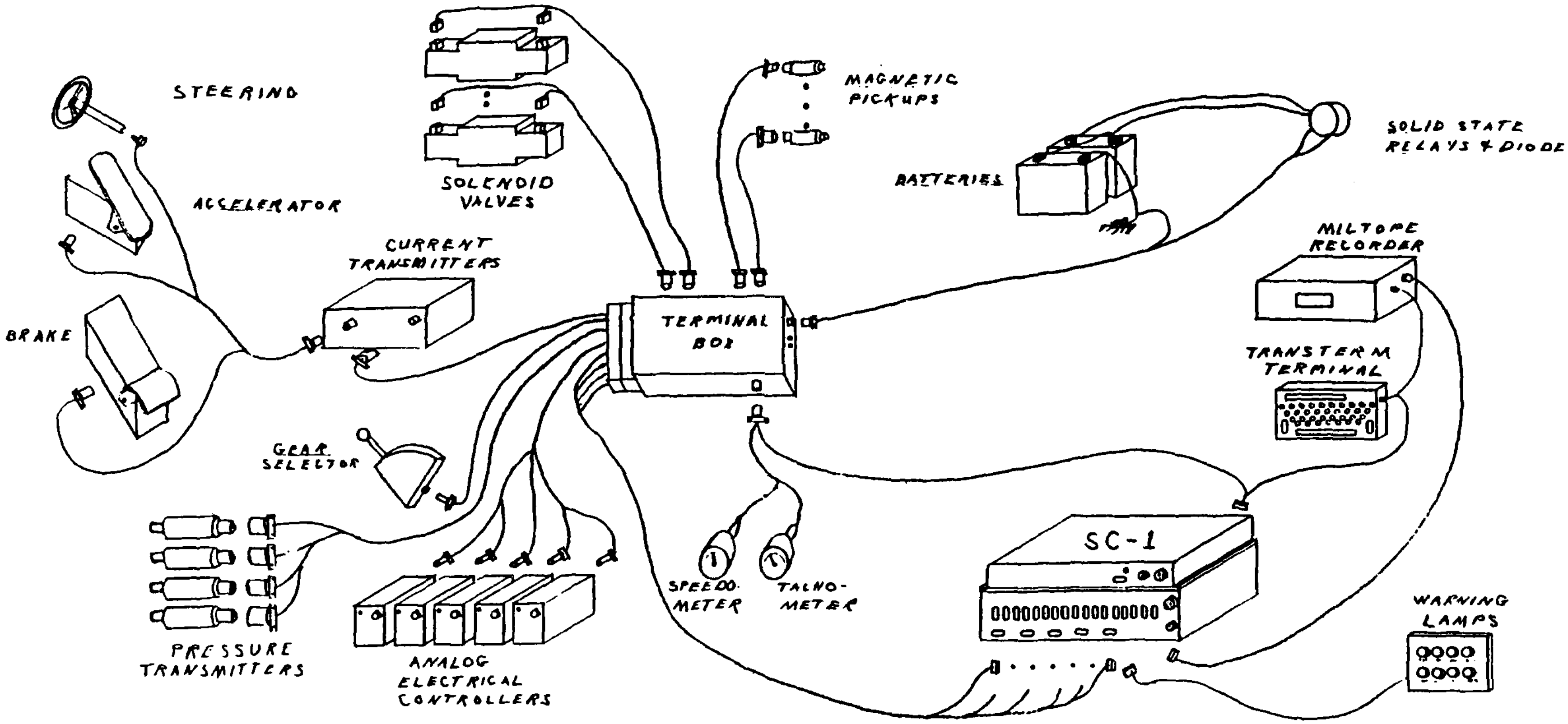


FIGURE 53. COMPONENTS OF THE VEHICLE ELECTRICAL SYSTEM

Table 6. Main Components of HTP Vehicle Electrical System

Description	Manufacturer	Part Number
Pressure Transmitter	Genesco	SP420-50000G-10
Magnetic Pickups	Airpax	089-504-0070
Gear Selector Switches	MicroSwitch	21EN9-S
Steering, Acclerator and Brake Potentiometers	Allen Bradley	JA1NO56SSO1UA
Current Transmitters	Transpak	TP 650
Analog Electrical Controllers	Amheiser Electronics	(No Part Numbers Available)
Transterm Terminal		Transterm II
Miltope Recorder	Miltope	CR300 Digital Tape Recorder
SC-1 Microcomputer	Southwest Research Institute	SC-1

FIGURE 54. CONTROL SYSTEM ELECTRICAL SCHEMATIC

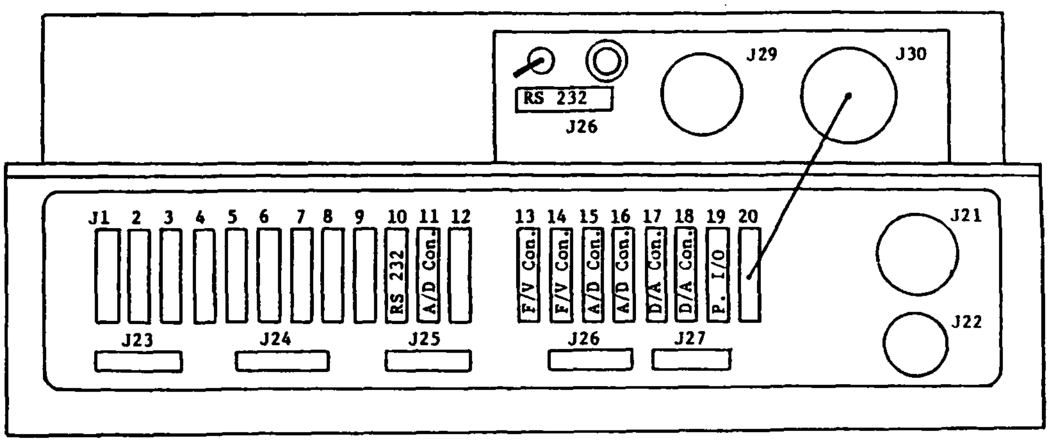


FIGURE 55. ILLUSTRATION OF SC-1 I/O DEVICE LOCATIONS

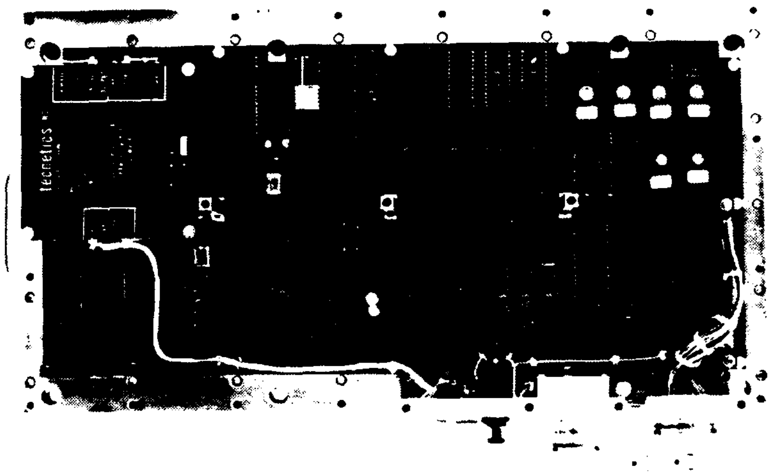


FIGURE 56. ILLUSTRATION OF SC-1 COMPUTER BOARD

engine magnetic pickup would be sampled for a specified period and the voltage output would be placed on a sample and hold capacitor to be used as a voltage input to the Voltage-to-Digital (V/D) converter. After sampling the engine frequency signal, the F/V converter would then sample one motor speed frequency signal, followed by the other motor speed frequency signal, and finally the sprocket speed signal. The other card was used exclusively to sample the other sprocket speed signal.

This scheme, although originally unproblematic because the speed control function was incorporated into the AECs, became problematic in the final control system design. The problem is associated with the time required to perform the sequential sample and convert functions. To obtain accurate results, the time required to sequence and convert four frequency signals required 0.6 second. At shorter sampling periods, the accuracy of the conversion was diminished.

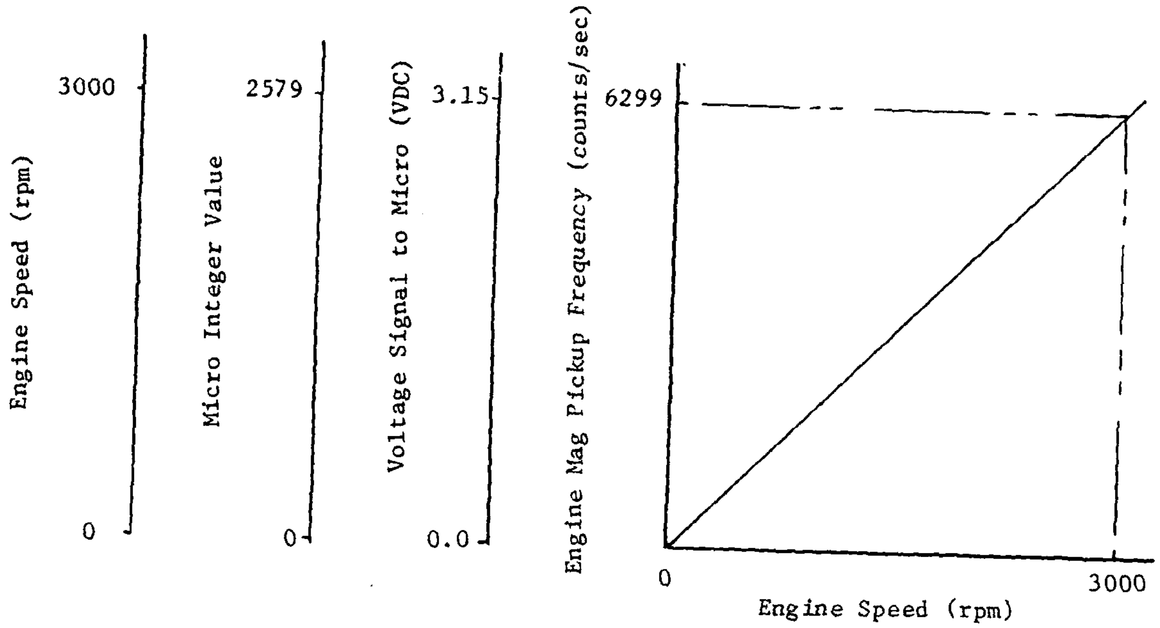
This 0.6 second period caused problems during shifting operations because of the requirement to change motor speeds during a shift for synchronization of the motor-to-clutch speeds for engagement. This problem was not overcome during this contract. A modification to the microcomputer has been made and tested, however, to incorporate Frequency-to-Digital (F/D) converters for the next vehicle known as the Automotive Test Rig (ATR). This task, in addition to the integration of Pulse Width Modulated (PWM) output drives into the SC-1 were completed as part of this contract. These modifications were carried as separate contract reporting items for this contract. Copies of the letter design report covering these items is included as Appendix C of this report.

Voltage-to-Digital (V/D) converters were used to convert analog signals to integer values for the SC-1 computer program. These V/D converters not only converted the voltage equivalent frequency signals but also converted signals from the steering wheel, accelerator pedal, brake pedal, and four hydrostatic working pressures to integer form. Figures 57 through 63 illustrate these conversions. Additionally, one A/D card was incorporated for use as an auxiliary input device. Its conversion relationship is presented in the following equation:

$$\text{Micro Integer Value} = \frac{\text{Voltage Signal to Micro}}{5} \; 4095$$

The Parallel I/O cards received digital signals from the transmission gear selected and provided output signals to engage the low and high clutches and also to turn on the warning lamps to indicate malfunctions of the various signals sent to the microcomputer.

ENGINE SPEED SIGNAL



$$\text{Engine Mag Pickup Frequency} = C/S = (\text{Engine Speed: rpm})\ \frac{126}{60}$$

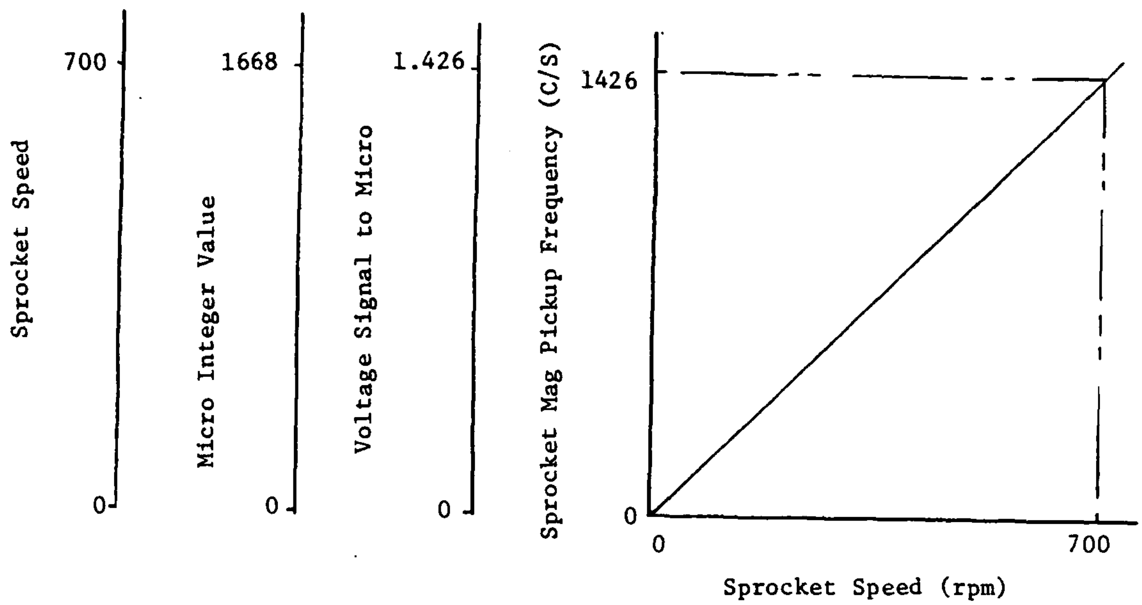
$$\text{Voltage Signal to Micro: VDC} = \frac{\text{Engine Mag Pickup Frequency: C/S}}{(2)(1000)}$$

$$\text{Micro Integer Value} = \frac{\text{Voltage Signal to Micro: VDC}}{5}\ (4095)$$

$$\text{Engine Speed: rpm} = 1.163\ \text{Micro Integer Value}$$

FIGURE 57. ENGINE SPEED SIGNAL CONVERSION

SPROCKET SPEED SIGNALS



Sprocket Mag Pickup Frequency: C/S = (Sprocket Speed: rpm) $\frac{(4.89)\ (25)}{60}$

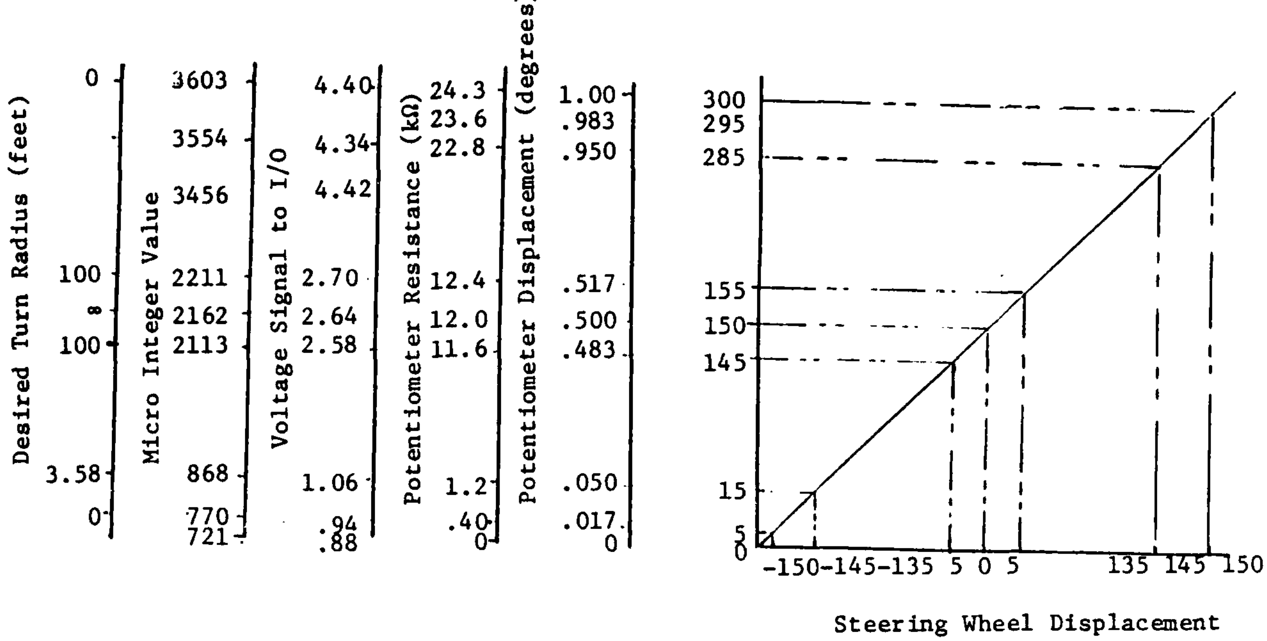
Voltage Signal to Micro: VDC = $\frac{\text{Sprocket Pickup Frequency: C/S}}{1000}$

Micro Integer Value = $\frac{\text{Voltage Signal in Micro: VDC}}{5}$ (4095)

Sprocket Speed: rpm = (.599)(Micro Integer Value)

FIGURE 59. SPROCKET SPEED SIGNALS CONVERSION

STEERING WHEEL SIGNAL



Potentiometer Disp. (degrees) = Steering Wheel Displacement (degrees)

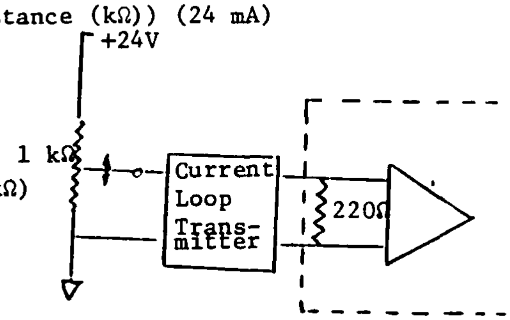
Potentiometer Resistance (kΩ) = $\frac{\text{Potentiometer Displacement (degrees)}}{300}$ (1 kΩ)

Potentiometer Voltage (VDC) = (Potentiometer Resistance (kΩ)) (24 mA)

Current Loop Transmitter Potentiometer Current (mA) = $\frac{\text{Voltage (VDC)}}{24}$ (16) + 4

Voltage Signal to I/O = Current Loop Transmitter) (.220 kΩ) Current (mA)

Micro Integer Value = $\frac{\text{Voltage Signal to I/O}}{}$ (4095)



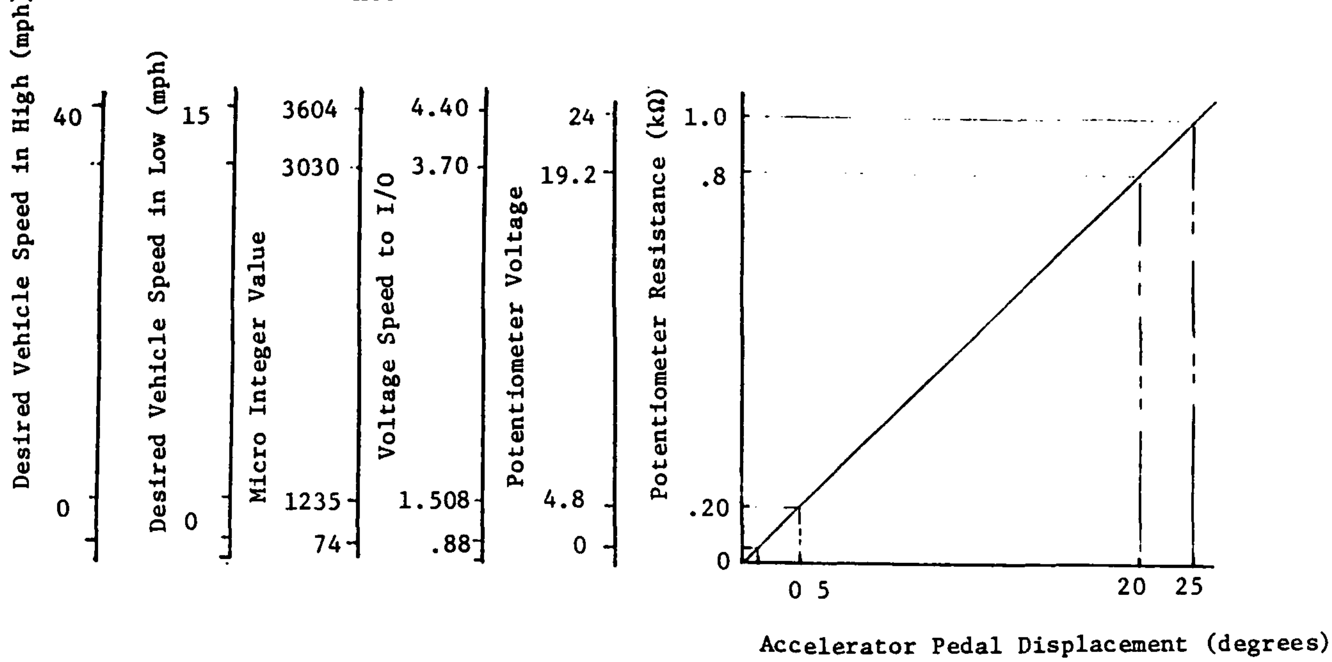
$i = \frac{24V}{1\ k\Omega} = 24\ mA$

For Left Turn
Desired Turn Radius: feet = (.077) (Micro Integer Value) - 63.26

For Right Turn
Desired Turn Radius: feet = -(.077)(Micro Integer Value) + 269.7

FIGURE 60. STEERING WHEEL SIGNAL CONVERSION

ACCELERATOR PEDAL SIGNAL



$$\text{Potentiometer} = \text{Accelerator Pedal Disp. (degrees)} \quad (5)\ \frac{1\ \text{k}\Omega}{300}$$

$$\text{Potentiometer Voltage (VDC)} = \text{Potentiometer Resistance (k}\Omega) \quad (24\ \text{mA})$$

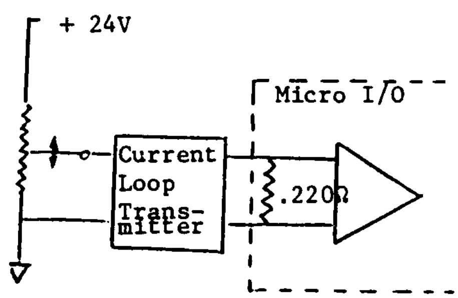
$$\text{Current Loop Transmitter Current (mA)} = \frac{\text{Potentiometer Voltage (VDC)}}{34}\ (16) + 4$$

$$\text{Voltage Signal to I/O} = \text{Current Loop Transmitter Current (mA)} \quad (.220\ \text{k}\Omega)$$

$$\text{Micro Integer Value} = \frac{\text{Voltage Signal to I/O}}{5}\ (4095)$$

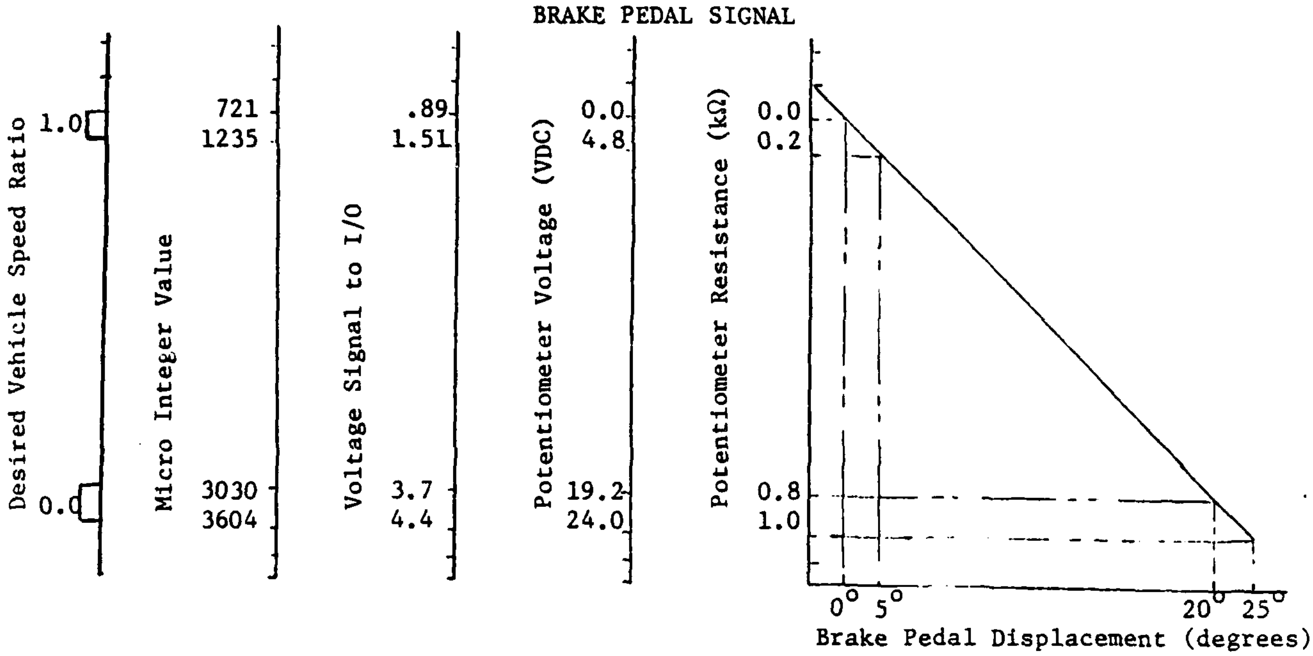
Desired Vehicle Speed in Low = .008 Micro Integer Value - 9.88

Desired Vehicle Speed in High = .021 Micro Integer Value - 9.88



$$i = \frac{24V}{1\ \text{k}\Omega} = 24\ \text{mA}$$

FIGURE 61 ACCELERATOR PEDAL SIGNAL CONVERSION

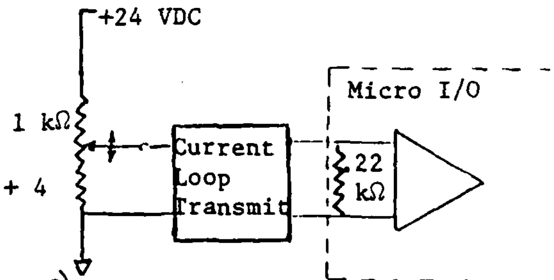


$$\text{Potentiometer Resistance (k}\Omega) = \left(\text{Brake Pedal Displacement: degrees}\right)\left(\frac{1\ \text{k}\Omega}{300^\circ}\right)$$

$$\text{Potentiomoter Voltabe: VDC} = \left(\text{Potentiomoter Resistance (k}\Omega)\right)\left(24\ \text{mA}\right)$$

$$\text{Current Loop Transmitter Current: mA} = \left(\frac{\text{Potentiometer Voltage: VDC}}{24}\right)(16) + 4$$

$$\text{Voltage Signal to I/O} = \left(\text{Current Loop Transmitter Current: mA}\right)\left(.22\ \text{k}\Omega\right)$$

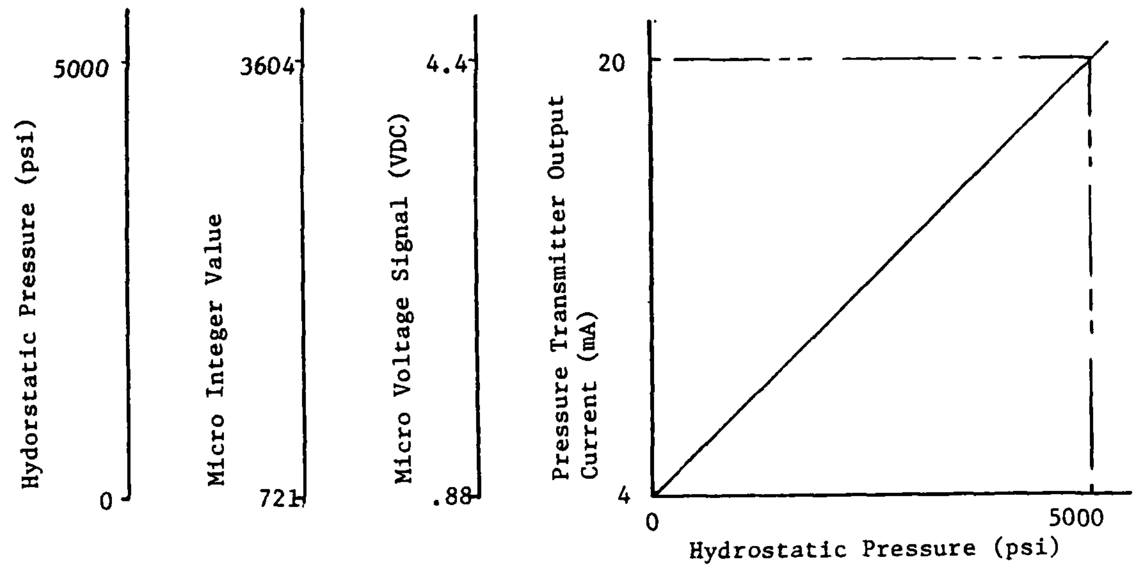


$$\text{Micro Integer Value} = \left(\frac{\text{Voltage Signal to I/O}}{5}\right)(4095)$$

$$\text{Desired Vehicle Speed Ratio} = -(.00056)(\text{Micro Integer Value}) + 1.697$$

FIGURE 62. BRAKE PEDAL SIGNAL CONVERSION RELATIONSHIPS

HYDROSTATIC WORKING PRESSURES



$$\text{Pressure Transmitter Output Current (mA)} = (312.5)\left(\text{Hydrostatic Pressure:psi}\right) + 4.0$$

$$\text{Voltage Signal To Micro I/O: VDC} = \left(\text{Pressure Transmitter Output Current: mA}\right)\left(.22\text{k}\Omega\right)$$

$$\text{Micro Integer Value} = \left(\frac{\text{Voltage Signal to I/O: VDC}}{5}\right)\left(4095\right)$$

$$\begin{aligned} 5000 &= 3604x + y \\ 0 &= \underline{721x + y} \\ 5000 &= 2883x \end{aligned} \qquad x = 1.734 \qquad y = -1250$$

$$\text{Hydrostatic Pressure: psi} = \left(1.734\right)\left(\text{Micro Integer Value}\right) - 1250$$

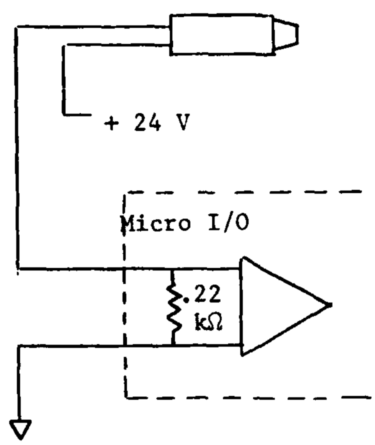


FIGURE 63. HYDROSTATIC WORKING PRESSURE SIGNAL

6.4.2 SC-1 Microcomputer Hardware Description

The requirements for a microcomputer to control the HTP vehicle are very strict. First and foremost are the requirements that it be fail safe and accurate. If the microcomputer fails while the vehicle is running at 40 mph, the possibility of personal injury is significant. To accomplish all of the engine optimization, the micro must be very fast in processing floating point calculations. Finally, the micro must easily communicate with several D/A, A/D, and F/V conversion boards. The micro chosen that most closely meets the perceived program requirements is the SC-1 developed at SwRI.

The SC-1 uses the 5 MHz Intel 8086 central processing unit in unison with the Intel 8087 math processor and 8089 Input/Output processor, all very large-scale integration (VLSI) processors. All reside on the system's local bus. Figure 64 is a block diagram of the computer and Table 7 summarizes the SC-1's general specifications.

Table 7

Configuration

8086/8087/8089 triprocessor on local bus

Word Size

Instructions: 8, 16, 24 or 32 bits

Data: 8, 16 bits (single word = 16 bits)

Cycle Time

Basic Instruction Cycle:	0.8 μs (instruction not in queue)
	0.25 μs (instruction in queue)

Memory Capacity

Onboard EPROM:	64K bytes (expandable to 128K)
Onboard DRAM:	128K bytes (error correcting, single-bit detect/ correct; multi-bit detect)
Onboard SRAM:	2K bytes

Table 7. (Continued)

<u>I/O Capacity</u>

Parallel: 48 lines programmable (8255s), using two parallel interface adapters (equipped with LSI controller to emulate IBM-360 I/O channel handshaking).

DMA: Two 16-bit DMA ports, at 1M-bytes max transfer rate.

Serial: RS-232 port, controlled by USART for both standard asynchronous or synchronous (8251A) communications.

<u>Interrupts</u>

Two 8-input priority interrupt controllers (15 hardware vectored interrupt lines available). Software configured for input priorities and mode (8259As).

<u>Timer</u>

Two timers, each equipped with three 16-bit interval timers. (Timer outputs available as interrupt inputs.) Software configured for mode and rate (8253s).

<u>Power Consumption</u>

20W

<u>Weight</u>

9.38 lbs

The SC-1 has three subsystems of memory. First, there are 64K bytes of EPROM to store the monitor and application programs. There are also 2K bytes of static RAM for use as a system stack. Last, for main memory, there are 128K bytes of fault tolerant dynamic RAM. This DRAM provides single-bit failure detect/correct and multi-bit failure detect for the main memory.

To further mitigate the effects of a momentary software failure, a watchdog timer has been placed in the circuit. The timer receives a signal every 100 msec from the software. If for some reason the software "locks up," a hardware reset is initiated and the program reboots from PROM. Execution restarts with a fresh copy of the

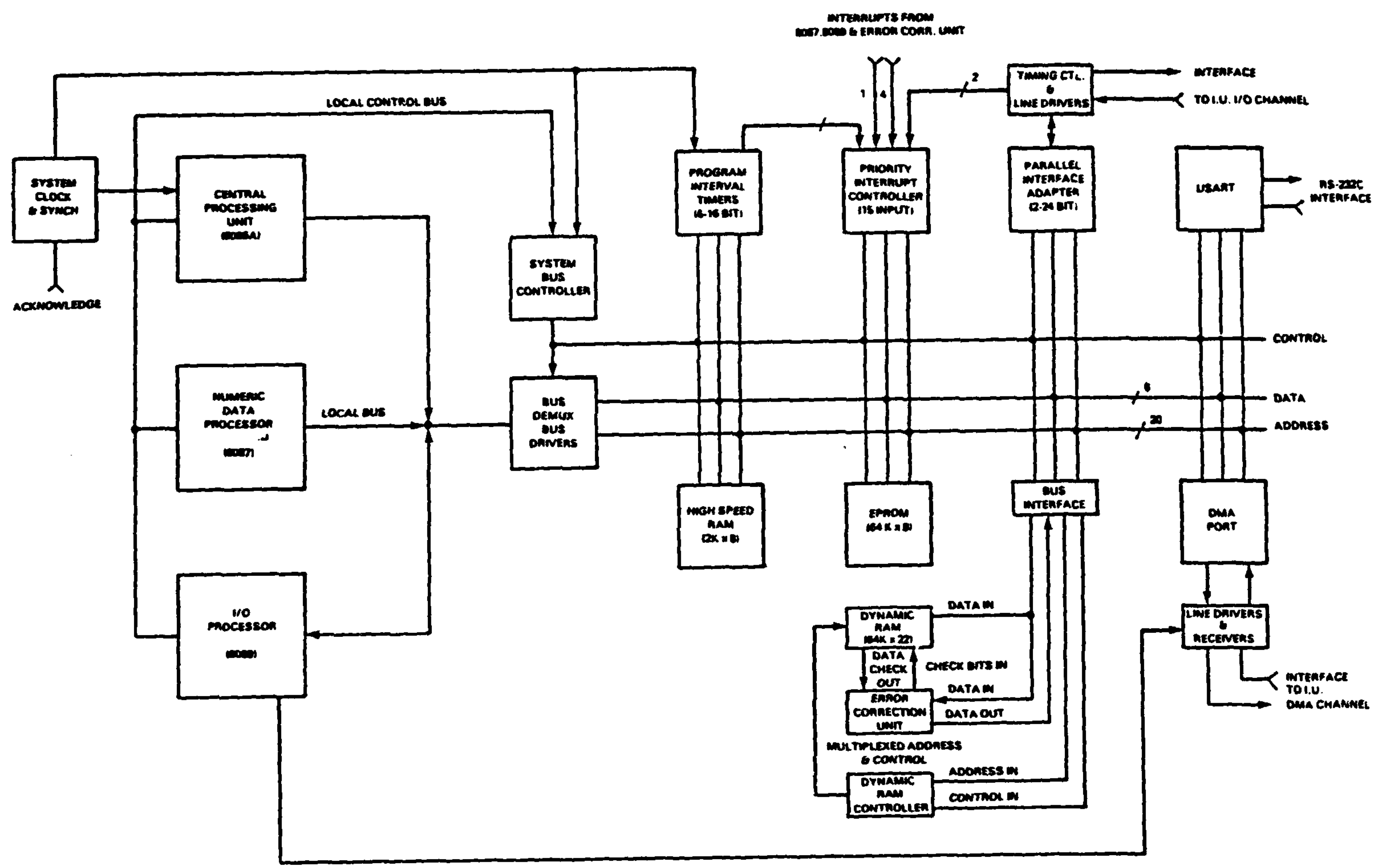


FIGURE 64. SC-1 COMPUTER BLOCK DIAGRAM

software without the operator's intervention. A checksum over the application program provides a secondary verification. The checksum is computed every 100 msec. This checksum is compared to the original value stored in PROM. If there is a discrepancy, the program has been inadvertently changed. Therefore, a hardware reset and software reload is initiated.

The SC-1's performance has been validated through many different environmental tests to make it acceptable to military and commercial applications. It has operated successfully through vibration tests to warrant use on any application. The SC-1 can operate in a pure vacuum and in the temperature range of -40° to +80°C. All power is dissipated through the base plate; no fan is required. The micro also has proven electromagnetic compatibility.

In it current configuration, the SC-1 uses the triprocessor configuration to provide increased throughput. Using the 8086's pipelined architecture, a great amount of parallel processing can be achieved. The 8087 is a purely numeric processor and can execute some numerical instructions 500 times faster than those instructions emulated from an 8086.

The Intel 8089 is a dedicated I/O processor. It communicates with an I/O expander unit which houses A/D, D/A and F/V convertors, and a parallel I/O board. The 8089 reads vehicle inputs at the I/O expander and places them in main memory where the applications program can process them. It also reads a block of data from memory which represents control outputs and sends them to the I/O expander. These signals are used as inputs to analog controllers.

6.4.3 Microcomputer Program Description

The hydrostatic vehicle's software follows the functional listing presented in this section. The flowchart relates the following sequence of logic. First, the micro gets all inputs and sets gear parameters according to the gear selector position. The desired vehicle speed has to be calculated using the accelerator pedal position and actual vehicle speed.

The brakes are applied in the next two routines. BKSTR is responsible for applying the brake in neutral to steer and in drive to help brake when requested. OVRSD is the routine called when the engine is running at a speed higher than rated engine speed. The brakes are applied to help slow the vehicle when the engine is overspeeding.

The next routines called for are responsible for setting the desired motor speeds. FNDRV is called whenever the driver requests a change in the final drive gear. FNDRV first places the clutch in the neutral position, drives the motors to a speed corresponding to the actual sprocket speeds, and re-engages the clutches when the motors are within a certain differential speed of the sprockets. MTRSD is the final and longest of the routines in the M113 system. MTRSD first will calculate the desired motor speeds by means of the accelerator pedal, brake pedal, and steering wheel position. The values of torque and power on each motor are calculated to be used to determine the optimum engine speed. Finally, MTRSD calculates the total available engine power. From the values of torque, MTRSD can determine the maximum motor speed allowable. MTRSD will then output the lower of the values of maximum and desired motor speeds. Finally, all of the parameters are outputted.

The following sections present the major logical questions and calculations which are performed in the program for the HTP vehicle. A listing of the actual program is presented in Appendix E of this report.

HTP PROGRAM FUNCTIONAL LISTING

M113

The following loop is executed every 100 msec.

```
Call DSTRN
Call ACCAV
IF (operator request deceleration - 5 mph per second) THEN
      DVS = Actual vehicle speed - 5 mph
            ELSE
      DVS = accelerator position
            END IF

IF (transmission in neutral) or (brake pedal - 50% depressed) THEN
      Call BRKSTR
            ELSE
      Desire Brake Pressure = 0
            END IF
IF (AES - 2850) and (Transmission not in neutral or park) THEN
      Call OVRSD
            END IF
IF (PFDGC - DFDGC) THEN
      Call FNDRV
IF (PFDGC - neutral) THEN
      Call MTRSD
            ELSE
      DES = DVS/40 * (2400) + 600
            END IF
END M113
```

DSTRN

```
Case of DTS
PARK:
      Desired Motor Speeds = 0
      DRDGC = Low

REVERSE:
      DFDGC = Low
```

```
        Desired Direction of Travel = Reverse

    NEUTRAL:
        DFDGC = Neutral
        Desired Motors Speeds = 0

    FORWARD1:
        DFDGC = Low
        Desired Direction of Travel = Forward

    FORWARD2:
        DFDGC = High
        Desired Direction of Travel = Forward

    OTHERWISE:
        (* use F1 *)
        DFDGC = Low
        Desired Direction of Travel = Forward

    END CASE
    END DSTRN
```

ACCAV

ACCAV does not average the accelerator pedal position; it only calculates DVS straight from the position.

BKSTR

```
    IF (PFDGC - Neutral) THEN
        HBVP = (1-DVSR) * 1500 psi
        LBP = HBP * (DTR-HTG)/(DTR+HTG)
            ELSE
        BPS = -20* DTR + 2000
```

```
        BPB = (1-DVSR) * (1500 psi - BPS)
        HPB = BPS + BPB
        LBP = BPB
              END IF

   IF (DTD = RIGHT) THEN
         DLBP = LBP
         DRBP = HBP
              ELSE
         DLBP = HBP
         DRBP = LBP
              END IF
   END BKSTR
```

OVRSD

```
   HBP = (AES - 2850)/150 * (1500 psi)
   LBP . HPB * (DTR - HTG)/(DTR + HTG)
   IF (DTD = RIGHT) THEN
         DLBP = LBP
         DRBP = HBP
              ELSE
         DLBP = HBP
         DRBP = LBP
              END IF
   END OVRSD
```

FNDRV

```
   PFDGC = Neutral
   IF (DFDGC = Low) THEN
         GearRat = 10.877
              ELSE
         GearRat = 4.100
```

```
            END IF
      DLMS = ALSS * GearRat
      DRMS = ARSS * GearRat
      IF (ARMS within 200 rpm of DRMS) and
            (ALMS within 200 rpm of DLMS) THEN
                  PFDGC = DFDGC
```

MTRSD

```
      IF (PFDGC = Low) THEN
            GearRat = 190.24
                  ELSE
            GearRat = 71.72
                  END IF
      THMS = DVS * DVSR * GearRat
      TLMS = THMS * (DTR-HTG)(DTR+HTG)
      LMD = AES/ALMS * 5.5233
      IF (LMD MNMD) LMD = MNMD
      IF (LMD MMD) LMD = MMD
      LMT = (LFMP - LRMP) * LMD - 1874.4)/75.396
      RMT = (RFMP - RRMP) * RMD - 1874.4)/75.396
      LMP = LMT * DLMS/5250
      RMP = RMT * DRMS/5250
      LTE = SQRT(SQRT(LMP/249))
      RTE = SQRT(SQRT(RMP/249))
      EPLM = LMP/LTE
      EPRM = RMP/RTE
      TREP = EPLM + EPRM +30
      DES = 1100 + .3666 * THMS + 8.5 * TREP - .00285 * TREP * THMS
      Find TAEP (total available engine power)

      TE = (LTE + RTE)/2
      AVMT = ABS(RMT + LMT)/2
      MMSP = (TAEP - (.013636 * AES - 3.182)) * 2625 * TE/AVMT
```

```
IF (THMS MMSP) THEN
      THMS = MMSP
      TLMS = THMS * (DTR-HTG)/(DTR + HTG)
            END IF

IF (DTD = RIGHT)THEN
      DLMS = THMS
      DRMS = TLMS
            ELSE
      DRMS = THMS
      DLMS = TLMS
            END IF
END MTRSD
```

6.4.4 Data Recording System Description

The data recording system consisted of a Miltope RC 300 digital tape recorder (shown in Figure 65) and a Transterm II terminal (shown in Figure 66). This system was used to record various control system variables and auxiliary variables throughout the field test program.

The Miltope recorder was configured with a serial interface to communicate with the SC-1 microcomputer. Every 0.2 seconds, during data recording operations, the SC-1 would transmit signals to the recorder.

The Transterm terminal was used to initialize the test sequence, provide pre- and post-test annotation, and conclude a test. The test sequence was initiated by placing a tape into the recorder, turning on the power, and waiting for a prompt from the SC-1. After acknowledgement of the prompt, up to 24 lines of pre-test annotation could be provided. Hitting the return key twice in succession initiated the recording operation. Hitting any key thereafter stopped the recording operation. AT this time, post-test annotation could be provided. Appendix F contains a list, with descriptions, of the variables which were recorded during this project. Since SwRI was not responsible for the actual recording and documentation of the field test, no field test data is included in this report. A substantial amount of data was recorded, however, by DTNSRDC personnel and this information may be available upon request.

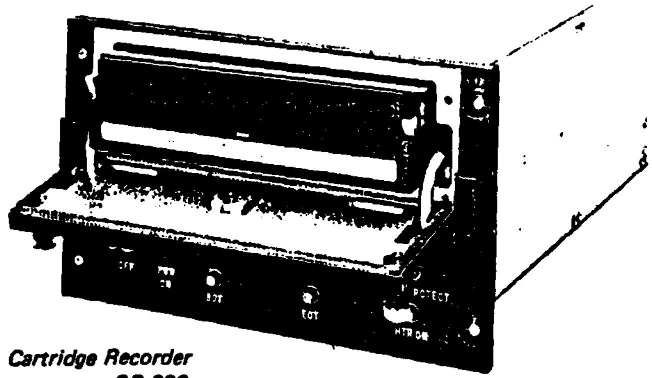
FEATURES

- Uses Standard DC300A Cartridge
- Sealed, removable Super-Pak Cartridge assures reliable operation in severe environments.
- 1, 2 or 4 Track, Serial or Parallel Recording
- Phase Encoded Format—
  1600 BPI Optional—3200 BPI
  23 Million Bit Capacity—1600 BPI
  46 Million Bit Capacity—3200 BPI
- Transfer Rate 192 K Bits/Sec at 1600 BPI, 384 K Bits/Sec at 3200 BPI
- Qualified to MIL-E-16400/MIL-E-5400/MIL-E-4158 Compliance
- MTBF: 5000 Hours
- MTTR: 1/2 Hour
- ANSI/ECMA Compatibility
- Read-While-Write Capability, Bi-Directional Read.

Miltope's CR300 is a militarized magnetic tape cartridge recorder which uses a standard DC300A cartridge. The recorder, designed to meet the requirements of hostile environments, features a sealed Super-Pak cartridge which houses the DC300A cartridge, making it impervious to dust, oil, humidity, water spray, etc.

The CR300 offers the advantage of a sealed 'Super-Pak' while providing for the removability of the DC300A cartridge. Thus, low cost commercial DC300A cartridges can be prepared in central computer facilities and sent to field sites for quick loading into protective Super-Pak cartridges. Typical applications include diagnostic and program load routines.

The unit operates at a 30 IPS tape speed (90 IPS Block-Count/Rewind) and meets all ANSI/ECMA standard requirements for 1/4" tape using 1600 BPI phase encoded format. A 3200 BPI phase-encoded



Cartridge Recorder CR-300

CR300 is also available for systems requiring greater throughput and higher storage capacity.

The basic recorder, qualified to the applicable requirements of MIL-E-16400, MIL-E-5400, and MIL-E-4158, consists of a tape drive, associated electronics, interface, and a Super-Pak cartridge.

TAPE DRIVE

The compact tape drive uses a DC servo motor to internally control tape acceleration and deceleration. The capstan, within the cartridge, is driven by a friction roller system coupled to the DC servo motor. Preset locating pins accurately position the cartridge within the drive to eliminate tolerance or interchangeability problems that are normally associated with friction drive systems. Springs are not used in any critical areas within the tape drive, thereby assuring trouble free operation in both shock and vibration environments.

The drive electronics within the CR300 provides for all required tape control functions. An integral optical encoded tachometer with crystal oscillator reference maintains precise speed control.

SUPER-PAK CARTRIDGE

The Super-Pak Cartridge assures reliable operation in severe military environments and provides operator-proof data security.

The front loading Super-Pak utilizes the widely accepted DC300A cartridge and provides fully compatible ANSI/ECMA data recording.

The Super-Pak can be inserted into the drive in the correct orientation only. Appropriate status/motion interlocks preclude damage to the tape that could be caused by faulty operator intervention or receipt of improper motion commands from the controller.

The Super-Pak, a completely sealed assembly, is impervious to dust, oil, humidity, water spray and other adverse environmental factors. It is interchangeable from drive to drive and provides compatibility with standard DC300A (or NC-900) Data Cartridges, DC300S Alignment Cartridges and DC300H Hostile Environment Cartridges. The Super-Pak can be readily opened to permit rapid interchange of the DC300 media.

The Super-Pak contains the drive capstan, the read/write head (4 channel), EOT/BOT and File Protect Sensors, and a replaceable desiccant. A thermostatically controlled heater is optionally available to extend the operating temperature of the cartridge from −40° to +55°C.

The EOT/BOT and File Protect sensors meet ANSI standards. To further assure failsafe operation, a cartridge loaded indicator assures that the DC300A cartridge is properly seated in the Super-Pak assembly and is ready for 'on-line' operation.

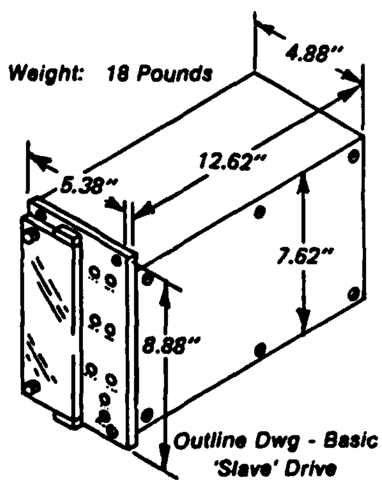
FIGURE 65. MILTOPE RECORDER INFORMATION

READ/WRITE ELECTRONICS

In accordance with the ANSI standard for 1/4" tape, the CR300 data electronics will read and write data in 1, 2 or 4 track compatible format.

The method of recording is 1600 BPI (or 3200 BPI) phase encoded wherein each data bit requires a reversal of flux polarity in a given direction for a logical "1" and in the opposite direction for a logical "0". Phase flux reversals occur at the nominal midpoint between data bits to permit the proper polarity shift for the ensuing data bit. Self clocking is attained in the phase encoded format through the consistent occurrence of the flux reversals of each data bit.

The electronics will record 1, 2 or 4 tracks serially. In this mode, each track will be independent of the other tracks and shall be written in a serial fashion starting at BOT and continuing to EOT with rewind to BOT before initiating writing on the next track. Optional parallel recording is also available in the 2 or 4 track configurations.



PERFORMANCE SPECIFICATIONS

Cartridge	DC300A, ANSI × 3BS/74-43/44
Tape	0.25" Wide, 1 Mil Thick, 300 Feet Long, Computer Grade
Recording Density/Format	1600 BPI Phase Encoded; Optional 3200 BPI PE
Number of Tracks	1, 2 or 4
Recording Head Type	Dual Gap (Read-While-Write) With Separate Erase Bar for Each Track
Record Mode	1, 2 or 4 Track Serial or 4 Track Parallel
Storage Capacity (DC300A)	23 Million Bits (1600 BPI), 46 Million Bits (3200 BPI)
(DC300XL)	34 Million Bits (1600 BPI), 69 Million Bits (3200 BPI)
Operating Speeds	30 IPS Write, Bi-directional Read 90 IPS Bi-directional Search & Rewind
Transfer Rates (Serial @ 30 ips)	48 K Bit/Sec. at 1600 BPI 96 K Bits/Sec. at 3200 BPI
(4 Track Parallel @ 30 ips)	192 K Bits/Sec. at 1600 BPI 384 K Bits/Sec. at 3200 bpi
Start/Stop Time	At 30 IPS—25 ms nominal At 90 IPS—75 ms nominal
Start/Stop Distance	At 30 IPS—0.3" to 0.45" At 90 IPS—3.0" to 3.5"
Speed Variation	Within ANSI Standard
Inter-record Gap	1.33" Nominal 1.22" Minimum
Interface Logic	TTL
Power Standard:	28VDC
Optional:	115V, 60 Hz, Single Phase
Optional:	230V, 400 Hz, Single Phase
Optional:	115V, 400 Hz, Single Phase
Size	Tape Drive 4⅞" H × 7⅝" W × 12⅝" D Super-Pak 1¾" H × 6⁹⁄₁₆" W × 6⅜" D
Weight	Tape Drive: 15 lbs Super-Pak: 3 lbs

ENVIRONMENTAL SPECIFICATIONS

Temperature	
Operating	Tape Drive: −40 to +70°C Super Pak: 0 to +55°C Normal −40 to +55°C with optional heater warm-up cycle
Storage	Tape Drive: −62 to +70°C Super Pak: −40 to +60°C
Humidity	5 to 100% RH
Altitude	
Operating	15,000 feet
Non-operating	50,000 feet
Vibration	MIL-E-5400 Curve IIIa; 0.1" Double Amplitude, 5 to 14 Hz 1g 14 to 23 Hz 0.036 Double Amplitude 25 to 52 Hz. 5g peak 52 to 2000 Hz
Shock	25g, 1/2 sine, 11 ms.
EMI	Per MIL-STD-461A Class
Fungus	Per MIL-STD-810, Method 508

11/83 5M

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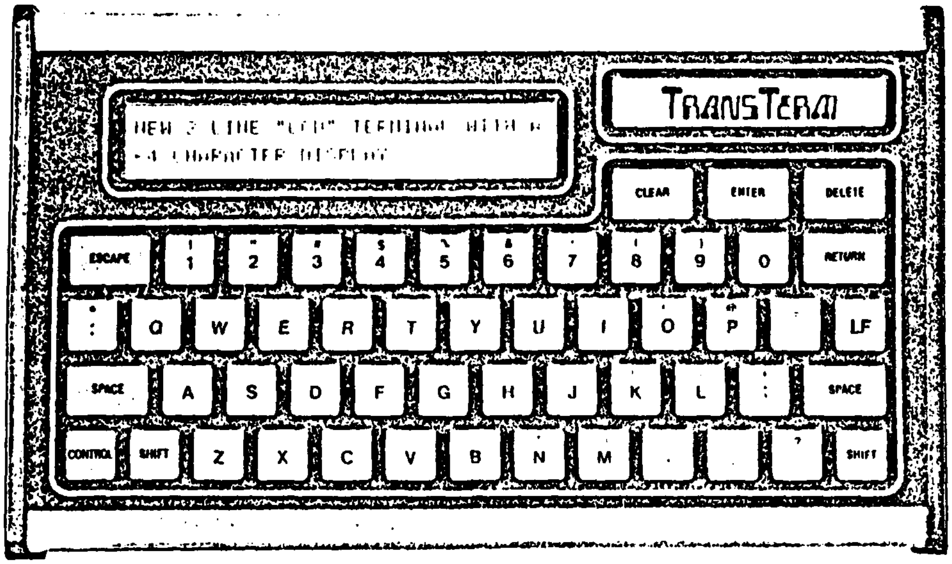
TEL: 516-420-0200 TWX: 510-221-1803

FIGURE 65. CONTINUED

TransTerm 1

FROM COMPUTERWISE



GENERAL PRODUCT DESCRIPTION

The TransTerm 1 is a compact, low cost alphanumeric keyboard/display terminal designed for efficient man-computer communications. The TransTerm 1 consists of a two line 64 character liquid crystal display and a 53 key TTY style keyboard packaged in a 2" high by 12" wide by 7" deep case. The terminal communicates in full duplex RS-232 serial asynchronous ASCII with 20 ma current loop or RS-422 available as options.

TransTerm APPLICATIONS

The TransTerm 1 is ideal for applications where low cost and minimum size or portability are desireable. The TransTerm 1 can be used on a horizontal desk-top surface or mounted on a vertical plane. Typical applications include:

Dial-up Data Entry/Retrieval
Factory floor data collection
Portable Console terminal
Microprocessor support device

TRANSTERM 1 FEATURES

- Rugged Attractive Case
- Compact Size (11.7" W x 6.9" D x 1.75" H)
- 64 Character LCD Display (5 x 7 dot matrix)
- Displays 96 ASCII Characters
- 53 Key Alphanumeric Keyboard (membrane switches)
- Audible Key-click for tactile feedback
- Standard RS-232 Serial Asynchronous ASCII Interface
- Eight switch selectable baud rates (110—9600)
- Data Formats—8 Data bits—No parity
  7 Data bits—Odd parity
- Three switch selectable operating modes:
  - Teletypewriter Emulation
  - Block Send
  - Multidrop Polled
- 20 ma Current Loop Interface (optional)
- RS-422 Compatible Party Line (optional)
- Powered by Wall Plug-in Transformer
- Low Power Consumption (less than 10 Watts 115 Vac)
- 25 pin RS232 Type Female I/O Connector
- Custom Configurations Available

COMPUTERWISE, INC.

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(816) 765 3330

FIGURE 66. TRANSTERM TERMINAL INFORMATION AND SPECIFICATIONS

7. HTP HYDRAULIC DESIGN

A block diagram of the HTP hydraulic system is shown in Figure 67. This diagram relates the hydraulic system interconnection as provided by SwRI. The drivetrain components discussed earlier from the heart of the hydraulic system with auxiliary devices added as needed. The overall description of the hydraulic system is as follows.

A 40-gallon hydraulic reservoir was used as the primary oil gathering and distribution device. From it, oil was provided to the two hydrostatic pumps and the one auxiliary hydraulic pump. The hydrostatic pumps contained 1.07 in^3/rev charge pumps which brought the charge pump pressure up to a value of approximately 310 psi at idle engine speed. This pressure rose to a value of approximately 450 psi at high idle engine speed.

The charge pump output flow was sent through an air-to-oil heat exchanger as the primary cooling means. Next, the oil entered the inlet of the transmission filters to remove debris prior to entering the hydrostatic components. The filters had a 10-micron filter rating. Upon exiting the filters the oil entered the respective hydrostatic transmissions. A hydraulic schematic of one transmission is included as Figure 68.

In principle the hydrostatic transmission charge pump system is intended to perform several functions, including cooling of the units themselves, providing make-up flow to the main return flow loop between the pump and motor, and to provide a hydraulic source for the operation of the transmission control valve. This valve was previously illustrated in Figure 14.

Control of the motor speed was obtained by varying the control valve voltage which varied the control pressure sent to the pump and motor for each transmission. Figure 15 related the theoretical pump and motor displacements for various levels of control voltage and pressure. Figure 69 is presented to relate the laboratory test data obtained to relate control pressure to control voltage. This data was obtained only after having to make modifications to the control valve itself to reduce the internal

HYDRAULIC BLOCK DIAGRAM

FIG 67

-106-

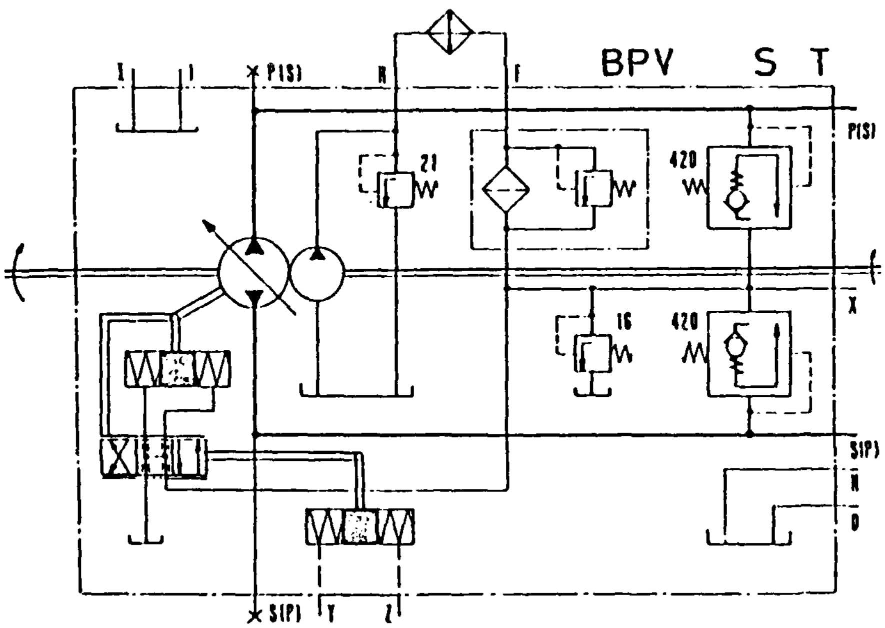


FIGURE 68. HYDRAULIC SCHEMATIC OF LINDE BPV 100 PUMP

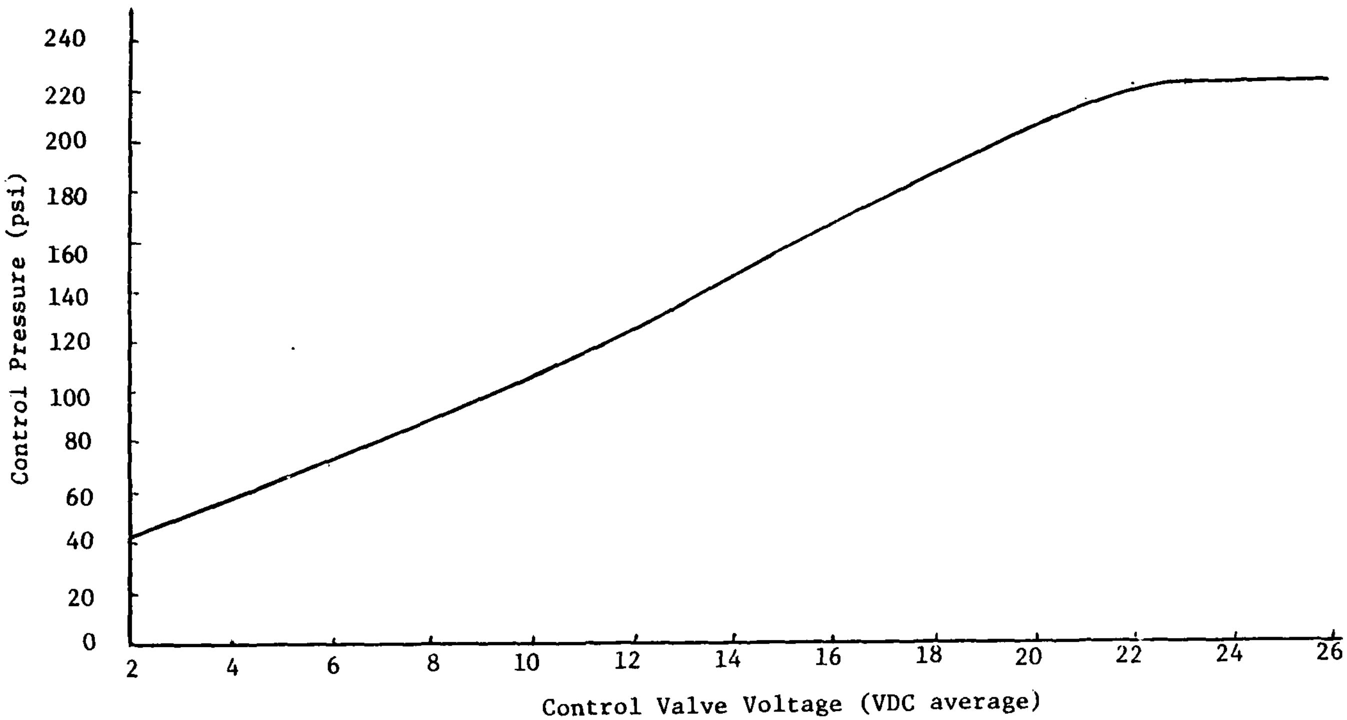


FIGURE 69. LABORATORY TEST RESULTS REGARDING TRANSMISSION CONTROL VALVE PERFORMANCE

pressure drops. This valve's performance is judged to be quite satisfactory in regard to its linearity and controllability.

Control pressure acts directly on the pump stroke control mechanism, but indirectly on the motor stroke control mechanism. In the pump the pressure acts against a spring-loaded stroke control piston that is displaced with increasing pressure. The pump displacement (amount of flow resulting from one rotation of the pump) is directly related to the value of the control pressure. In the motor, the control pressure acts against a spring-loaded displacement control valve. As this valve is displaced, charge pump pressure (which is supplied from the pump) is allowed to act against the motor stroke piston. As the motor stroke piston is displaced against its own preloaded spring, a hydraulic balance develops across the motor displacement control valve which blocks off the charge pump pressure source and maintains the motor's stroke piston displacement. The motor's displacement (amount of flow required to turn the motor one revolution) is directly controlled by the displacement of the stroke piston. The motor's output speed is therefore determined by the motor's displacement per revolution, the pump's displacement per revolution, the pump's input speed, and the volumetric losses throughout the system.

Charge pump pressure was also used in this vehicle to actuate the high and low clutches through an electro-hydraulic, 3-position, 4-way valve. It was also used to disengage the failsafe brakes so that the vehicle could be operated and to provide a pressure source for the governor control valve.

The other main hydraulic circuit included the auxiliary pump and its actuation devices. This pump was primarily used to run the cooling fan but was also used to raise and lower the rear ramp, provide a pressure source for the service brakes, and provide lubrication flow for the final drives and gear drive splitter box.

All return flow was filtered prior to reentering the hydraulic reservoir via Pall Land and Marine 3-micron filters. Main system turn to tank flow from the valves and transmission components was maintained separately from the return flow from the gear boxes. A DC-driven suction pump was used in the vehicle to continuously scavenge the gear drive splitter box and the two final drives. This return flow was also filtered via a Pall 3-micron return filter.

The overall hydrostatic drivetrain and auxiliary hydraulic system performance was judged to be adequate for this concept vehicle. The performance of the hydrostatic components was not as aggressive as it was expected to be. The performance of the oil cooling system was also somewhat marginal as the engine coolant and hydraulic systems were continuously operating at elevated temperatures throughout the test program. These problems, however, were not caused by the inadequacy of the hydraulic system design.

Poor performance of the hydrostatic components may be traceable to the subjection of debris to the hydrostatic components and the low viscosity hydraulic fluid which was used. The lack of sufficient heat exchanger performance was due to the inability to redesign the entire cooling system. Engine cooling was provided through the existing radiator with the oil cooler located upstream of the radiator. Suction cooling was utilized which pulled ambient air through the oil cooler and then through the radiator and into the engine compartment and then through the exhaust fan. Adequate cooling was intended to be obtained through increased air flow rates, but the fan exhibited a tendency to operate in the turbulent regime if it were turned at an increased speed.

The major hydraulic problems encountered had to do with the operation of the transmission control valves. These valves exhibited two primary problems; the first problem was the existence of control pressure oscillation and the second problem was the frequent plugging of the .030-inch orifices in the valves. Changing from a ball-type variable orifice valve to a more linear cone-type variable orifice corrected the oscillation problem. Providing additional pre-filtration of the oil to the control valve corrected the second problem. Adding filtration seems to be questionable in regard to the logic used.

When the oil for these valves is provided by the charge pumps, the oil is filtered via the Mann 10-micron filters in the hydrostatic pumps. This should be sufficient filtration but was not; and the reason for the inadequacy of the filtration system was not determined. One possible explanation is that the filters were by-passing and allowing contaminated oil to enter the valves. This possibility is being eliminated on the ATR vehicle as hydraulic filter by-pass indicators are being incorporated to account for this possibility.

8. FAILURE MODES AND EFFECTS ANALYSIS

A Failure Modes and Effects Analysis (FMEA) was performed on the control system during the course of the control system design effort. The results of this analysis are presented in Table 8. This analysis indicated that a failure of many of the operator input, sensor, controller, and actuator devices would effect the controllability of the vehicle. These is, however, a rather small possibility that the vehicle could not be stopped in a short distance if any one failure would occur.

This analysis indicates that failure of the steering wheel potentiometer circuit is potentially the most serious failure to occur. This failure will most likely result in a short or open circuit for this signal and would result in the vehicle wanting to turn hard to the right or to the left. A default value of straight-ahead travel is included in our software. The normal operator reaction in this situation would be to stop the vehicle.

Tests performed in the field and the failures that results therefrom have indicated that valve failures are the most predominant failure. Other failures have occurred, however, which are noteworthy. These failures include pressure transducer failures and magnetic pickup failures.

The pressure transducers originally installed in the vehicle all failed because they could not take the shock and vibration associated with this application. Their failure, however, was not overly detrimental as a default differential pressure between the forward and reverse motor pressures is assumed.

Failure at the engine magnetic pickup resulted in the inoperation of the vehicle. This occurred because the program is transferred to the initialization subroutine and waits until engine speed is again sensed. This failure occurred once during this development project and indicated that same default mode of operation is needed. The default chosen is to drive the engine to wide-open throttle and to assume that it is there. Detecting an error condition versus a condition where the engine is actually not running is possible if some hydraulic pressure source, such as charge pump pressure, is also monitored. This will be done in future applications.

Table 8. Results of Failure Modes and Effects Analysis

Component	Failure Mode	Failure Effect	Compensating Provision	Remarks
SENSORS				
Accelerator Potentiometer	Short Output High or Output Low	Drive both tracks to max or zero speed	Operator can apply brake and always control speed if output shorted high. Output shorted low, vehicle will stop.	<u>Operator Display</u> "Accelerator Pedal Position Sensor Failure" Light on.
Brake Potentiometer	Short Output High or Low	Service brake goes to full "ON" or "OFF" on both tracks	Vehicle can be stopped by allowing accelerator to go to zero speed or placing gear selector in "PARK" (parking brake applied automatically).	<u>Operator Display</u> "Brake Pedal Position Sensor Failure" Light on.
Steering Potentiometer	Short Output High or Low	Vehicle executes a pivot turn	Computer will not allow a turn radius of >10 feet at vehicle speed greater than 12 mph. Maintains previous steering command.	<u>Operator Display</u> "Steering Wheel Position Sensor Failure" Light on.
Gear Selector Switches	Open or Closed	Limited selection of gears available	With a single switch failure vehicle can always be driven forward. Vehicle can be driven in reverse unless "F1" or "R" switches are failed. Computer checks for valid switch codes.	<u>Operator Display</u> "Gear Selector Failure" Light on.
Motor Speed Magnetic Pickup	Output Low	Track goes to zero speed during final drive range change		<u>Operator Display</u> "Speed Sensor Failure" Light on.
Sprocket Speed Magnetic Pickup	Output Low	Track goes to zero speed during final drive change	Computer detects loss of pulse stream and will not allow initiation of final drive range change except at zero speed.	<u>Operator Display</u> "Speed Sensor Failure" Light on.
Engine Speed Magnetic Pickup	Output Low	Vehicle stops		<u>Operator Display</u> Engine Speed Sensor Failure" Light on.
Motor Pressure Transducer	Output High or Low	Fail High: engine speed increases Fail Low: engine speed decreases	NONE required.	Failure reduces efficiency and top speed. "Motor Pressure Transducer Failure" Light on.
Brake Pressure Transducer	Output High or Low	Fail High: brake will not activate Fail Low: brake will go full "ON"		<u>Operator Display</u> "Brake Pressure Transducer Failure" Light on.

Table 8. (Continued)

Component	Failure Mode	Failure Effect	Compensating Provision	Remarks
ACTUATORS				
Hydrostatic Motor Displacement Control Valve	Seizes or goes to max. or min. position	Limits max. vehicle speed, causes gentle turn	Operator can correct for turn with steering wheel.	
Hydrostatic Pump Displacement Control Valve	Seizes or goes to max. or min. position	A. Min. position: the track is at zero speed.	Shift to neutral and tow vehicle or replace/bypass valve.	
		B. Seizes at other than min. position: the track has limited max. and min. speed	Put in neutral. NONE required.	
Engine Speed Control Valve	Seizes or goes to max. or min. position	A. Seizes on Max: reduced engine efficiency	NONE required (engine can be stopped with manual fuel shut-off).	
		B. Min. Position: engine speed goes to low idle	Operator can set approximate engine speed with manual override mechanism.	
Brake Pressure Control Valve	Seizes or goes to max. or min. position	A. Seizes on max.: the brake-applied hydrostatics will compensate for speed change automatically	Operator can counter steer and stop vehicle.	
		B. Min. Position: no brake effort	Operator can stop vehicle with dynamic braking.	

Table 3. (Continued)

Component	Failure Mode	Failure Effect	Compensating Provision	Remarks
ANALOG ELECTRONIC CONTROLLERS				
Hydrostatic Pump/ Motor Controller	Output Low	Track goes to zero speed	Operator can counter steer and stop.	
	Output High	Track goes to full speed	Operator can shift vehicle into neutral and brake steer to a stop.	
Engine Speed Controller	Output High or Low	A. Seizes on Max. Reduced engine efficiency	NONE required (engine can be stopped with manual fuel shut-off).	
		B. Min. Position: Engine speed goes to low idle	Operator can set approximate engine speed with manual override mechanism.	
Brake Pressure Controller	Output High or Low	A. Seizes on Max.: the brake-applied hydrostatics will compensate for speed change automatically	Operator can counter steer and stop vehicle.	
		B. Min. Position: No brake effort	Operator can stop vehicle with dynamic braking.	
DIGITAL CONTROLLER				
SC-1	Failure to Null Position	Clutches disengage, engine speed decreases, vehicle coasts to stop	Operator can stop vehicle by applying brakes.	
	Failure to Random Position	Vehicle response will be random and impossible to predict	Operator can stop vehicle by applying brakes.	

The last noteworthy failure is associated with leaky fittings. Numerous leaks were obtained during the debugging and testing of the various systems. Leaks in the hydraulic system are not acceptable in a production environment, and should not be tolerated even on a technology demonstrator. To minimize future hydraulic leak problems, it is suggested that connectors with an "O" ring face be used wherever possible.

9. DRIVETRAIN WEIGHT

Table 9 presents the data gathered to relate the drivetrain weight obtained for this application. These values have been obtained from manufacturer's where possible, or have been weighted or estimated. Estimated weights are noted.

These weights represent a weight increase of 273 lbs over our original weight estimate and are largely associated with the hydraulic pump and motor required to drive the cooling fan.

The weight is associated with the HTP drivetrain components have been the subject of much discussion especially in regard to the drivetrain equivalent weights for an M113. Only one observation is presented here: the HTP drivetrain is assembled largely from commercially-available industrial components. As such, they are designed for longer average B-10 life. This resulted in increased weight.

The benefit to be gained from the application of these commercially-available components is increased flexibility of the placement of the components. One main goal in utilizing this drivetrain concept is the be able to place the hydrostatic motors and final drives in the aft of the vehicle. This is currently being undertaken in the ATR vehicle.

Decreased weight is possible beyond the adaptation of special low weight two-speed final drives. By integrating the pump design into the gear drive splitter box addition weight savings could be obtained. The trade-off will of course be additional cost of the components.

Table 9. HTP Drive Train Weight

	Weight Each (lbs)	Number Required	Total Weight
Funk Model 28211 XA Splitter Box	230	1	230
Linde Model BPV 100 Series Pumps	130	2	260
Hydura Model PVW-15-LSAS-CNSN Hyd. Pump	54	1	54
Linde Model BMV 186 Series Motors	165		330
Funk 2-speed Final Drives	509	2	1018
Racine Mode SSC-434371 Hydraulic Reservoir	170	1	170
Racine 3-position, 4-way Clutch Valve	10	1	10
Dayton Model 4Z143 Electric Motor	19	1	9
AVSCO Model 34800 Brakes	55	2	110
HPI Nickols Cooling Fan Motor	34	1	34
Tuthill Model 1LA Scavenge Pump*	13	1	13
Dunham-Bush Oil Cooler	84	1	84
Pall Filters (3 used)	6	3	18
Oil (30 gallons in reservoir, 15 gallons elsewhere)	300		300
Manifolds (SwRI Fabricated)	32		32
Hydraulic Hoses*	325		325
SC-1 Microcomputer	20		20
AEC's	2	5	10
Electrical Wiring, Sensors, Actuators*	65		65
			3092

*NOTE: These weights are estimated.

10. CLOSURE

Southwest Research Institute has provided the design and integration of a 300 hp hydrostatic transmission in a Marine Corps amphibious armored personnel carrier. The basic objective this project, testing hydrostatic drive in a high-speed tracked vehicle, was surpassed by the incorporation of microcomputer control of the entire drivetrain.

This project is significant in two respects. First, it proved the feasibility of hydrostatic drive as a reasonable drivetrain alternative from a performance point of view. Second, it proved the feasibility and practicality of providing durable reliable microcomputer control in a vehicle environment long noted for its hostility.

Not all objectives of this project were met. In particular, the efficiency objectives of the hydrostatic drivetrain were not met. Reasons for this may include prematurely worn components and improper hydrostatic fluid specifications, or the inefficiency may be inherent in their design over certain operating conditions. It is most probable that the efficiency of the transmission can be improved to meet the project objectives (efficiency values of 82-87 percent have been obtained with new components and a more viscous fluid). However certain other questions must still be answered.

How effective can regeneration during turns become? Regeneration of power from the inside track to the outside track is imperative for effective vehicle handling characteristics while operating at high speed. Higher system relief settings may improve the regeneration ability of the hydrostatic transmission, but the question will be "is it sufficient for the mission?"

Low-speed turns in second gear have been difficult in the HTP vehicle because of the high ratio associated with second gear. Low-speed turning torque must be improved to be satisfactory. Here too, higher relief settings would be beneficial, as would greater transmission efficiency, and more power to the tracks. Determining the best combination of alternatives will require considerable efforts.

SwRI is greatly appreciative of the opportunity to contribute to the DTNSRDC development efforts. We feel that the technical advances made during this project outweigh the setbacks encountered and look forward to having the opportunity to support future activities.

APPENDIX A

COMPUTER PROGRAM AND SUMMARY DATA SHEETS FOR SINGLE REDUCTION FINAL DRIVE VERSUS TWO-SPEED FINAL DRIVE DESIGN OPTIONS

AHDTEF T=00004 IS ON CR00015 USING 00036 BLKS R=0000

```
FTN4,L,Q
      PROGRAM HDTEF
      IMPLICIT REAL (A-Z)
      INTEGER TT,LP
      DATA TT/1/,LP/6/
100   CONTINUE
      WRITE(TT,999)
999   FORMAT(///,' WHAT IS VEHICLE SPEED ? _')
      READ(TT,998) VEHSPD
998   FORMAT(F6.0)
      WRITE(TT,997)
997   FORMAT(' WHAT IS TOTAL VEHICLE RESISTANCE ? _')
      READ(TT,998) VEHRES
      WRITE(TT,996)
996   FORMAT(' WHAT IS FINAL DRIVE GEAR RATIO ? _')
      READ(TT,998) FDGR
      WRITE(TT,995)
995   FORMAT(' WHAT IS MAXIMUM PUMP DISPLACEMENT ? _')
      READ(TT,998) MPD
      WRITE(TT,994)
994   FORMAT(' WHAT IS MAXIMUM MOTOR DISPLACEMENT ? _')
      READ(TT,998) MMD

      SPRSPD = VEHSPD * 17.507
      SPRTRQ = VEHRES * 0.4
      SPRPWR = SPRTRQ * SPRSPD / 5250.
      MTROPR = SPRPWR / .96
      MTROTQ = SPRTRQ / FDGR / .96
      MTRSPD = SPRSPD * FDGR
      TRNSEF = SQRT(SQRT(MTROPR/249.))
      EPRMTR = MTROPR / TRNSEF
      TREP = 2 * EPRMTR + 30
      MDISP = -0.00092857 * MTRSPD + 6.65
      IF(MDISP.LT.3.37) MDISP = 3.37
C     DES = SQRT((8.33*TREP+600)**2 + (MDISP*MTRSPD*.1358)**2)
      DES = 1100. + .3666 * MTRSPD + 8.5 * TREP - .00185 * MTRSPD *TREP
      IF (DES.GT.2800) DES = 2800
      MD = DES / MTRSPD * 5.5233
      IF(MD.LT.3.37) MD = 3.37
      IF(MD.GT.MMD) MD = MMD
C     MTRPRS = (MTROTQ + 24.86) * 75.4 / MD
      MTRPRS = (MTROTQ * 75.4 + MMD * 125) / MD
C     VEFFM = 1.0 - 115. * MMD / MTRPRS / MD
      EFFMM = 1.0 - 115. * MMD / MTRPRS / MD
C     EFFMM = .99 -  (.01696*MMD*MTRPRS/MD/MTRSPD)**2
      VEFFM = .99 -  (.01696*MMD*MTRPRS/MD/MTRSPD)**2
C     EFFMM = EFFMM - MTRPRS / 145000.
      VEFFM = VEFFM - MTRPRS / 145000.
C     EFFMM = EFFMM - (24.692*MMD/MTRSPD/MD) ** 2
      VEFFM = VEFFM - (24.692*MMD/MTRSPD/MD) ** 2
C     MTRIFW = MTRSPD * MD / 231. / EFFMM
      MTRIFW = MTRSPD * MD / 231. / VEFFM
      MTRIPR = MTRPRS * MTRIFW / 1714.
      MTREFF = MTROPR / MTRIPR
      HOSFPS = MD * MTRSPD * (2 - .96) /1272.345
      FF = 1./(-4 * LOG(.141987/HOSFPS + .00043243))
      PSIDRP = FF * .34264 * HOSFPS ** 2
      LINPWR = PSIDRP * MTRIFW / 1714.
```

```
      PMPOPR = MTRIPR + LINPWR
      PMPOPS = MTRPRS + PSIDRP
      A =  .00000005394 * (MPD*PMPOPS/MTRIFW) ** 2
      A = A + .011424 * (MPD/MTRIFW) ** 2
      C = .0000068966 * PMPOPS - .98
      PVEFF = ( -1 + SQRT(1-4*A*C))/2/A
      PDISP = MTRIFW * 231/DES/PVEFF
      IF (PDISP.GT.MPD) PDISP = MPD
      PEFFM = 1. - 165. * MPD / (PDISP*PMPOPS)
      PMPITQ = PMPOPS * PDISP / PEFFM/75.4
      PMPIPR = PMPITQ * DES / 5250
      PMPEFF = PMPOPR / PMPIPR
      CPMPPR = DES / 1639.5
      SBXOPR = 2 * CPMPPR + 2 * PMPIPR
      TRNIPR = SBXOPR / .98
      TTRNEF = 2 * SPRPWR / TRNIPR

      CALL EXEC(2,406B,14B,1)
      WRITE(LP,900)VEHSPD, VEHRES, FDGR, MPD,MMD,SPRSPD, SPRTRQ, SPRPWR,
     *            MTROPR,
     *            MTROTQ, MTRSPD, TRNSEF, EPRMTR, TREP, DES, MD, MTRPRS,
     *            VEFFM, EFFMM, MTRIFW, MTRIPR, MTREFF, PSIDRP, LINPWR,
     *            PMPOPR, PMPOPS, PDISP, PVEFF, PEFFM, PMPITQ, PMPIPR,
     *            PMPEFF, CPMPPR, SBXOPR, TRNIPR, TTRNEF
      WRITE(TT,900)VEHSPD, VEHRES, FDGR, MPD,MMD,SPRSPD, SPRTRQ, SPRPWR,
     *            MTROPR,
     *            MTROTQ, MTRSPD, TRNSEF, EPRMTR, TREP, DES, MD, MTRPRS,
     *            VEFFM, EFFMM, MTRIFW, MTRIPR, MTREFF, PSIDRP, LINPWR,
     *            PMPOPR, PMPOPS, PDISP, PVEFF, PEFFM, PMPITQ, PMPIPR,
     *            PMPEFF, CPMPPR, SBXOPR, TRNIPR, TTRNEF
900   FORMAT (///,20X,
     *       ' HYDRAULIC DRIVE TRAIN EFFICIENCY CALCULATIONS ',/,
     *       ' VEHICLE SPEED :MPH  - ',F6.2,/,
     *       ' TOTAL VEHICLE RESISTANCE :LBS  - ',F8.2,/,
     *       ' FINAL DRIVE GEAR RATIO :RATIO  - ',F6.3,/,
     *       ' MAXIMUM PUMP DISPLACEMENT :IN^3/REV  - ',F6.3,/,
     *       ' MAXIMUM MOTOR DISPLACEMENT :IN^3/REV  - ',F6.3,/,
     *       ' SPROCKET SPEED :RPM  - ',F7.2,/,
     *       ' SPROCKET TORQUE :FTLBS  - ',F7.2,/,
     *       ' SPROCKET POWER :HP  - ',F7.3,/,
     *       ' MOTOR OUTPUT POWER :HP  - ',F7.3,/,
     *       ' MOTOR OUTPUT TORQUE :FTLBS  - ',F8.3,/,
     *       ' MOTOR OUTPUT SPEED :RPM  - ',F8.3,/,
     *       ' TRANSMISSION EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' ENGINE POWER FOR EACH MOTOR :HP  - ',F7.2,/,
     *       ' TOTAL REQUIRED ENGINE POWER :HP  - ',F7.2,/,
     *       ' DESIRED ENGINE SPEED : RPM  - ',F8.2,/,
     *       ' MOTOR DISPLACEMENT :IN^3/REV  - ',F6.3,/,
     *       ' MOTOR PRESSURE :PSI  - ',F8.2,/,
     *       ' MOTOR MECHANICAL EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' MOTOR VOLUMETRIC EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' MOTOR INPUT FLOW :GPM  - ',F7.3,/,
     *       ' MOTOR INPUT POWER :HP  - ',F7.2,/,
     *       ' MOTOR OVERALL EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' LINE PRESSURE DROP  :PSI  - ',F7.4,/,
     *       ' LINE POWER LOSS  :HP  - ',F7.4,/,
     *       ' PUMP OUTPUT POWER :HP  - ',F7.3,/,
     *       ' PUMP OUTPUT PRESSURE :PSI  - ',F7.2,/,
     *       ' PUMP DISPLACEMENT :IN^3/REV  - ',F6.4,/,
     *       ' PUMP VOLUMETRIC EFFICIENCY :RATIO  - ',F6.4,/,
```

```
     *       ' PUMP MECHANICAL EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' PUMP INPUT TORQUE :FTLBS  - ',F7.2,/,
     *       ' PUMP INPUT POWER :HP  - ',F7.3,/,
     *       ' PUMP OVERALL EFFICIENCY :RATIO  - ',F6.4,/,
     *       ' CHARGE PUMP POWER :HP  - ',F7.4,/,
     *       ' SPLITTER BOX OUTPUT POWER :HP  - ',F7.4,/,
     *       ' TRANSMISSION INPUT POWER :HP  - ',F7.3,/,
     *       ' TOTAL TRANSMISSION EFFICIENCY :RATIO  - ',F6.4)
      GO TO 100
      END
  CR=00015
   ILAB=SP01   NXTR= 00186 NXSEC=052 #SEC/TR=096 LAST TR=00202 #DR TR=01

  NAME   TYPE   SIZE/LU    OPEN TO
```

SINGLE REDUCTION FINAL DRIVE
TRANSMISSION EFFICIENCY ANALYSIS

Input Variables:

Final Drive Gear Ratio = 3.71
Maximum Pump Displacement = 12.2 in^3/rev
Maximum Motor Displacement = 31.72 in^3/rev

Vehicle Speed (mph)	Vehicle Total Resistance (lb_f)	Sprocket Speed (rpm)	Sprocket Torque ($ft\text{-}lb_f$)	Total Transmission Efficiency (ratio)
16.64	3625	300	2900	.642
9.42	7500	165	6000	.713
5.71	7500	100	6000	.650
11.42	4250	200	3400	.644
5.71	4250	100	3400	.570
40.0	1250	700	1000	.521
40.0	625	700	500	.387
28.56	1000	500	800	.456
17.14	1250	300	1000	.454
17.14	2500	300	2000	.573
8.57	2500	150	2000	.525
2.86	2500	50	2000	.273
2.86	7500	50	1000	.533
2.86	12500	50	1000	.554
5.71	5000	100	4000	.517
11.42	5000	200	4000	.671
14.28	2500	250	2000	.557
1.43	7500	25	6000	.307
5.71	2750	100	2200	.483
2.86	16000	50	12800	.530
2.86	18000	50	14400	.506
11.42	6200	200	4960	.703
17.14	3900	300	3120	.658
25.40	2450	450	1960	.619
40.0	1400	700	1120	.553
1.43	14250	25	11400	.194

TWO-SPEED FINAL DRIVE
TRANSMISSION EFFICIENCY ANALYSIS

Input Variables:

Maximum Pump Displacement = 6.12 in^3/rev
Maximum Pump Displacement = 11.36 in^3/rev

Final Drive Ratio	Vehicle Speed (mph)	Vehicle Total Resistance	Sprocket Speed (rpm)	Sprocket Torque ($ft-lb_f$)	Total Transmission Efficiency (ratio)
10.92	2.86	21000	50	16800	.720
10.92	5.71	12000	100	9600	.766
10.92	11.42	6625	200	5300	.752
10.92	16.64	3625	291	2100	.707
4.07	9.42	7500	165	6000	.743
4.07	17.14	4250	300	3400	.769
4.07	25.7	2875	450	2300	.759
4.07	40.0	1750	700	1400	.731
4.07	5.71	7500	100	6000	.674
4.07	11.42	4250	200	3400	.741
4.07	5.71	4250	100	3400	.674
4.07	40.0	1250	700	1000	.692
4.07	40.0	625	700	500	.579
4.07	28.56	1000	500	800	.637
4.07	17.14	1250	300	1000	.633
4.07	17.14	2500	300	2000	.723
4.07	8.57	2500	150	2000	.668
4.07	2.86	2500	50	2000	.479
4.07	2.86	7500	50	6000	.499
10.92	2.86	12500	50	1000	.711
10.92	2.86	7500	50	6000	.670
10.92	2.86	2500	50	2000	.470
10.92	5.71	5000	100	4000	.683
10.92	11.42	5000	200	4000	.727
10.92	14.28	2500	250	2000	.645
10.92	1.43	15000	25	12000	.619
10.92	1.43	21000	25	16800	.589
10.92	1.43	7500	25	6000	.566
10.92	5.71	3750	100	3000	.727

APPENDIX B

WHOLE VEHICLE DYNAMOMETER TEST RESULTS

WHOLE VEHICLE TEST DATA

Test No	Final Drive Gear Ratio (ratio)	Engine Speed (rpm)	Left Sprocket Speed (rpm)	Right Sprocket Speed (rpm)	Left Sprocket Torque ($ft\text{-}lb_f$)	Right Sprocket Torque ($ft\text{-}lb_f$)	Total Sprocket Output Power (hp)	Auxiliary System Power (hp)	Fuel Flow Rate (lb_m/hr)	Estimated Engine Power From Fuel Flow (hp)	Trans. Eff. From Fuel Flow (percent)	Corrected Right Sprocket Torque For Clutch Slip ($ft\text{-}lb_f$)	Corrected Total Sprocket Power For Clutch Slip (hp)	Corrected Trans. Eff. For Clutch Slip Using Fuel Flow (percent)	Calculated Engine Output Power Using Pump Displacement Speed Mechanical Effeciency and Pressure (hp)	Trans. Eff. Using Corrected Sprocket Torque and Calculated Engine Power (percent)
A	4.1	1809	346	347	707	745	95.8	19.7	86	201	53	778	98.0	49	168	66
B	4.1	2143	380	395	809	816	119.7	25	101.5	275	41	851	122.4	45	191	74
C	4.1	2761	582	542	214	242	48.6	30	64	190	39	238.7	48.3	25	225	25
D	4.1	2775	523	556	425	437	88.6	28.7	85	256	39	414	86.2	34	269.5	36
E	4.1	2761	500	501	700	602	124	28.6	121	320	43	717	135.1	42	223	69
F	4.1	2357	421	448	773	756	126.5	26.8	108	295	47	1052	151.7	51	254	67
G	4.1	1966	321	312	861	854	103.4	18.83	92.4	280	40	1051	115	41	189.5	67
50	4.1	2048	303	300	175	175	20.1	21.2	39.5	104	19	266	25.3	30	96	34
51	4.1	2054	304	300	352	350	40.4	20.7	44	120	41	475	47.5	48	120.4	48
52	4.1	2051	302	301	702	700	80.5	20.4	63.4	185	49	762	84	51	168.5	57
53	4.1	2034	301	305	1099	1053	124.2	19	91.6	285	47	1.29	122.8	46	225.2	60
54																
55	4.1	2380	409	404	357	350	54.7	26.8	61.4	156	42	581.5	72.6	56	147.7	60
56	4.1	2383	407	400	700	700	107.6	26.5	88	240	50	964	127.7	59	207.7	70
57	4.1	2163	396	389	885	875	131.6	21.6	102.2	276	52	1180	154.2	61	226	75
58	10.9	1965	103	102	357	353	13.9	19.6	27.8	54	40	480	16.33	47	86.4	24
59	10.9	1975	102	103	700	696	27.3	19.7	34.1	83	44	734	28.0	45	96.2	37
60	10.9	1952	103	102	931	931	36.4	19.2	37.8	97	47	931	36.4	47	105.0	42
61	10.9	2396	153	151	1054	1043	60.5	27.4	58.8	128	60	1172	64.23	64	136.2	59
62	10.9	2390	153	151	1225	1218	70.7	26.9	61.0	156	55	1412	76.3	59	148.2	63
63	10.9	2672	193	190	1400	1417	102.9	29.8	84.4	250	47	1722	113.8	52	211.3	63
64	10.9	2681	248	244	703	696.5	63.6	30.5	72.2	182	47	961	78.1	52	174.8	54
65	10.9	2696	248	244	1047	1047	98.1	30.0	88.2	234	48	1420	115.5	57	208.0	65
66	4.1	2682	505	498	700	700	133.7	30.6	106.0	288	52	872	150	58	252.9	67
67	4.1	2110	380	376	840	875	123.5	21.7	102.2	276	43	1275	152	60	222.6	76
68	4.1	2333	313	307	689	700	83	38.4	69.0	178	55	787	87.1	58	187.8	55
69	4.1	2450	310	309	1109	1123	131.6	28.5	92.4	228	66	1154	133.5	67	254	59
70	4.1	2368	406	400	710	693	108	26.97	87.4	236	52	865	120.8	58	203	68
71	4.1	2428	606	570	553	542	123	28.3	106.8	286	1	718	141.8	55	265	51
72	4.1	2428	615	605	175	179	41.5	27.7	72.8	190	26	564	85.5	53	171.61	59
73	4.1	2428	614	570	353	382	82.8	27	93.4	251	42	724	119.8	54	204.2	68
74	4.1	2200	697	-56	351	-52.5	47.9	30.6	47.2	122	52	1	1	1	101.2	68
75	4.1	2500	686	-63	728	-59	95.84	28.0	80.2	213	52	1	1	1	101.2	68
76	4.1	2762	620	-69	1060	-56	126	32.2	110	300	47	1	1	1	234.2	62
77	4.1	940	0	50	0	171	1.63	7.1	9	17	16	1	1	1	2	2
78	4.1	918	0	52	0	413	4.09	7	11	22	27	1	1	1	2	2
79	4.1	1179	0	50	0	665	6.33	12.3	21	52	16	1	1	1	2	2
80	4.1	1300	0	108	0	346	7.13	14.9	18	40.5	28	1	1	1	2	2
81	4.1	1393	0	99	0	704	13.3	17	32	82	20	1	1	1	2	2
82	4.1	1800	0	213	0	357	14.5	27.9	35	96	21	1	1	1	2	2
83	4.1	2413	0	197	0	703	26.4	41.7	62	158	23	1	1	1	2	2
84	4.1	1844	0	299	0	357	20.3	27.9	68	102	27	1	1	1	118	23
85	4.1	2113	0	296	0	717	40.4	33.5	68	195	25	1	1	1	199.33	24
86	4.1	2694	0	402	0	1455	111.48	43.6	114	308	42	1	1	1	225	61
87	4.1	2179	0	500	0	700	66.7	35.3	72	200	40	1	1	1	145	61
88	4.1	2259	0	493	0	1039	97.6	37.4	96	264	43	1	1	1	203	59
89	4.1	2523	0	390	0	1428	106	40.9	104	281	44	1	1	1	230	56
90	4.1	2228	0	587	0	696	77.3	36.5	76	212	44	1	1	1	176	55
91	4.1	2720	0	562	0	994	106.4	44	112	306	41	1	1	1	214	62

Note: 1 refers to tests where the clutches where repaired so the should have been no slip. 2 refers to tests where the pump was not at its maximum displacement which makes the calulations less accurate.

APPENDIX C

LABORATORY DYNAMOMETER EFFICIENCY DATA

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
1006.9	20.97	4.02	32.37	100.36	.62	.15	5.98	75.82	302.26
1001.3	28.94	5.52	131.40	100.30	2.51	.45	8.00	79.82	212.25
1002.2	40.60	7.75	88.98	201.27	3.41	.44	7.99	74.21	169.72
1001.2	47.69	9.10	50.84	301.17	2.92	.32	7.99	72.58	129.88
997.19	77.89	14.79	57.78	400.08	4.40	.30	7.95	89.87	267.19
1006.3	95.15	18.25	46.33	499.24	4.41	.24	7.95	89.44	161.38
996.68	39.86	7.57	243.84	101.28	4.70	.62	9.96	101.77	209.93
997.16	63.32	12.03	217.04	201.08	8.31	.69	9.96	93.43	185.78
997.52	83.57	15.88	167.45	298.10	9.51	.60	9.96	87.09	156.91
993.49	81.87	15.49	85.90	397.95	6.51	.42	9.98	72.02	84.58
999.81	149.10	28.39	144.79	499.76	13.78	.49	10.01	106.51	139.11
1004.5	51.74	9.90	350.11	101.25	6.75	.68	11.94	116.17	187.43
1009.3	90.67	17.43	326.35	202.88	12.61	.72	12.05	113.30	184.20
969.85	122.24	22.58	272.79	298.41	15.51	.69	12.05	108.86	155.86
998.51	176.31	33.53	290.24	400.35	22.13	.66	11.91	125.97	274.96
1004.0	220.73	42.21	271.78	500.83	25.93	.61	12.08	126.32	131.91
993.33	64.60	12.22	461.90	100.57	8.85	.72	13.94	138.43	198.88
1020.4	116.00	22.55	436.99	201.74	16.79	.74	13.99	129.38	171.38
999.52	136.72	26.03	329.19	300.27	18.83	.72	14.02	112.01	148.65
1010.0	234.64	45.14	391.24	400.63	29.86	.66	14.02	146.95	181.22
999.63	73.06	13.91	527.35	101.18	10.16	.73	15.97	157.10	201.01
1015.1	118.59	22.93	449.40	201.49	17.25	.75	16.01	133.45	166.68
993.78	135.35	25.62	328.93	299.74	18.76	.73	16.01	116.78	138.93
1002.2	273.74	52.25	441.26	400.43	33.66	.64	15.95	167.43	96.74
1001.3	73.90	14.09	542.73	100.82	10.42	.74	17.90	160.02	198.32
1015.5	117.77	22.78	454.92	201.89	17.49	.77	17.93	132.44	172.46
997.75	136.73	25.99	327.93	300.95	18.80	.72	17.94	116.02	138.90
1006.5	74.23	14.23	552.88	101.19	10.66	.75	19.83	161.78	201.72
1014.5	119.38	23.07	448.77	202.70	17.33	.75	19.86	133.63	166.92
992.80	134.24	25.39	323.56	301.16	18.56	.73	19.88	115.73	141.00
1002.4	74.49	14.22	529.17	101.92	10.27	.72	21.94	155.56	194.33
1006.0	116.01	22.23	429.39	200.40	16.39	.74	21.99	133.58	161.42
1015.1	133.90	25.89	324.55	301.72	18.65	.72	21.84	110.36	144.25
1004.4	135.34	25.89	508.81	200.45	19.43	.75	23.89	155.56	190.74
1011.9	151.86	29.27	369.17	302.90	21.30	.73	23.90	126.10	150.36

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1022.2	104.49	44.02	318.07	4.82	.40	11.36	.11	.11
942.12	248.25	24.30	248.17	5.36	1.65	11.36	.14	.12
1618.0	223.02	23.42	188.50	6.18	1.12	11.36	.11	.35
2349.2	136.99	27.94	148.52	6.52	.64	11.36	.11	.29
3108.2	112.35	43.86	320.22	8.12	.73	11.36	.11	.54
3483.6	197.86	43.90	319.79	8.99	.58	11.36	.11	.47
933.70	255.75	24.63	255.84	4.89	3.08	11.36	.73	.52
1655.5	231.96	23.47	208.96	8.22	2.74	11.36	.66	.74
2230.0	158.71	25.64	168.71	9.24	2.11	11.36	.44	.77
2859.6	107.29	25.83	112.18	8.70	1.09	11.36	.11	.66
3539.0	138.50	42.08	318.88	12.59	1.82	11.36	.23	.84
877.04	236.43	23.72	233.03	6.78	4.39	11.36	.86	.64
1605.3	207.23	25.59	203.19	4.53	4.07	11.36	.83	.82
2240.6	178.24	24.42	175.37	10.84	3.54	11.36	.77	.86
3065.2	117.03	42.62	310.99	14.22	3.66	11.36	.78	.91
3646.8	92.13	42.40	313.88	17.31	3.41	11.36	0.00	0.00
1012.4	243.87	24.43	233.65	7.66	5.85	11.36	.91	.78
1715.1	209.08	25.84	201.18	10.56	5.39	11.36	.89	.88
2254.9	171.17	25.53	173.49	11.17	4.15	11.36	.83	.88
3454.4	234.62	42.59	311.35	18.04	4.88	11.36	.86	.94
1114.6	244.17	24.60	234.81	7.63	6.12	10.47	.91	.81
1740.9	190.73	24.47	192.60	11.30	5.57	11.36	.90	.88
2276.4	169.28	26.03	172.20	11.11	4.17	11.36	.83	.88
3936.0	84.36	42.24	316.34	21.26	5.54	11.36	0.00	0.00
1136.2	239.69	24.99	229.66	8.73	6.12	10.19	.91	.82
1737.4	204.94	26.64	192.16	10.36	5.64	11.36	.90	.88
2325.8	181.22	23.85	165.06	11.75	4.14	11.36	.83	.87
1130.0	243.66	24.91	237.28	8.76	6.12	10.05	.91	.82
1755.0	204.62	26.10	194.81	10.57	5.57	11.36	.90	.88
2289.6	165.51	26.82	173.00	11.40	4.10	11.36	.82	.88
1107.5	762.33	21.64	226.75	7.27	6.12	10.46	0.00	0.00
1697.1	762.65	22.13	195.71	10.27	5.37	11.36	0.00	0.00
2252.4	762.88	23.45	170.12	11.43	4.03	11.36	0.00	0.00
1991.2	237.02	20.67	225.21	12.11	6.12	10.90	.91	.91
2380.4	185.35	24.44	175.12	12.31	4.59	11.36	.86	.90

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.17	.86	.02	0.00	.15	.00
.94	.82	.02	0.00	.77	.01
.33	.91	.04	0.00	.76	.03
.20	.94	.03	0.00	.18	.01
.11	.96	.05	0.00	.11	.01
.11	.96	.05	0.00	.10	.00
.97	.82	.38	.00	.79	.30
.95	.91	.49	.00	.87	.43
.91	.94	.34	.00	.86	.29
.59	.95	.07	0.00	.57	.04
.78	.96	.19	0.00	.75	.15
.98	.83	.55	.01	.79	.43
.97	.91	.69	.02	.88	.61
.95	.94	.66	.00	.89	.59
.93	.96	.71	.00	.89	.63
0.00	0.00	0.00	0.00	0.00	0.00
.98	.84	.70	.03	.82	.58
.97	.92	.78	.02	.89	.70
.96	.94	.73	.02	.90	.66
.94	.96	.80	.01	.91	.73
.98	.84	.74	.03	.83	.61
.97	.92	.79	.02	.89	.71
.95	.94	.73	.02	.90	.66
0.00	0.00	0.00	0.00	0.00	0.00
.98	.84	.74	.03	.83	.61
.97	.92	.79	.02	.89	.71
.96	.94	.73	.02	.90	.66
.98	.84	.75	.03	.83	.62
.97	.92	.79	.02	.89	.71
.96	.94	.73	.01	.90	.66
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.77	.93	.82	.03	.90	.74
.96	.94	.77	.01	.91	.70

[illegible] OF 4 OF 32 RUNS.

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
102.0	79.4	154.3	68.6	108.6	85.6	99.0	63.1	78.0
101.4	93.4	133.8	80.0	98.1	90.8	90.2	86.5	85.1
101.8	92.2	132.8	80.2	99.8	91.6	91.2	86.8	85.6
102.7	93.8	132.0	79.8	104.3	93.3	92.4	87.0	85.7
101.7	79.2	146.4	68.2	111.1	85.2	98.5	63.5	77.0
102.0	89.5	143.2	68.1	120.5	89.8	98.7	63.9	77.1
99.7	93.1	127.9	89.3	97.6	90.6	89.8	87.5	91.6
101.9	94.5	128.7	89.5	99.8	91.7	91.1	87.9	92.5
103.3	94.1	129.3	89.5	103.1	92.7	92.3	88.7	93.4
100.2	91.1	122.3	87.9	105.8	91.7	90.6	86.3	94.2
99.9	78.4	136.6	68.2	123.6	91.4	100.8	64.1	78.3
98.9	90.4	123.3	88.1	105.7	92.7	92.7	85.5	90.8
99.4	90.7	124.0	88.2	104.2	90.9	91.2	85.5	91.2
101.6	90.7	125.8	88.2	105.8	91.2	90.8	85.3	92.8
109.0	80.0	137.1	68.7	125.5	92.8	104.2	64.4	79.9
108.0	79.3	135.5	69.0	128.8	94.9	104.0	64.4	81.3
101.3	89.7	127.4	89.1	105.9	91.5	91.7	84.1	93.5
100.6	89.9	127.7	89.3	104.8	90.1	90.0	83.9	94.1
101.7	90.2	128.5	89.6	106.9	90.9	90.3	84.4	95.0
114.1	* 81.8	139.5	70.1	134.2	98.3	105.1	65.2	84.4
99.9	89.7	129.5	69.0	105.9	91.0	91.3	83.5	92.7
101.6	91.0	130.4	88.6	105.5	90.9	91.2	84.2	94.2
102.8	92.3	131.1	88.8	107.6	91.7	91.0	84.8	94.3
101.6	79.5	132.5	70.8	130.4	95.2	104.6	66.1	84.2
100.4	90.1	131.0	87.2	104.1	91.0	90.1	84.1	92.3
102.7	92.7	131.2	86.5	105.5	91.9	91.0	85.1	93.1
103.7	93.3	131.8	86.0	107.1	92.4	91.9	85.7	93.3
101.0	89.9	131.8	85.3	106.3	92.6	92.6	85.2	91.6
102.6	92.8	132.2	85.0	106.4	92.3	92.2	85.8	91.9
104.8	92.8	132.5	85.4	108.6	93.3	92.7	86.5	92.9
108.5	95.7	135.2	84.8	110.5	96.7	97.5	89.3	90.9
106.9	96.0	135.7	85.4	110.2	96.4	96.0	89.5	91.6
108.6	97.5	136.8	65.9	112.9	96.7	96.1	89.5	92.7
102.4	95.7	95.5	73.1	90.5	88.6	87.0	88.3	80.7
108.5	97.4	114.3	74.4	103.2	93.8	92.8	91.3	84.0

PAGE # [illegible] OF [illegible] OF 16 RUNS.

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
1197.6	33.76	7.70	78.62	200.59	3.00	.39	8.00	72.17	191.14
1193.9	42.95	9.77	36.89	299.28	2.10	.22	8.00	69.03	179.69
1196.6	45.89	10.46	323.96	101.10	6.24	.60	9.99	103.53	238.72
1203.0	74.61	17.10	278.55	200.40	10.63	.62	10.01	102.04	225.77
1198.7	99.05	22.61	246.20	299.77	14.06	.62	10.01	100.54	186.67
1200.0	111.77	25.55	176.98	401.47	13.53	.53	10.01	87.94	112.36
1201.6	58.71	13.44	447.06	104.27	8.88	.66	12.02	123.54	230.23
1193.1	97.24	22.10	417.56	202.95	16.14	.73	12.02	120.41	211.34
1196.5	137.07	31.24	397.24	302.46	22.89	.73	12.03	116.11	180.46
1196.0	124.17	28.29	544.57	202.78	21.03	.74	13.90	141.66	220.50
1207.1	172.84	39.74	508.93	302.44	29.32	.74	14.04	135.42	182.36
1202.0	175.68	40.22	369.47	400.70	28.20	.70	14.05	112.60	138.45
1204.7	77.30	17.74	639.42	100.65	12.26	.67	16.00	153.93	229.84
1196.1	143.47	32.67	632.67	202.37	24.39	.75	15.89	160.65	201.05
1198.8	173.82	39.69	505.53	301.15	29.00	.73	15.89	140.98	167.62
1203.7	205.29	47.07	474.49	400.60	36.22	.77	16.00	129.51	165.41

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1719.3	227.24	26.12	229.50	6.55	.83	11.36	.11	.18
2306.5	176.78	30.84	173.69	7.31	.39	11.36	.11	.11
944.78	286.05	23.77	286.04	7.95	3.41	11.36	.84	.55
1702.0	287.64	22.98	268.84	9.62	2.92	11.36	.78	.76
2396.0	241.79	24.81	240.02	11.39	2.59	11.36	.72	.82
3071.6	166.16	23.75	148.85	12.32	1.86	11.36	.48	.81
991.04	281.50	26.48	269.32	8.58	4.68	11.36	.90	.70
1701.6	257.90	26.32	246.17	11.30	4.41	11.36	.89	.84
2323.2	237.53	25.06	212.89	14.64	4.18	11.36	.87	.88
1856.7	265.84	24.58	256.91	12.55	5.73	11.36	.92	.89
2529.0	225.20	24.59	216.18	16.53	5.31	11.36	.91	.72
2759.2	174.14	23.35	162.55	16.48	3.87	11.36	.85	.91
1139.0	760.25	19.96	272.14	9.85	6.12	10.41	0.00	0.00
2135.6	245.28	26.11	238.35	14.11	6.12	10.44	.72	.91
2535.8	208.28	25.46	202.12	16.39	5.31	11.36	.91	.92
3000.0	781.95	21.17	195.37	19.17	4.96	11.36	0.00	0.00

PAGE 4 2 OF 4 [illegible] 16 RUNS.

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.78	.92	.02	0.00	.71	.01
.11	.94	.02	0.00	.09	.00
.98	.81	.46	.02	.79	.36
.96	.91	.37	.00	.88	.52
.94	.94	.59	.00	.89	.53
.87	.96	.39	.00	.84	.33
.98	.82	.63	.02	.81	.51
.97	.91	.75	.02	.89	.66
.96	.94	.77	.02	.91	.70
.97	.92	.82	.04	.90	.73
.97	.95	.83	.03	.91	.76
.95	.96	.77	.01	.91	.70
0.00	0.00	0.00	0.00	0.00	0.00
.97	.93	.84	.05	.90	.76
.97	.95	.83	.03	.91	.76
0.00	0.00	0.00	0.00	0.00	0.00

PAGE # 4 OF 4 OF 16 RUNS.

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
106.7	96.9	165.1	82.7	121.5	103.4	104.1	87.5	93.8
107.9	96.7	157.6	83.1	119.7	102.2	101.9	89.7	93.0
101.1	93.6	118.9	85.1	102.4	93.6	93.6	86.7	90.3
103.3	94.2	123.9	85.4	104.0	93.9	93.5	87.9	92.8
105.0	95.7	128.3	85.3	107.4	95.5	94.6	88.7	94.1
108.8	95.7	134.9	84.5	119.5	101.4	100.4	89.7	95.4
105.2	95.0	136.9	86.2	112.2	97.6	98.4	88.5	94.3
104.0	93.6	137.4	86.8	111.4	96.6	96.8	88.2	95.8
100.9	90.3	128.8	85.8	105.5	92.5	91.3	85.3	104.0
104.7	94.8	129.0	74.8	106.1	96.0	94.5	90.9	86.1
107.5	97.8	131.9	75.4	111.6	98.3	96.4	92.3	89.7
112.4	98.9	134.9	76.5	117.8	101.2	98.9	93.2	92.3
101.6	94.4	132.6	83.2	110.0	97.3	95.6	87.8	91.3
106.3	96.7	140.9	76.6	112.1	98.8	97.0	91.9	89.0
110.9	97.7	141.5	76.5	117.0	101.0	99.7	93.1	91.3
106.8	95.5	116.3	70.5	104.6	93.2	90.6	88.4	86.6

PAGE # 1 OF 4 OF 45 RUNS.

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSURE AT VALVE (PSI)
1404.6	24.87	6.65	88.37	100.09	1.68	.25	6.03	78.75	334.32
1399.8	34.98	9.33	73.70	199.20	2.80	.30	6.03	79.68	322.61
1402.6	45.44	12.14	56.73	299.91	3.24	.27	6.01	79.78	313.78
1403.3	28.73	7.68	152.16	99.93	2.90	.38	8.00	82.37	248.49
1398.1	42.35	11.28	123.57	199.85	4.70	.42	8.01	81.53	243.31
1397.4	54.31	14.46	91.00	301.47	5.23	.36	8.02	77.85	215.58
1403.5	88.16	23.57	146.12	400.59	11.15	.47	8.00	92.64	323.93
1407.0	101.84	27.29	104.03	499.80	9.90	.36	8.00	90.80	300.22
1398.3	118.25	31.50	74.42	600.02	8.51	.27	8.01	89.63	241.51
1400.2	115.64	30.84	52.68	599.45	6.02	.20	8.01	90.42	167.27
1410.3	44.18	11.87	345.92	102.41	6.75	.57	10.02	103.01	243.78
1397.3	71.94	19.15	308.11	201.53	11.83	.62	10.02	104.33	238.56
1404.7	96.42	25.80	278.45	303.36	16.09	.62	10.02	101.66	222.70
1399.0	115.96	30.90	240.30	400.29	18.32	.59	10.02	93.98	186.70
1400.5	130.25	34.75	181.87	499.26	17.30	.50	10.02	88.38	117.27
1412.4	186.73	50.24	226.94	601.03	25.98	.52	10.05	107.33	249.18
1393.7	210.24	55.81	188.01	700.15	25.07	.45	10.06	107.12	94.52
1407.1	57.12	15.31	512.55	100.39	9.80	.64	12.20	122.67	242.10
1400.2	99.52	26.54	488.87	202.51	18.86	.71	12.21	121.25	227.86
1391.6	142.29	37.72	467.38	302.60	26.94	.71	12.02	121.81	214.69
1400.3	173.09	46.17	419.28	401.21	32.04	.69	12.21	115.98	169.38
1411.6	128.64	34.59	168.12	502.35	16.09	.47	12.20	88.56	111.14
1416.0	270.99	73.09	394.67	600.58	45.15	.62	11.96	128.30	118.94
1402.3	70.42	18.81	663.12	101.27	12.79	.68	13.98	140.86	245.17
1405.9	124.09	33.23	629.59	201.25	24.13	.73	13.94	139.16	230.71
1405.3	174.27	46.65	596.06	302.13	34.30	.74	13.93	134.20	202.02
1403.2	212.77	56.87	535.27	400.79	40.86	.72	13.94	127.42	163.57
1421.5	289.68	78.43	539.04	501.55	51.50	.66	14.03	147.66	121.14
1403.0	82.70	22.10	806.02	101.08	15.52	.70	15.99	162.93	240.17
1400.8	144.20	38.48	747.91	201.64	28.73	.75	16.00	160.35	222.33
1406.7	194.23	52.04	660.94	301.76	37.99	.73	16.03	153.99	191.30
1399.5	211.05	56.26	531.66	401.83	40.69	.72	16.03	126.51	154.71
1394.5	314.16	83.45	554.34	499.99	52.79	.63	15.92	161.27	74.34
1408.2	158.35	42.47	815.14	201.37	31.27	.74	17.95	172.49	215.83
1400.0	190.68	50.85	647.65	301.62	37.21	.73	17.95	150.11	188.73
1405.8	210.27	56.27	535.79	400.97	40.92	.73	17.94	124.83	157.59
1406.2	174.02	46.61	893.37	201.05	34.21	.73	19.91	181.42	226.98
1403.7	198.79	53.16	677.53	301.23	38.87	.73	19.92	154.19	193.98
1398.4	215.35	57.36	544.19	400.29	41.49	.72	19.93	127.30	160.75
1403.9	155.69	41.63	795.51	201.65	30.56	.73	21.93	167.69	209.83
1407.6	188.87	50.64	645.77	301.99	37.15	.73	21.92	148.24	184.94
1396.6	202.45	53.86	507.58	400.48	38.72	.72	21.92	123.56	156.54
1402.6	153.65	41.05	789.66	202.04	30.39	.74	23.84	167.74	208.75
1400.6	187.63	50.06	632.88	302.02	36.41	.73	23.88	148.90	180.95
1400.1	204.99	54.67	519.83	400.97	39.70	.73	23.90	123.37	151.32

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
960.80	41.80	44.69	318.21	7.31	.79	11.36	0.00	0.00
1631.2	42.83	45.38	317.12	7.34	.66	11.36	0.00	0.00
2514.6	159.27	44.90	317.29	7.95	.51	11.36	.11	.16
918.30	763.12	26.79	293.02	8.22	1.37	11.36	0.00	0.00
1623.7	763.22	26.40	287.42	8.99	1.11	11.36	0.00	0.00
2434.8	763.26	26.56	272.26	9.85	.82	11.36	0.00	0.00
2986.2	210.49	44.45	319.77	12.60	1.31	11.36	.26	.72
3583.0	233.94	43.67	319.66	13.26	.93	11.36	.11	.69
4573.6	141.81	43.56	319.21	14.95	.67	11.36	.11	.66
4172.4	277.11	44.34	319.12	14.70	.47	11.36	.11	.45
980.50	763.27	24.63	296.04	8.91	3.09	11.36	0.00	0.00
1734.5	763.28	24.74	285.35	11.14	2.78	11.36	0.00	0.00
2446.2	763.35	25.36	277.39	13.10	2.50	11.36	0.00	0.00
3048.8	763.41	25.36	204.90	14.49	2.16	11.36	0.00	0.00
3765.8	763.49	25.48	125.95	15.66	1.63	11.36	0.00	0.00
4334.6	208.37	43.40	318.47	21.06	2.02	11.36	.65	.88
4858.2	203.87	43.50	318.26	23.05	1.70	11.36	.50	.87
980.28	763.55	26.50	283.57	9.86	4.59	11.36	0.00	0.00
1685.7	763.65	26.95	271.65	13.09	4.40	11.36	0.00	0.00
2380.6	262.36	26.05	260.46	17.68	4.23	11.36	.90	.89
2999.8	763.72	25.80	204.49	19.21	3.77	11.36	0.00	0.00
3700.6	763.85	27.42	120.21	15.24	1.50	11.36	0.00	0.00
4302.2	283.52	42.33	309.91	28.76	3.51	11.36	.85	.93
1081.0	763.86	26.61	288.07	11.22	5.95	11.36	0.00	0.00
1848.2	763.79	26.43	274.40	15.29	5.64	11.36	0.00	0.00
2574.8	763.78	26.39	241.53	19.24	5.34	11.36	0.00	0.00
3079.6	763.84	26.58	182.69	22.47	4.80	11.36	0.00	0.00
4150.8	126.36	42.75	312.38	28.90	4.77	11.36	.90	.95
1247.6	764.21	27.21	283.82	11.82	6.12	9.61	0.00	0.00
2162.3	764.29	27.02	260.70	16.78	6.12	10.34	0.00	0.00
2863.8	764.39	27.20	222.90	20.88	5.92	11.36	0.00	0.00
3054.6	764.65	26.75	187.41	22.14	4.78	11.36	0.00	0.00
4532.4	239.92	42.84	313.64	31.58	5.00	11.36	.90	.95
2352.0	764.85	26.58	253.63	17.79	6.12	9.54	0.00	0.00
2813.4	765.02	26.81	225.77	20.48	5.82	11.36	0.00	0.00
3057.2	765.11	28.00	184.81	22.12	4.80	11.36	0.00	0.00
2566.8	764.39	25.90	265.99	19.37	6.12	8.69	0.00	0.00
2933.6	764.85	26.16	225.83	21.42	6.08	11.36	0.00	0.00
3134.2	765.07	26.07	192.49	22.68	4.90	11.36	0.00	0.00
2303.4	765.23	27.14	245.26	17.66	6.12	9.75	0.00	0.00
2760.8	765.32	27.79	218.69	20.21	5.78	11.36	0.00	0.00
3031.8	765.43	28.33	178.30	21.39	4.58	11.36	0.00	0.00
2205.4	765.58	27.66	245.22	17.41	6.12	9.81	0.00	0.00
2775.4	765.53	27.73	219.69	20.27	5.69	11.36	0.00	0.00
3034.0	765.51	27.91	182.66	21.78	4.67	11.36	0.00	0.00

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.29	.95	.02	0.00	.27	.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.34	.95	.19	0.00	.80	.15
.61	.96	.07	0.00	.59	.04
.11	.97	.07	0.00	.10	.01
.11	.97	.05	0.00	.11	.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.35	.97	.57	.00	.83	.47
.76	.97	.43	.00	.74	.32
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.97	.94	.80	.03	.91	.72
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.93	.97	.79	.01	.90	.71
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.94	.97	.85	.04	.91	.78
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.94	.97	.86	.04	.91	.78
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00

PAGE # 4 OF 4 OF 45 RUNS.

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
128.7	73.9	150.1	71.7	118.9	94.4	105.4	67.0	84.1
128.0	105.8	151.9	71.5	117.5	94.1	103.8	66.9	84.3
123.2	92.5	153.0	71.4	119.5	95.1	102.8	67.1	84.4
101.2	91.2	139.8	84.3	107.7	95.7	96.5	85.4	94.8
101.0	91.5	140.4	85.4	107.3	94.6	95.0	84.8	95.2
100.8	91.4	141.7	85.9	109.9	95.9	95.2	84.3	96.8
110.2	72.0	119.7	63.3	98.5	83.5	88.6	62.1	75.8
121.0	111.8	137.6	64.9	110.5	88.5	92.8	62.3	81.8
115.4	78.7	138.4	65.5	116.1	90.5	94.0	62.3	83.2
118.9	91.3	141.5	66.6	128.4	99.9	97.8	62.5	84.3
97.3	88.7	141.5	82.6	107.1	94.1	94.1	84.2	93.6
99.1	89.9	142.1	85.0	107.0	93.5	93.4	83.8	97.2
100.8	90.1	142.9	85.9	109.5	94.3	93.6	84.1	99.5
102.4	90.5	144.3	86.4	114.8	97.0	95.5	84.5	101.6
103.0	91.7	145.7	87.0	123.5	101.3	98.7	84.4	103.7
123.0	103.3	144.7	67.1	124.3	95.6	99.5	62.7	89.1
113.6	75.8	143.8	67.9	126.6	95.7	99.9	63.1	90.0
102.8	91.5	146.8	86.1	118.0	99.3	102.0	83.5	98.5
103.2	92.1	147.5	85.1	114.4	97.6	98.0	84.7	100.3
105.3	93.3	133.5	86.9	111.5	96.8	95.0	87.0	105.5
105.2	93.3	148.0	87.0	119.6	100.1	97.9	86.2	107.4
109.0	74.9	149.8	88.2	132.1	107.2	104.4	86.9	108.1
140.4	120.6	152.6	68.9	144.5	110.3	106.6	63.7	104.8
100.9	90.7	147.2	86.1	116.6	99.8	97.9	85.6	98.4
103.1	92.1	147.2	84.2	116.0	99.2	98.8	86.6	102.6
107.9	96.2	148.8	86.2	121.1	101.8	100.7	88.7	109.0
111.6	97.1	151.6	86.2	129.3	106.6	104.7	90.3	113.3
161.6	90.7	169.0	71.1	152.6	115.1	113.0	64.5	111.6
104.2	93.5	149.9	87.9	119.7	101.7	100.0	88.5	101.4
105.0	93.6	149.7	88.3	119.4	101.5	101.4	88.8	105.7
108.7	96.6	150.5	89.4	124.6	104.0	102.5	90.4	111.7
112.5	97.6	153.4	89.3	132.7	109.2	107.0	91.8	115.3
152.5	111.9	167.9	72.9	147.8	111.8	107.2	68.2	113.7
110.3	96.6	150.4	88.9	124.0	104.4	103.5	91.0	108.7
111.7	97.7	152.0	88.2	126.9	105.9	104.8	91.9	110.9
113.3	98.7	154.2	87.9	131.8	108.9	107.1	92.9	114.6
104.0	93.9	133.5	87.5	110.8	96.5	94.6	88.8	105.2
108.8	95.2	140.4	87.7	120.3	100.8	99.0	89.5	111.1
110.5	94.2	145.4	88.6	128.0	104.5	103.4	89.9	114.6
103.8	90.9	148.6	88.7	127.1	103.7	103.8	87.8	109.6
107.3	92.7	150.4	88.0	128.8	104.4	103.8	87.9	113.0
108.7	93.4	152.9	86.3	133.4	107.2	106.0	88.4	113.9
104.7	92.1	153.6	88.5	129.2	105.1	105.0	87.0	110.0
104.5	91.9	153.5	88.7	129.3	105.0	104.7	87.5	112.8
106.5	92.9	154.1	89.5	132.5	107.2	105.7	88.5	115.2

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
1603.2	21.53	6.57	42.55	99.59	.81	.12	5.92	73.32	338.77
1598.1	29.42	8.96	27.19	199.79	1.03	.12	6.08	74.71	339.88
1605.6	29.17	8.92	181.77	100.57	3.48	.39	7.97	83.50	250.83
1599.0	44.04	13.41	151.10	200.17	5.76	.43	7.94	87.15	249.03
1597.7	58.13	17.69	142.63	301.11	8.18	.46	7.97	83.08	234.95
1602.6	76.22	23.27	116.80	401.21	8.93	.38	8.04	88.01	314.27
1614.9	94.10	28.95	96.31	499.23	9.16	.32	8.04	88.25	300.38
1607.5	108.79	33.31	61.02	601.88	7.00	.21	8.07	88.22	195.89
1599.2	40.48	12.33	347.08	99.99	6.61	.54	9.99	100.54	255.04
1600.4	67.39	20.54	320.43	200.88	12.26	.60	9.99	101.99	251.05
1595.4	91.65	27.65	297.96	300.48	17.05	.61	9.98	98.77	247.91
1602.8	112.26	34.27	255.08	399.21	19.40	.57	9.98	99.48	220.18
1599.4	152.13	46.35	270.62	499.74	25.76	.56	9.99	106.85	301.34
1605.1	180.10	55.06	239.28	600.53	27.37	.50	10.01	106.86	254.14
1600.8	180.71	55.10	236.73	601.23	27.11	.49	10.01	107.09	224.65
1603.9	55.19	16.86	549.94	100.23	10.50	.62	12.04	122.12	253.65
1599.6	94.82	28.89	532.27	201.34	20.41	.71	12.03	122.15	250.37
1606.2	153.71	47.03	573.18	309.22	33.76	.72	12.01	125.29	240.40
1602.9	165.03	50.39	451.48	401.37	34.52	.69	12.05	116.13	205.34
1602.9	248.22	75.79	403.42	599.56	46.07	.61	12.01	123.53	159.00
1599.6	248.82	75.81	411.42	600.00	47.02	.62	12.02	123.01	228.96
1625.7	267.82	82.93	347.41	699.45	46.28	.56	12.03	124.02	86.35
1597.2	131.59	40.03	810.92	201.77	31.17	.78	14.13	152.03	251.02
1604.1	183.30	56.01	754.22	301.48	43.31	.77	14.14	147.90	235.00
1597.7	223.76	68.10	677.97	401.85	51.89	.76	14.14	141.47	196.37
1609.3	225.01	68.97	532.26	500.73	50.77	.74	14.14	122.31	152.97
1604.3	334.58	102.24	570.13	601.02	65.27	.64	14.00	145.72	97.25
1601.0	145.73	44.44	901.32	201.95	34.67	.78	15.93	165.42	241.63
1603.8	194.81	59.51	801.63	301.68	46.06	.77	15.94	158.38	213.23
1600.0	232.09	70.73	698.42	402.31	53.52	.76	15.99	146.39	184.11
1609.1	227.19	69.63	532.63	500.82	50.81	.73	15.99	122.16	150.02
1609.3	173.90	53.31	1072.3	201.61	41.18	.77	17.91	183.73	241.64
1602.6	210.44	64.24	847.72	302.14	48.79	.76	17.91	167.83	210.71
1601.5	250.15	76.31	940.99	299.90	53.75	.70	17.81	184.83	294.08
1607.0	180.66	55.30	1026.0	202.51	39.58	.72	19.90	186.41	231.49
1602.4	204.38	62.38	778.50	300.45	44.55	.71	19.91	162.11	200.64
1595.0	218.96	66.52	625.35	392.67	46.77	.70	19.93	139.48	165.43
1614.6	285.05	87.67	1520.8	201.83	58.47	.67	21.90	220.53	233.76
1624.6	297.46	92.05	1609.5	199.04	61.02	.66	23.81	229.58	163.61

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1043.7	211.58	45.06	316.95	7.98	.33	11.36	.11	.11
1711.7	223.31	46.27	314.74	8.56	.21	11.36	.11	.11
975.02	765.33	28.16	303.10	9.59	1.43	11.36	0.00	0.00
1789.8	765.20	26.41	293.33	10.80	1.19	11.36	0.00	0.00
2519.0	765.08	29.51	286.19	11.82	1.12	11.36	0.00	0.00
3056.4	72.97	44.90	317.54	12.81	.92	11.36	0.00	0.00
3711.6	134.46	45.75	317.41	14.57	.75	11.36	.11	.62
4535.0	214.71	45.37	318.65	16.05	.48	11.36	.11	.51
945.88	764.98	28.23	306.73	10.40	2.73	11.36	0.00	0.00
1736.8	764.89	26.28	295.31	12.49	2.52	11.36	0.00	0.00
2411.0	764.81	29.34	287.99	14.89	2.35	11.36	0.00	0.00
3146.4	764.79	27.17	273.07	16.66	2.00	11.36	0.00	0.00
3713.6	87.91	44.48	317.41	20.13	2.13	11.36	0.00	0.00
4323.6	260.88	44.36	318.89	22.62	1.88	11.36	.68	.87
4291.0	280.29	44.89	318.45	23.16	1.86	11.36	.68	.86
992.90	764.78	27.13	300.73	11.54	4.32	11.36	0.00	0.00
1709.5	764.76	27.36	295.28	14.91	4.19	11.36	0.00	0.00
2528.4	290.35	27.53	285.51	21.47	4.49	11.36	.92	.90
3074.0	764.71	28.47	236.44	21.33	3.55	11.36	0.00	0.00
4277.4	220.39	43.06	310.10	29.03	3.17	11.36	.86	.92
4360.8	146.08	43.12	310.65	29.12	3.24	11.36	.86	.93
4863.2	355.02	43.21	310.69	32.05	2.69	11.36	.82	.92
1994.5	782.49	27.50	292.30	18.57	6.12	10.88	0.00	0.00
2744.6	781.17	28.21	274.35	23.42	5.92	11.36	0.00	0.00
3338.8	783.49	28.22	233.56	27.22	5.34	11.36	0.00	0.00
3546.8	783.08	29.85	176.38	27.32	4.16	11.36	0.00	0.00
4838.4	176.85	43.72	312.86	37.56	4.47	11.36	.90	.95
2211.1	782.50	29.68	286.10	19.85	6.12	9.81	0.00	0.00
2909.4	782.63	29.71	249.90	24.38	6.12	11.05	0.00	0.00
3446.6	782.58	26.31	213.62	28.10	5.50	11.36	0.00	0.00
3554.0	783.18	27.17	179.36	27.60	4.17	11.36	0.00	0.00
2621.8	784.54	27.19	282.29	22.86	6.12	8.29	0.00	0.00
3130.6	785.38	29.31	243.52	25.81	6.12	10.44	0.00	0.00
3691.4	297.85	43.46	316.01	29.05	6.12	9.40	.93	.95
2739.2	13.13	26.21	268.66	23.47	6.12	8.65	0.00	0.00
3085.4	10.90	26.61	229.13	25.90	6.12	11.36	0.00	0.00
3253.4	9.60	27.31	196.96	26.35	4.94	11.36	0.00	0.00
4159.2	145.08	42.25	314.98	32.63	6.12	5.86	.93	.96
4704.1	-102.7	98.81	313.53	35.36	6.12	5.58	0.00	0.00

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.54	.85	.02	0.00	.46	.00
.11	.92	.02	0.00	.09	.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.50	.97	.06	0.00	.49	.03
.11	.97	.05	0.00	.10	.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.87	.97	.59	.00	.84	.50
.87	.97	.58	.00	.84	.49
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.97	.94	.83	.95	.91	.76
0.00	0.00	0.00	0.00	0.00	0.00
.93	.97	.79	.01	.90	.71
.93	.97	.80	.02	.90	.72
.91	.97	.75	.02	.88	.66
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.74	.97	.86	.04	.91	.78
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.96	.96	.87	.11	.92	.81
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.95	.94	.89	.12	.90	.80
0.00	0.00	0.00	0.00	0.00	0.00

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
162.3	127.4	177.3	74.2	129.7	104.1	111.2	68.6	94.5
147.6	129.1	179.2	74.4	124.1	99.9	108.1	68.7	93.0
99.6	91.4	150.7	89.4	112.8	98.8	98.5	85.0	101.0
99.6	91.4	150.7	89.4	111.4	97.8	97.8	85.0	102.5
100.9	91.3	151.1	89.1	113.1	98.5	98.0	85.4	104.1
146.8	129.0	180.5	74.2	125.8	100.0	106.1	68.9	94.2
126.2	122.1	173.9	73.8	129.6	101.2	104.4	69.1	94.7
132.8	120.6	171.7	73.6	131.3	101.4	104.8	69.2	95.9
100.8	91.6	150.6	89.4	110.9	98.1	97.8	85.3	102.2
101.6	92.3	151.1	88.6	110.7	97.9	97.6	85.9	104.5
102.7	92.3	151.9	89.2	112.4	98.4	98.1	86.7	107.2
104.2	93.0	152.9	89.8	117.2	101.0	99.4	87.3	109.9
132.8	123.3	152.9	71.6	128.0	101.4	102.5	68.8	98.6
146.1	129.5	166.8	72.0	134.1	103.5	104.0	68.5	102.9
145.1	77.2	164.0	72.6	139.9	108.0	106.4	68.7	104.3
104.2	93.7	154.0	90.5	115.3	100.6	100.8	86.8	105.6
104.3	93.9	154.7	90.6	114.5	100.2	100.2	87.5	108.7
106.5	94.8	138.0	88.2	115.0	99.9	97.7	88.0	114.9
107.8	96.0	156.1	91.2	122.4	104.4	101.4	89.3	117.9
163.2	139.5	178.0	73.8	151.5	117.1	113.9	68.8	118.7
160.0	104.8	180.1	74.5	142.3	108.6	111.8	68.9	114.0
164.7	121.0	183.3	75.0	148.3	112.1	111.8	69.0	119.6
108.0	95.3	137.9	72.0	109.8	97.8	95.8	89.6	97.6
111.9	97.4	147.0	72.8	119.3	102.9	100.2	91.4	105.3
111.6	97.2	150.8	73.3	124.8	105.6	102.2	92.4	110.4
115.0	98.7	155.8	73.5	134.9	111.9	108.6	93.5	114.0
150.9	123.3	180.6	75.3	148.4	111.9	112.2	69.5	125.6
106.4	95.5	152.4	73.5	121.8	104.3	100.8	91.3	99.2
111.8	97.3	155.2	74.1	129.5	103.9	106.5	92.7	107.9
114.6	99.2	139.1	74.4	129.0	109.2	105.4	93.8	113.9
116.0	100.2	146.5	74.0	136.3	113.4	109.3	95.3	115.0
103.3	97.1	146.0	74.4	121.7	105.5	101.0	93.0	102.1
113.0	99.2	150.2	74.7	129.4	109.8	106.7	94.4	110.2
147.5	129.5	171.7	74.5	141.2	109.8	109.8	70.5	115.3
108.9	94.3	154.6	76.0	123.7	107.0	105.0	88.8	112.7
110.0	94.9	157.7	76.5	134.4	110.4	108.3	89.1	116.6
110.8	95.4	157.2	76.9	138.8	112.7	109.9	89.9	118.4
173.5	129.2	190.0	76.0	152.1	116.3	113.2	70.8	126.5
106.8	90.4	149.9	81.9	159.3	123.0	122.3	77.8	131.5

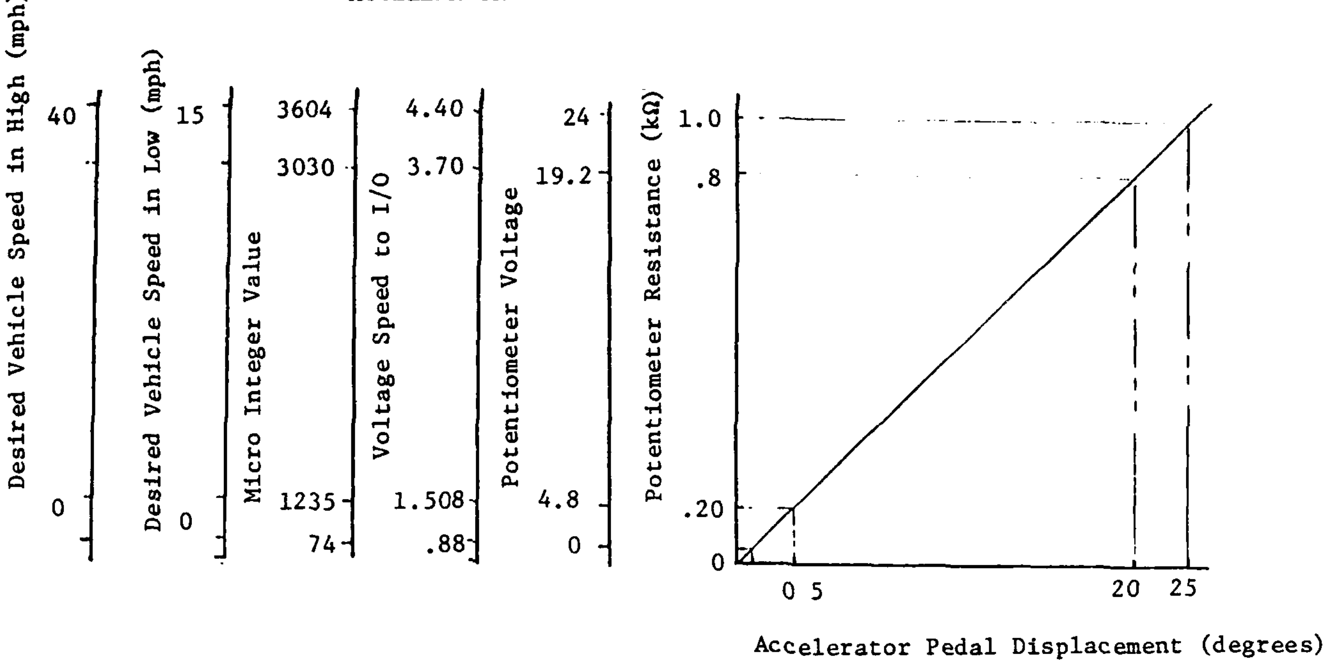
PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
1806.0	35.71	12.29	86.04	199.20	3.26	.27	6.01	77.70	363.31
1801.1	44.32	15.20	62.28	299.21	3.55	.23	6.02	78.98	354.68
1803.9	53.48	18.38	39.00	401.12	2.98	.16	6.03	78.50	343.30
1802.9	27.77	9.54	139.74	100.12	2.66	.28	7.95	80.47	262.91
1801.6	38.51	13.22	120.73	200.00	4.60	.35	7.96	83.10	255.14
1812.3	48.79	16.84	94.74	301.64	5.44	.32	7.96	79.35	251.47
1808.6	83.35	28.72	183.99	400.84	14.05	.49	8.06	89.82	251.26
1802.3	102.61	35.22	152.37	501.80	14.56	.41	7.98	91.34	331.70
1807.5	119.76	41.23	127.52	599.74	14.57	.35	7.98	91.71	314.06
1815.3	137.49	47.54	99.37	701.64	13.28	.28	7.99	91.22	286.14
1800.8	41.49	14.23	366.21	101.08	7.05	.50	9.86	101.24	267.21
1801.1	65.76	22.56	353.91	201.42	13.58	.60	9.97	100.67	259.29
1800.7	89.44	30.68	322.09	301.69	18.51	.60	9.97	102.82	250.83
1798.8	112.36	38.50	283.65	400.43	21.63	.56	9.97	96.81	245.63
1799.9	129.51	44.40	227.52	501.08	21.72	.49	9.98	93.70	199.86
1809.1	189.80	65.40	331.61	600.85	37.95	.58	10.07	109.33	314.79
1811.1	216.89	74.82	288.45	700.07	38.46	.51	10.08	110.24	217.47
1796.6	65.84	22.53	712.70	101.65	13.80	.61	12.04	131.22	268.84
1802.0	105.41	36.18	654.43	201.23	25.08	.69	12.02	127.08	261.44
1807.0	147.89	50.90	633.98	301.05	36.35	.71	12.03	125.94	250.63
1798.7	180.75	61.93	562.50	401.46	43.01	.69	12.04	124.54	240.53
1805.1	206.21	70.90	485.42	499.48	46.18	.65	12.05	116.07	188.97
1806.7	203.24	69.94	343.71	599.09	39.22	.56	12.02	99.30	115.74
1810.4	316.86	109.27	519.51	700.30	69.30	.63	12.13	130.11	263.47
1822.6	337.34	117.11	443.21	798.46	67.41	.58	12.14	129.41	115.44
1800.8	131.31	45.04	833.36	202.21	32.10	.71	13.98	141.30	252.30
1806.1	182.42	62.76	782.73	301.73	44.99	.72	13.98	139.79	237.17
1801.1	225.16	77.24	706.22	401.01	53.94	.70	13.98	132.90	195.32
1804.0	212.46	73.01	492.92	498.81	46.83	.64	13.99	113.55	143.34
1800.6	331.02	113.53	649.79	600.43	74.31	.65	14.08	143.92	145.13
1807.3	153.85	52.96	992.50	201.72	38.13	.72	15.99	164.78	251.40
1800.3	208.69	71.58	884.42	302.11	50.89	.71	16.00	158.85	221.52
1803.3	240.98	82.77	750.08	401.62	57.38	.69	16.00	145.71	177.21
1805.6	206.97	71.18	475.73	498.28	45.15	.63	16.01	112.08	136.76
1801.8	172.02	59.04	1093.5	201.50	41.97	.71	18.04	176.59	234.98
1802.1	219.44	72.24	882.09	301.87	50.72	.70	17.88	160.40	199.17
1805.6	229.93	79.08	717.21	401.63	54.87	.69	17.89	138.18	168.75
1801.3	185.76	63.74	395.53	498.83	37.58	.59	17.89	102.63	136.47
1802.6	271.41	93.19	1723.8	201.70	66.23	.71	19.88	214.31	330.47
1843.7	313.73	110.18	1150.1	300.18	65.76	.60	19.89	209.83	94.64
1800.7	298.55	102.40	1769.0	201.55	67.91	.66	21.77	222.93	233.55
1809.3	184.39	63.55	1156.2	207.87	45.78	.72	23.87	186.92	231.67
1805.2	211.71	72.80	893.70	302.01	51.41	.71	23.88	164.90	206.41
1804.7	223.07	76.68	709.05	401.90	54.28	.71	23.88	139.60	171.24
1806.9	181.22	62.37	389.35	500.13	37.09	.59	23.88	106.16	137.42

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1730.9	101.72	43.31	318.92	12.03	.60	11.36	.11	.11
2521.6	146.98	43.39	318.71	12.39	.44	11.36	.11	.11
3093.2	111.76	43.94	319.33	13.14	.27	11.36	.11	.11
988.82	315.26	28.24	309.76	11.13	.98	11.36	.24	.11
1770.8	312.23	28.48	309.99	12.30	.84	11.36	.11	.18
2525.2	300.00	30.62	296.74	13.49	.66	11.36	.11	.31
3091.4	284.06	30.12	295.70	17.40	1.28	11.36	.52	.72
3794.2	182.94	44.70	320.23	17.50	1.06	11.36	.30	.74
4407.0	199.01	43.39	320.32	19.10	.89	11.36	.11	.73
5060.0	285.82	42.78	318.84	21.18	.69	11.36	.11	.69
1004.7	320.01	28.85	308.45	12.67	2.56	11.36	.87	.42
1679.0	307.42	29.75	314.47	15.16	2.47	11.36	.85	.70
2450.2	304.65	29.40	298.82	16.71	2.25	11.36	.82	.79
3165.0	293.14	29.25	281.05	18.91	1.99	11.36	.77	.82
3823.6	213.91	28.36	230.78	20.86	1.59	11.36	.66	.82
4384.6	248.06	42.85	318.28	26.13	2.31	11.36	.81	.89
4983.6	315.32	43.88	316.67	28.77	2.01	11.36	.76	.89
1068.4	317.47	28.65	315.67	15.06	4.99	11.36	.95	.73
1022.0	313.61	27.39	306.40	18.72	4.57	11.36	.94	.85
2506.2	295.32	29.00	295.86	23.40	4.42	11.36	.93	.90
3205.0	295.78	25.94	288.33	25.91	3.94	11.36	.91	.91
3756.6	236.94	27.49	234.51	28.60	3.39	11.36	.89	.92
4396.0	150.68	26.40	148.81	28.29	2.40	11.36	.82	.90
5130.0	259.85	42.90	312.30	39.43	3.61	11.36	.89	.94
5703.0	301.46	42.57	313.14	42.51	3.06	11.36	.86	.94
1959.8	300.65	29.15	293.98	21.00	5.83	11.36	.95	.90
2714.4	282.83	29.20	281.52	26.05	5.46	11.36	.94	.92
3279.6	234.04	29.50	227.13	30.41	4.94	11.36	.93	.93
3684.4	165.48	28.74	166.14	29.10	3.44	11.36	.89	.92
4778.6	213.71	42.63	312.39	40.50	4.54	11.36	.91	.95
2299.6	293.48	29.81	293.87	23.41	6.12	10.06	.95	.92
3063.2	265.28	28.99	259.22	28.58	6.12	11.25	.94	.94
3529.6	200.73	28.76	205.23	32.35	5.24	11.36	.93	.94
3686.4	156.83	29.86	160.08	28.42	3.32	11.36	.89	.91
2552.4	269.84	29.62	274.19	24.66	6.12	9.10	.95	.93
3080.8	232.60	29.98	234.01	28.67	6.16	11.36	.94	.94
3329.6	192.81	30.01	198.04	31.23	5.00	11.36	.93	.94
3645.4	139.28	30.19	157.81	26.27	2.76	11.36	.86	.90
3999.2	151.14	41.40	319.32	37.07	6.12	5.78	.93	.96
4968.2	245.67	40.04	317.30	41.65	6.12	8.85	.93	.97
4387.6	152.14	40.09	316.04	39.92	6.12	5.62	.93	.96
3449.4	8.75	28.82	268.17	26.72	6.12	8.64	0.00	0.00
3381.6	10.78	28.73	237.13	29.61	6.12	11.16	0.00	0.00
2794.0	9.49	28.65	198.24	30.85	4.95	11.36	0.00	0.00
2265.6	7.30	29.00	142.39	26.91	2.71	11.36	0.00	0.00

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER. LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.79	.92	.02	0.00	.73	.01
.40	.95	.02	0.00	.38	.00
.11	.96	.02	0.00	.11	.00
.95	.81	.02	0.00	.77	.02
.90	.91	.02	0.00	.82	.01
.75	.94	.03	0.00	.71	.02
.87	.96	.37	.00	.85	.32
.78	.97	.22	0.00	.75	.16
.61	.97	.07	0.00	.59	.04
.23	.97	.07	0.00	.23	.02
.98	.82	.37	.01	.80	.29
.97	.91	.60	.01	.88	.53
.96	.94	.65	.01	.90	.59
.93	.96	.64	.00	.89	.57
.88	.97	.54	.00	.85	.46
.91	.97	.72	.02	.88	.64
.88	.97	.68	.00	.85	.58
.98	.83	.69	.09	.82	.56
.98	.92	.80	.07	.90	.71
.97	.94	.83	.06	.91	.76
.96	.96	.83	.04	.92	.76
.95	.96	.82	.03	.91	.75
.91	.97	.74	.02	.88	.65
.93	.97	.84	.03	.90	.76
.91	.98	.81	.02	.89	.71
.98	.92	.85	.14	.90	.76
.97	.95	.87	.12	.92	.80
.96	.96	.87	.09	.92	.80
.95	.96	.82	.03	.91	.75
.94	.97	.87	.07	.92	.79
.97	.93	.87	.17	.91	.78
.97	.95	.69	.16	.92	.82
.96	.96	.88	.10	.92	.81
.95	.96	.81	.03	.91	.74
.97	.93	.88	.16	.91	.79
.97	.96	.89	.17	.92	.82
.96	.96	.87	.09	.92	.80
.94	.96	.77	.01	.91	.70
.96	.94	.89	.16	.90	.80
.95	.97	.90	.17	.92	.82
.95	.94	.89	.16	.90	.80
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
109.5	98.5	140.4	59.9	89.9	78.2	80.0	55.7	80.2
125.3	121.9	150.8	60.9	95.6	81.1	83.3	56.6	82.3
132.3	126.6	158.3	61.6	97.9	82.1	84.9	57.0	84.2
106.8	97.3	145.2	78.8	111.8	101.6	101.6	90.5	96.3
105.4	96.1	149.8	78.9	112.0	101.3	100.8	89.7	97.1
105.4	95.6	153.0	79.4	115.2	102.4	101.3	89.4	99.7
104.6	94.8	136.8	79.5	116.1	102.9	99.6	89.3	103.6
144.0	72.0	167.4	62.7	108.6	88.4	88.6	58.1	92.6
144.0	133.0	174.0	63.7	115.7	91.6	90.6	58.9	96.7
148.3	127.0	178.1	64.4	118.8	91.6	92.9	59.3	97.9
103.6	94.8	153.2	79.6	113.4	100.9	98.9	89.0	97.7
103.5	93.1	155.1	79.7	112.4	99.9	100.2	88.5	101.7
104.5	94.1	156.7	80.0	114.9	100.8	99.8	88.3	105.5
105.1	94.2	158.7	79.3	119.6	103.0	101.1	87.9	109.6
106.2	93.5	161.1	77.4	129.8	106.6	105.1	87.6	113.8
153.6	102.4	165.2	65.9	120.8	94.1	95.9	61.1	107.5
153.3	139.6	187.9	66.6	136.5	104.9	99.2	61.4	115.8
99.4	92.2	134.6	79.7	101.3	93.5	90.4	85.9	98.7
103.8	93.8	141.9	79.8	107.0	96.6	94.7	87.4	106.5
108.0	95.6	148.4	89.6	120.9	104.5	102.2	89.6	125.2
107.7	95.2	148.5	80.2	116.5	101.8	98.0	89.5	119.5
110.5	96.1	154.0	80.9	128.3	108.1	104.1	91.1	127.0
112.4	97.3	158.6	82.4	141.5	114.9	110.3	91.9	130.3
144.8	125.8	179.5	68.6	129.5	99.0	96.8	65.0	129.8
158.4	116.8	187.6	69.6	135.2	101.3	101.3	65.2	136.6
108.0	95.6	162.6	83.7	130.5	110.8	110.4	90.4	116.6
111.2	96.8	165.8	83.9	135.1	113.4	111.3	92.2	126.4
114.5	98.4	170.4	84.1	144.6	118.5	115.2	94.4	135.9
115.8	98.9	173.5	85.6	152.1	123.7	119.8	94.7	137.1
180.9	84.5	192.8	71.4	154.1	118.5	111.1	66.0	148.4
109.3	96.8	166.6	84.0	130.6	111.0	108.7	92.4	120.7
112.9	98.8	169.0	83.6	138.6	115.6	112.0	93.8	130.7
115.8	100.6	171.7	84.8	147.1	120.4	116.3	95.2	139.7
116.9	99.9	175.3	85.4	155.4	125.9	123.1	95.8	136.3
113.7	99.1	176.0	84.8	147.1	121.2	120.7	94.6	128.1
116.0	101.0	177.1	85.2	152.2	124.1	122.3	95.7	135.0
116.4	100.5	178.1	84.6	155.2	125.5	123.4	96.6	138.6
117.0	100.8	179.7	83.1	159.4	128.5	125.5	96.2	133.4
103.8	91.4	111.0	71.5	117.9	101.3	98.7	71.4	116.8
113.4	95.2	130.3	72.0	160.4	129.5	117.7	71.2	142.3
106.4	92.2	136.4	72.0	149.2	119.5	117.2	71.0	125.4
109.5	95.1	164.1	78.2	145.1	118.1	117.4	89.3	123.6
111.0	95.7	166.9	78.5	148.5	120.0	118.0	90.4	130.4
112.6	96.5	171.1	79.8	154.4	124.0	121.5	94.2	134.8
112.5	97.1	172.8	80.7	158.7	126.7	124.1	95.3	128.8

ACCELERATOR PEDAL SIGNAL



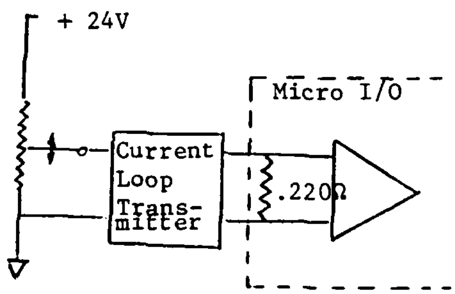
$$\text{Potentiometer} = \text{Accelerator Pedal Disp. (degrees)}\ (5)\ \frac{1\ \text{k}\Omega}{300}$$

$$\text{Potentiometer Voltage (VDC)} = \text{Potentiometer Resistance (k}\Omega\text{)}\ (24\ \text{mA})$$

$$\text{Current Loop Transmitter Current (mA)} = \frac{\text{Potentiometer Voltage (VDC)}}{34}\ (16) + 4$$

$$\text{Voltage Signal to I/O} = \text{Current Loop Transmitter Current (mA)}\ (.220\ \text{k}\Omega)$$

$$\text{Micro Integer Value} = \frac{\text{Voltage Signal to I/O}}{5}\ (4095)$$



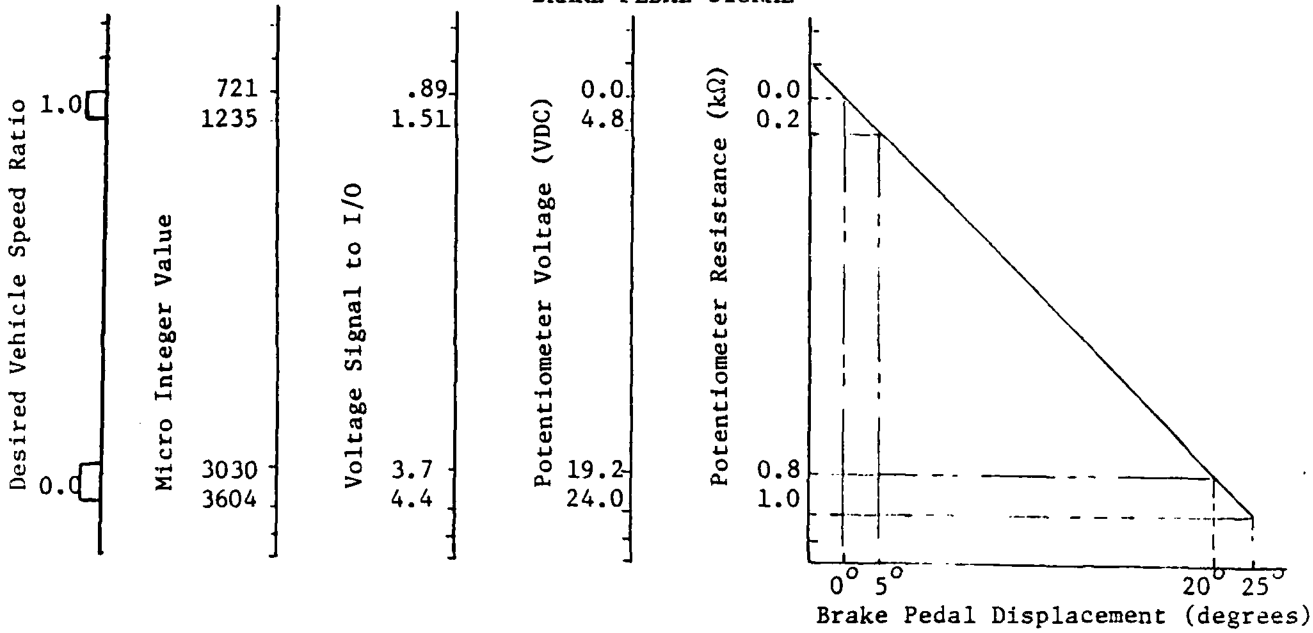
$$i = \frac{24\text{V}}{1\ \text{k}\Omega} = 24\ \text{mA}$$

Desired Vehicle Speed in Low = .008 Micro Integer Value - 9.88

Desired Vehicle Speed in High = .021 Micro Integer Value - 9.88

FIGURE 61 ACCELERATOR PEDAL SIGNAL CONVERSION

BRAKE PEDAL SIGNAL



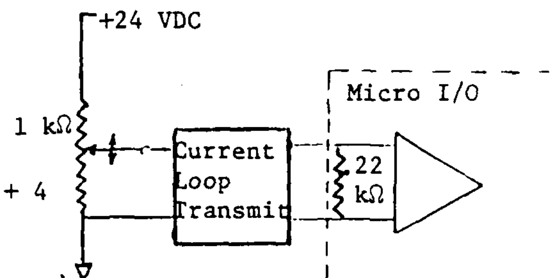
$$\text{Potentiometer Resistance (k}\Omega\text{)} = \left(\text{Brake Pedal Displacement: degrees}\right)\left(\frac{1\ \text{k}\Omega}{300^{\circ}}\right)$$

$$\text{Potentiomoter Voltabe: VDC} = \left(\text{Potentiomoter Resistance (k}\Omega\text{)}\right)\left(24\ \text{mA}\right)$$

$$\text{Current Loop Transmitter Current: mA} = \left(\frac{\text{Potentiometer Voltage: VDC}}{24}\right)(16) + 4$$

$$\text{Voltage Signal to I/O} = \left(\text{Current Loop Transmitter Current: mA}\right)\left(.22\ \text{k}\Omega\right)$$

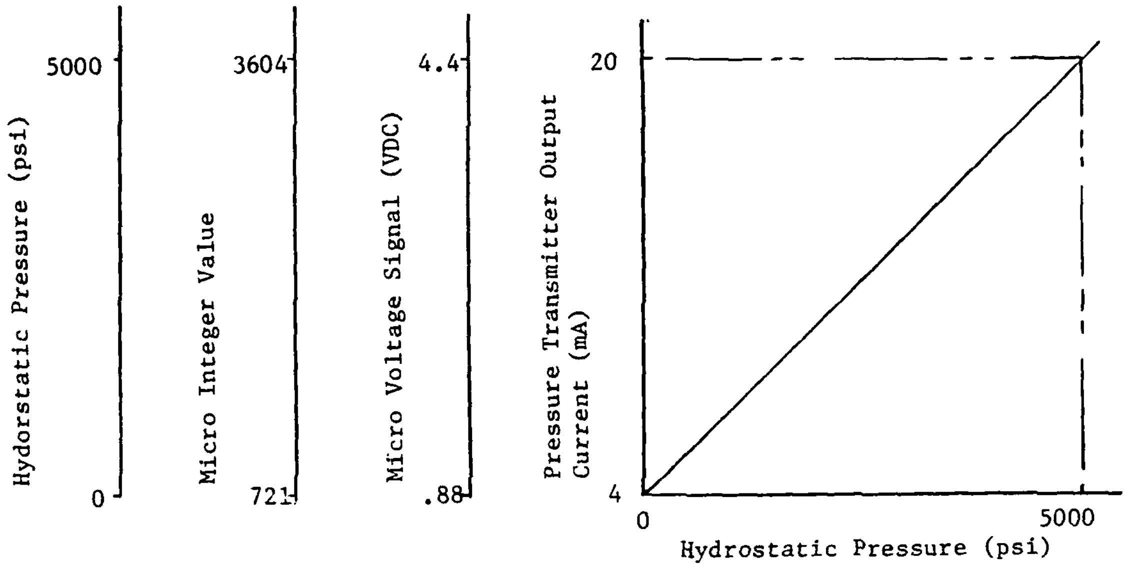
$$\text{Micro Integer Value} = \left(\frac{\text{Voltage Signal to I/O}}{5}\right)(4095)$$



Desired Vehicle Speed Ratio = -(.00056)(Micro Integer Value) + 1.697

FIGURE 62. BRAKE PEDAL SIGNAL CONVERSION RELATIONSHIPS

HYDROSTATIC WORKING PRESSURES



$$\text{Pressure Transmitter Output Current (mA)} = (312.5)\left(\text{Hydrostatic Pressure:psi}\right) + 4.0$$

$$\text{Voltage Signal To Micro I/O: VDC} = \left(\text{Pressure Transmitter Output Current: mA}\right)\left(.22\text{k}\Omega\right)$$

$$\text{Micro Integer Value} = \left(\frac{\text{Voltage Signal to I/O: VDC}}{5}\right)\left(4095\right)$$

$$5000 = 3604x + y$$
$$0 = 721x + y$$
$$5000 = 2883x \qquad x = 1.734 \qquad y = -1250$$

$$\text{Hydrostatic Pressure: psi} = \left(1.734\right)\left(\text{Micro Integer Value}\right) - 1250$$

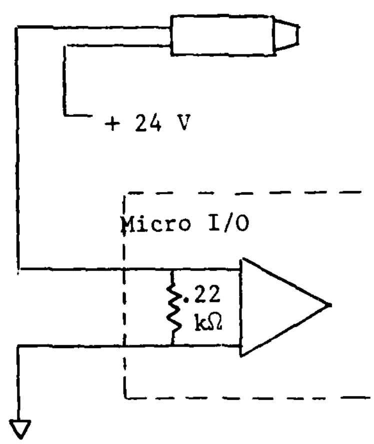


FIGURE 63. HYDROSTATIC WORKING PRESSURE SIGNAL

6.4.2 SC-1 Microcomputer Hardware Description

The requirements for a microcomputer to control the HTP vehicle are very strict. First and foremost are the requirements that it be fail safe and accurate. If the microcomputer fails while the vehicle is running at 40 mph, the possibility of personal injury is significant. To accomplish all of the engine optimization, the micro must be very fast in processing floating point calculations. Finally, the micro must easily communicate with several D/A, A/D, and F/V conversion boards. The micro chosen that most closely meets the perceived program requirements is the SC-1 developed at SwRI.

The SC-1 uses the 5 MHz Intel 8086 central processing unit in unison with the Intel 8087 math processor and 8089 Input/Output processor, all very large-scale integration (VLSI) processors. All reside on the system's local bus. Figure 64 is a block diagram of the computer and Table 7 summarizes the SC-1's general specifications.

Table 7

Configuration

8086/8087/8089 triprocessor on local bus

Word Size

Instructions: 8, 16, 24 or 32 bits

Data: 8, 16 bits (single word = 16 bits)

Cycle Time

Basic Instruction Cycle:	0.8 μs (instruction not in queue)
	0.25 μs (instruction in queue)

Memory Capacity

Onboard EPROM:	64K bytes (expandable to 128K)
Onboard DRAM:	128K bytes (error correcting, single-bit detect/ correct; multi-bit detect)
Onboard SRAM:	2K bytes

Table 7. (Continued)

I/O Capacity

Parallel: 48 lines programmable (8255s), using two parallel interface adapters (equipped with LSI controller to emulate IBM-360 I/O channel handshaking).

DMA: Two 16-bit DMA ports, at 1M-bytes max transfer rate.

Serial: RS-232 port, controlled by USART for both standard asynchronous or synchronous (8251A) communications.

Interrupts

Two 8-input priority interrupt controllers (15 hardware vectored interrupt lines available). Software configured for input priorities and mode (8259As).

Timer

Two timers, each equipped with three 16-bit interval timers. (Timer outputs available as interrupt inputs.) Software configured for mode and rate (8253s).

Power Consumption

20W

Weight

9.38 lbs

The SC-1 has three subsystems of memory. First, there are 64K bytes of EPROM to store the monitor and application programs. There are also 2K bytes of static RAM for use as a system stack. Last, for main memory, there are 128K bytes of fault tolerant dynamic RAM. This DRAM provides single-bit failure detect/correct and multi-bit failure detect for the main memory.

To further mitigate the effects of a momentary software failure, a watchdog timer has been placed in the circuit. The timer receives a signal every 100 msec from the software. If for some reason the software "locks up," a hardware reset is initiated and the program reboots from PROM. Execution restarts with a fresh copy of the

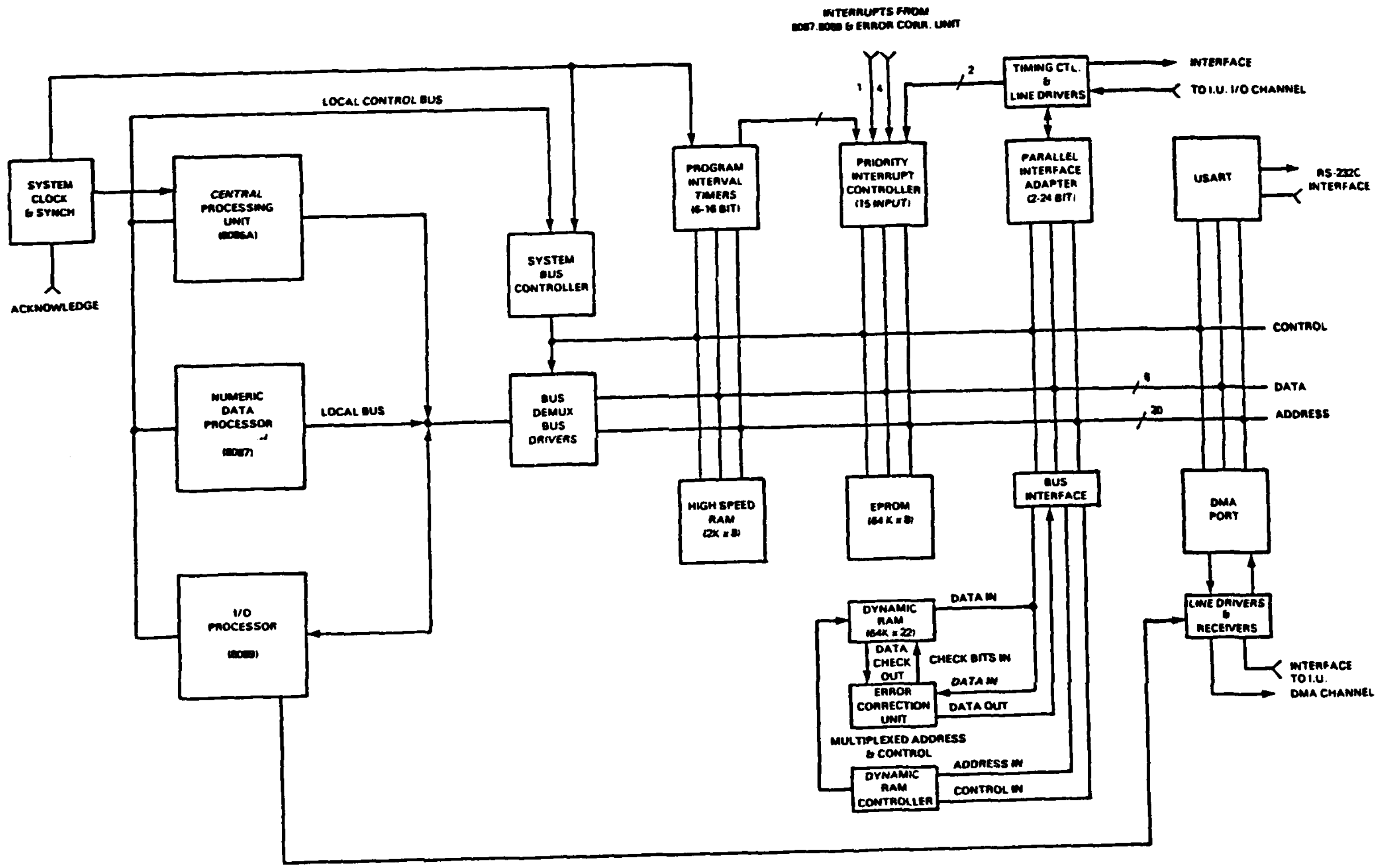


FIGURE 64. SC-1 COMPUTER BLOCK DIAGRAM

software without the operator's intervention. A checksum over the application program provides a secondary verification. The checksum is computed every 100 msec. This checksum is compared to the original value stored in PROM. If there is a discrepancy, the program has been inadvertently changed. Therefore, a hardware reset and software reload is initiated.

The SC-1's performance has been validated through many different environmental tests to make it acceptable to military and commercial applications. It has operated successfully through vibration tests to warrant use on any application. The SC-1 can operate in a pure vacuum and in the temperature range of -40° to +80°C. All power is dissipated through the base plate; no fan is required. The micro also has proven electromagnetic compatibility.

In it current configuration, the SC-1 uses the triprocessor configuration to provide increased throughput. Using the 8086's pipelined architecture, a great amount of parallel processing can be achieved. The 8087 is a purely numeric processor and can execute some numerical instructions 500 times faster than those instructions emulated from an 8086.

The Intel 8089 is a dedicated I/O processor. It communicates with an I/O expander unit which houses A/D, D/A and F/V convertors, and a parallel I/O board. The 8089 reads vehicle inputs at the I/O expander and places them in main memory where the applications program can process them. It also reads a block of data from memory which represents control outputs and sends them to the I/O expander. These signals are used as inputs to analog controllers.

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
1994.7	30.44	11.57	160.00	100.73	3.22	.28	5.97	82.16	380.90
2003.7	40.85	15.59	145.72	201.00	5.58	.36	5.97	81.79	374.26
1999.9	51.00	19.43	124.02	300.13	7.09	.36	5.97	82.42	367.34
2003.9	61.46	23.46	82.64	400.55	6.30	.27	5.97	82.29	357.69
1977.9	71.81	27.33	32.63	500.21	3.11	.11	5.97	80.95	328.34
2002.3	53.68	20.47	272.72	201.08	10.45	.51	7.86	91.32	366.55
2008.4	73.14	27.98	250.79	301.19	14.39	.51	8.03	92.08	361.14
2004.2	83.08	31.72	204.92	400.11	15.62	.49	8.06	86.60	255.73
2002.9	110.47	42.14	190.33	500.67	18.15	.43	8.03	92.68	332.35
2005.7	132.84	50.75	161.18	602.10	18.49	.36	8.06	94.38	303.55
2005.0	141.08	53.88	104.60	698.71	13.92	.26	8.04	92.95	152.26
1996.9	74.76	28.44	475.33	201.94	18.28	.64	9.98	108.77	373.28
1998.7	104.34	39.72	454.86	301.62	26.13	.66	9.99	110.36	363.26
2007.3	132.78	50.77	421.05	401.07	32.17	.63	9.99	109.15	344.16
2005.7	160.11	61.17	388.27	499.10	36.91	.60	9.99	108.91	335.59
2005.4	187.55	71.64	332.11	600.96	38.02	.53	9.99	108.32	303.25
2006.8	224.47	85.80	332.96	700.67	44.44	.52	10.03	109.95	277.33
1999.3	93.93	35.77	652.15	201.20	24.99	.70	12.03	122.33	361.96
2004.5	150.06	57.29	690.28	304.38	40.02	.70	12.03	127.37	257.24
2007.7	171.74	65.75	594.20	401.78	45.47	.69	12.04	123.19	336.39
2000.9	209.67	79.91	552.44	501.89	52.80	.66	12.05	122.81	318.09
2004.4	243.30	92.89	498.42	600.34	56.99	.61	11.99	123.46	246.82
2024.9	308.31	118.91	553.97	699.85	73.85	.62	12.00	126.66	211.75
2000.9	127.01	48.41	927.66	201.35	35.58	.73	13.99	144.66	355.36
2006.2	181.34	69.30	888.22	301.44	51.00	.74	13.99	144.50	340.95
2000.0	240.80	91.73	853.83	401.24	65.26	.71	13.97	148.60	332.48
2006.3	290.20	110.90	774.72	501.13	73.95	.67	13.97	146.57	255.54
1996.3	342.38	130.19	736.70	601.00	84.33	.65	14.02	145.95	176.55
2007.0	154.14	58.93	1144.9	201.50	43.94	.75	15.90	169.56	362.69
2003.2	218.64	83.42	1064.1	301.98	61.21	.73	15.90	168.56	343.34
2007.2	281.00	107.43	967.42	401.23	73.93	.69	15.91	167.91	308.53
1995.6	327.50	124.49	833.59	500.12	79.41	.64	15.91	167.31	108.07
2000.3	220.03	83.83	1605.6	201.57	61.65	.74	17.90	201.41	360.43
1999.7	291.95	111.20	1322.6	301.61	75.98	.68	17.91	196.05	315.30
2002.8	337.22	128.64	1079.3	401.83	82.61	.64	17.88	188.06	146.16
2005.5	251.57	96.10	1733.1	202.70	66.91	.70	19.88	211.33	319.61
2010.1	335.05	128.28	1398.0	301.96	80.41	.63	19.87	208.29	128.76
1999.8	310.84	118.40	1937.8	201.14	74.24	.63	21.84	226.68	157.92
2002.5	312.93	119.36	1955.7	201.80	75.17	.63	23.85	233.41	159.69

PAGE # 2 OF 4   OF   39 RUNS.

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1014.0	108.24	33.40	315.15	14.53	1.06	11.36	.46	.11
1741.1	14.69	37.89	315.42	15.76	.92	11.36	0.00	0.00
2454.4	41.32	37.12	314.19	16.28	.78	11.36	0.00	0.00
3208.2	187.09	34.67	315.34	16.74	.52	11.36	.11	.36
3964.2	187.77	33.33	314.19	17.33	.21	11.36	.11	.11
1656.3	28.73	35.86	313.24	16.06	1.71	11.36	0.00	0.00
2347.2	55.85	38.23	313.55	18.20	1.57	11.36	0.00	0.00
3125.2	303.11	27.71	300.42	19.53	1.29	11.36	.60	.72
3745.8	116.43	37.23	312.79	22.31	1.20	11.36	.53	.77
4524.4	117.35	33.18	314.97	24.95	1.01	11.36	.34	.77
4865.2	214.52	39.00	312.38	25.63	.66	11.36	.11	.67
1706.2	161.82	36.59	313.04	18.26	3.00	11.36	.90	.78
2376.4	113.68	37.21	313.21	21.42	2.87	11.36	.89	.84
3034.4	82.61	36.06	312.92	24.80	2.64	11.36	0.00	0.00
3690.4	130.59	36.88	313.11	28.43	2.44	11.36	.85	.88
4401.4	148.64	37.48	312.26	31.20	2.09	11.36	.81	.89
5050.6	247.25	41.95	316.85	34.32	2.09	11.36	.80	.90
1688.3	206.19	37.27	306.35	20.44	4.11	11.36	.94	.83
2550.0	307.99	30.37	302.68	27.61	4.34	11.36	.93	.70
3066.2	111.30	37.78	304.03	29.25	3.73	11.36	.92	.91
3733.4	131.56	38.01	305.06	34.02	3.48	11.36	.91	.92
4347.4	122.29	35.76	305.87	37.58	3.13	11.36	.89	.92
5096.0	356.27	42.20	311.48	44.21	3.44	11.36	.90	.94
1912.8	210.67	37.40	305.02	24.04	5.84	11.36	.95	.90
2738.0	66.24	36.59	305.91	29.97	5.57	11.36	0.00	0.00
3582.8	174.50	36.23	307.70	38.03	5.37	11.36	.94	.74
4271.6	207.32	35.01	307.51	43.07	4.86	11.36	.93	.95
4933.4	188.61	41.53	312.18	48.05	4.65	11.36	.92	.95
2316.2	80.14	36.33	309.51	27.69	6.12	9.68	0.00	0.00
3272.2	138.78	36.28	310.26	34.91	6.12	10.40	.94	.95
4156.0	91.32	36.51	307.88	42.54	6.07	11.36	0.00	0.00
4788.6	187.63	34.25	313.04	48.64	5.26	11.36	.93	.96
3258.4	207.76	32.60	317.91	35.49	6.12	6.88	.94	.95
4298.8	114.90	32.45	316.43	45.61	6.12	8.35	.93	.76
4902.4	144.41	33.49	314.07	1.44	6.12	10.25	.93	.97
3721.2	196.17	33.48	316.86	39.41	6.12	6.39	.94	.95
4067.2	155.63	31.72	314.97	50.56	6.12	7.94	.93	.96
4497.4	130.84	32.03	313.40	46.96	6.12	5.70	.93	.96
4541.2	254.86	40.74	323.08	47.27	6.12	5.66	.93	.96

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.95	.86	.05	.00	.82	.04
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.50	.96	.04	0.00	.47	.02
.11	.97	.02	0.00	.11	.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.90	.96	.44	.00	.86	.38
.84	.97	.41	.00	.81	.33
.72	.97	.27	0.00	.70	.19
.33	.97	.07	0.00	.32	.02
.97	.92	.71	.03	.89	.63
.96	.94	.75	.02	.91	.69
0.00	0.00	0.00	0.00	0.00	0.00
.94	.96	.75	.01	.90	.68
.91	.97	.72	.02	.88	.63
.89	.97	.72	.01	.87	.63
.98	.92	.78	.07	.89	.70
.97	.94	.84	.08	.92	.77
.96	.96	.83	.05	.92	.77
.95	.97	.83	.04	.92	.76
.94	.97	.82	.03	.91	.75
.93	.97	.84	.04	.91	.76
.98	.93	.85	.20	.90	.77
0.00	0.00	0.00	0.00	0.00	0.00
.96	.96	.88	.15	.93	.82
.95	.97	.88	.11	.92	.81
.94	.97	.88	.09	.92	.80
0.00	0.00	0.00	0.00	0.00	0.00
.96	.96	.89	.22	.92	.82
0.00	0.00	0.00	0.00	0.00	0.00
.95	.97	.89	.14	.92	.82
.97	.93	.89	.22	.90	.80
.96	.96	.90	.21	.92	.82
.95	.97	.90	.21	.92	.83
.96	.94	.90	.22	.90	.80
.95	.96	.90	.21	.91	.82
.95	.94	.90	.21	.90	.81
.95	.94	.90	.21	.90	.81

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
85.9	76.8	120.3	75.4	102.9	89.6	92.3	75.6	96.2
89.3	78.9	135.4	76.4	106.6	91.4	94.4	76.0	100.7
89.6	79.2	142.2	76.7	110.2	93.6	96.3	76.3	102.5
90.3	79.4	146.5	77.2	115.4	96.2	98.6	76.8	105.3
90.1	78.4	150.3	77.0	125.2	102.0	102.1	77.1	106.0
91.4	79.1	159.7	77.9	130.6	106.8	111.8	77.5	107.3
90.7	79.9	160.4	78.2	130.2	106.1	110.0	77.7	109.2
108.4	96.7	147.1	81.9	123.4	108.2	105.3	89.7	113.9
93.0	79.9	161.5	78.2	135.6	108.0	110.2	78.2	115.5
93.7	79.6	155.4	77.2	142.3	113.4	110.6	77.4	120.2
96.1	80.9	163.7	78.7	156.2	121.4	116.8	78.4	124.4
91.6	79.0	145.8	76.9	125.2	103.6	107.0	78.5	106.6
93.6	81.1	152.1	77.2	127.9	104.9	107.6	78.5	113.9
93.4	80.2	156.0	77.7	133.4	108.2	109.1	78.5	121.9
94.6	81.1	158.7	78.2	137.6	110.4	111.5	78.4	124.7
97.9	81.2	162.8	78.9	154.1	121.3	117.8	78.4	135.2
158.3	129.1	191.0	61.9	138.1	106.8	104.3	61.7	122.4
95.4	80.1	165.7	81.1	142.1	114.7	119.5	79.6	118.0
109.0	96.1	156.3	90.3	124.9	107.4	105.1	90.8	132.5
97.2	83.0	166.9	81.1	147.0	117.8	119.3	80.3	132.7
98.4	82.8	169.1	81.5	154.2	121.8	121.7	80.7	142.2
103.6	84.3	172.4	81.8	165.8	129.5	126.8	80.8	152.3
168.1	107.9	201.0	63.4	150.4	115.7	110.4	61.2	145.7
96.9	81.9	173.7	81.6	153.7	122.3	127.9	81.2	129.1
100.1	82.9	173.6	81.4	154.9	122.8	125.3	81.0	137.2
99.1	83.4	157.2	80.0	146.7	117.0	115.5	80.9	145.9
103.0	84.9	167.0	82.1	167.4	131.2	127.3	81.6	165.3
165.2	98.2	202.4	64.5	157.7	121.2	114.9	61.6	157.5
92.8	80.7	138.9	80.0	131.4	108.0	109.5	86.4	123.4
97.7	83.4	150.4	81.0	141.5	114.1	113.4	87.0	142.6
105.7	82.8	158.6	82.0	154.6	121.8	118.7	87.2	157.8
107.5	84.5	152.1	80.2	171.5	134.2	125.2	87.1	172.5
102.2	87.2	133.7	70.7	120.6	101.3	98.0	68.8	134.0
105.4	87.1	148.3	72.5	145.7	117.2	110.6	69.1	155.5
107.5	87.6	143.8	74.7	166.2	130.9	120.4	72.9	166.3
103.7	87.6	141.4	74.9	151.4	121.4	117.7	76.9	144.3
111.7	92.3	134.8	77.0	168.8	133.6	123.7	77.3	172.8
100.6	91.2	144.1	77.9	170.7	135.6	126.0	77.5	168.8
111.5	94.7	146.9	78.9	167.7	134.3	124.1	77.2	165.7

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU AT VALVE (PSI)
2200.1	29.46	12.34	133.61	100.91	2.57	.21	6.03	78.05	378.34
2212.2	36.38	15.33	93.44	201.62	3.59	.23	6.06	77.06	376.32
2207.8	46.79	19.68	88.08	300.96	5.05	.26	6.04	77.99	373.02
2204.6	55.07	23.12	57.13	399.91	4.35	.19	6.03	78.14	377.71
2202.8	48.39	20.31	225.80	200.96	8.64	.43	7.98	85.20	368.64
2201.1	63.16	26.48	209.25	300.94	11.99	.45	7.99	86.18	360.69
2204.1	80.38	33.74	191.47	399.21	14.56	.43	8.06	83.73	262.62
2207.5	90.70	38.14	133.35	500.68	12.72	.33	7.96	86.10	328.45
2208.0	120.53	50.69	141.28	601.04	16.17	.32	8.05	89.85	307.93
2207.7	142.07	59.74	117.07	700.07	15.61	.26	8.08	91.78	183.10
2203.6	44.33	18.61	485.95	101.93	9.43	.51	10.00	103.24	373.21
2205.1	69.62	29.24	458.34	201.25	17.57	.60	10.01	104.05	375.18
2200.6	94.63	39.66	433.23	301.32	24.86	.63	10.01	102.73	366.33
2195.1	119.20	49.84	392.81	399.66	29.90	.60	10.01	102.74	351.29
2202.3	146.07	61.27	359.54	500.37	34.27	.56	10.04	103.39	334.68
2199.9	167.24	70.08	297.73	601.96	34.14	.49	10.03	102.13	300.52
2280.6	100.89	43.83	.37	700.51	.05	.00	10.01	100.44	120.26
2210.7	210.91	88.81	346.83	702.25	46.39	.52	10.03	107.12	304.40
2206.1	102.52	43.08	785.02	200.57	29.99	.70	12.06	124.09	377.15
2200.9	146.19	61.29	764.71	301.67	43.94	.72	12.07	125.40	363.78
2206.3	177.07	74.42	692.74	401.05	52.92	.71	12.06	123.31	354.77
2204.5	215.06	90.30	647.61	500.11	61.69	.68	12.10	123.68	335.36
2211.2	244.77	103.09	571.56	601.48	65.48	.64	12.00	121.00	311.31
2202.7	267.50	112.23	487.66	700.01	65.02	.58	12.00	120.22	141.95
2204.1	135.18	56.75	1093.4	200.31	41.72	.74	13.94	148.32	374.50
2200.7	187.36	78.75	1016.7	301.47	58.38	.74	13.94	146.49	364.29
2201.3	241.22	101.14	963.35	401.66	73.70	.73	14.01	145.41	349.67
2206.7	289.33	121.61	884.52	499.10	84.09	.69	14.01	144.57	314.81
2215.4	338..32	142.76	827.18	600.32	94.59	.66	14.02	143.44	255.91
2205.9	146.15	61.41	1201.3	200.42	45.86	.75	15.93	161.96	366.75
2200.2	208.61	87.43	1117.7	301.58	64.20	.73	15.94	161.60	342.16
2208.1	270.04	113.58	1043.0	401.27	79.72	.70	15.92	162.55	319.15
2214.2	324.69	136.94	938.40	500.95	89.54	.65	15.91	161.63	183.57
2200.5	182.38	76.44	1488.1	201.06	56.99	.75	17.89	186.52	359.72
2209.6	255.99	107.74	1329.1	301.18	76.25	.71	17.89	185.21	333.01
2210.4	326.48	137.46	1183.2	401.53	90.49	.66	17.90	183.09	227.37
2205.2	218.20	91.65	1715.4	201.15	65.72	.72	19.91	200.98	333.94
2222.9	301.43	126.48	1442.7	300.43	82.56	.65	19.92	198.30	196.09
2210.8	279.58	117.73	2016.5	201.70	77.47	.66	21.79	217.80	244.90
2200.8	312.66	131.07	2160.0	201.48	82.89	.63	23.79	230.94	173.96

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
996.14	93.56	44.54	320.56	18.35	.76	11.36	0.00	0.00
1726.7	115.02	44.30	321.41	18.44	.53	11.36	.11	.11
2450.2	104.43	44.74	322.19	18.60	.50	11.36	.11	.14
3003.6	102.54	43.72	320.55	19.20	.33	11.36	.11	.11
1718.2	102.66	43.80	317.63	18.07	1.29	11.36	.68	.52
2396.6	113.60	43.51	316.25	20.00	1.20	11.36	.63	.63
3182.8	300.94	30.68	309.06	22.13	1.09	11.36	.55	.68
3754.6	241.82	43.24	317.12	23.71	.76	11.36	.11	.62
4523.6	127.23	43.28	317.07	27.62	.81	11.36	.16	.71
5045.2	213.81	44.19	317.08	34.43	.67	11.36	.11	.67
984.04	18.38	43.36	319.48	3.73	2.78	11.36	0.00	0.00
1700.2	153.02	43.60	319.25	17.78	2.62	11.36	.90	.75
2377.4	81.83	43.46	317.74	10.54	2.48	11.36	0.00	0.00
3067.8	186.25	43.93	318.61	27.40	2.25	11.36	.86	.84
3736.0	249.25	43.20	318.05	30.05	2.06	11.36	.94	.86
4377.2	186.70	44.11	318.24	31.82	1.70	11.36	.78	.86
4607.0	130.75	43.80	316.56	26.78	.00	11.36	.11	.11
5108.6	242.65	44.62	316.78	39.07	1.98	11.36	.81	.89
1745.6	150.37	43.27	312.86	19.70	4.48	11.36	.95	.86
2464.6	84.51	43.20	313.03	29.67	4.37	11.36	0.00	0.00
3111.4	82.02	43.37	311.17	33.64	3.95	11.36	0.00	0.00
3747.4	122.87	42.96	310.58	38.44	3.70	11.36	.92	.72
4394.2	144.26	44.11	313.60	42.76	3.25	11.36	.90	.93
4851.4	231.98	43.21	314.55	45.60	2.79	11.36	.88	.92
2011.6	115.39	42.37	312.83	28.92	6.12	11.13	.95	.91
2796.8	105.29	42.08	314.23	35.35	5.82	11.36	.95	.94
3582.8	190.43	41.78	313.82	42.66	5.51	11.36	.94	.95
4287.4	255.42	42.04	313.33	48.87	5.05	11.36	.93	.95
4943.8	192.01	42.56	312.19	56.29	4.70	11.36	.92	.95
2186.8	143.77	41.63	312.83	30.42	6.12	10.14	.95	.92
3116.4	214.60	42.70	313.74	38.30	6.12	10.87	.95	.94
4007.2	221.21	42.48	314.33	47.05	5.95	11.36	.94	.76
4719.8	234.08	42.07	314.78	53.85	5.34	11.36	.93	.96
2738.2	182.49	42.38	315.47	35.35	6.12	8.17	.95	.94
3809.6	112.32	42.79	315.77	45.06	6.12	9.18	.94	.96
4763.4	94.63	42.31	313.48	55.64	6.12	10.32	0.00	0.00
3221.2	89.30	41.31	316.72	39.48	6.12	7.10	0.00	0.00
4331.0	258.63	41.60	315.95	50.84	6.12	8.43	.94	.96
4075.8	128.47	41.78	315.60	48.25	6.12	6.06	.94	.96
4517.9	260.79	41.55	321.34	52.71	6.12	5.63	.94	.76

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
0.00	0.00	0.00	0.00	0.00	0.00
.82	.92	.02	0.00	.76	.02
.69	.95	.01	0.00	.65	.01
.1[illegible]	.96	.02	0.00	.11	.00
.95	.92	.35	.00	.88	.31
.93	.95	.49	.00	.88	.35
.89	.96	.[illegible]8	.00	.85	.32
.73	.96	.06	0.00	.71	.04
.65	.97	.12	0.00	.63	.07
.42	.97	.07	0.00	.41	.03
0.00	0.00	0.00	0.00	0.00	0.00
.97	.92	.67	.02	.89	.60
0.00	0.00	0.00	0.00	0.00	0.00
.95	.96	.73	.01	.91	.66
.93	.96	.72	.01	.90	.65
.70	.97	.67	.00	.87	.58
.11	.97	.02	0.00	.10	.00
.89	.97	.73	.02	.87	.63
.78	.92	.81	.12	.90	.73
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.95	.97	.85	.07	.92	.78
.94	.97	.84	.04	.92	.77
.93	.97	.[illegible]1	.03	.90	.73
.98	.93	.87	.30	.91	.79
.97	.95	.89	.25	.92	.82
.96	.96	.89	.21	.93	.82
.96	.97	.89	.16	.93	.82
.95	.97	.88	.13	.92	.81
.97	.93	.88	.30	.91	.79
.97	.95	.89	.29	.92	.82
.96	.97	.90	.26	.93	.83
.95	.97	.89	.19	.93	.82
.97	.93	.89	.29	.90	.80
.96	.76	.90	.29	.92	.83
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.96	.96	.90	.28	.92	.82
.96	.94	.90	.29	.90	.81
.96	.94	.90	.28	.90	.81

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
92.0	85.9	102.0	71.4	95.6	89.4	90.4	71.6	97.9
94.5	86.3	117.3	72.1	102.6	93.4	94.7	71.8	100.3
98.2	87.9	131.1	72.6	110.6	98.6	99.2	72.0	105.6
98.3	89.3	141.0	73.3	115.1	102.4	100.5	73.3	109.0
105.9	93.6	157.3	79.2	142.0	120.0	123.6	77.4	116.0
104.4	92.2	156.7	80.5	139.1	117.6	120.1	78.1	116.7
112.2	98.0	161.6	82.3	130.0	113.5	110.7	90.5	125.2
103.3	92.0	156.7	80.7	146.0	121.4	119.9	78.8	123.0
103.0	92.7	156.4	81.4	151.5	124.7	120.5	79.2	128.5
106.2	91.0	15[illegible].4	80.7	159.4	129.7	122.3	79.5	133.4
101.0	93.3	135.9	80.9	128.0	111.6	114.2	82.0	109.6
106.4	93.3	154.6	81.6	130.8	113.1	115.4	82.2	121.1
108.7	95.4	162.5	82.8	134.7	115.6	117.7	82.2	129.5
110.5	93.5	168.0	83.4	141.1	119.6	120.4	82.4	136.6
108.4	95.2	167.3	84.1	147.1	122.9	120.7	83.2	140.2
110.4	94.6	166.8	84.2	155.5	128.6	122.9	83.9	144.2
112.7	98.3	169.4	84.6	173.6	141.1	133.7	85.0	148.7
103.8	93.1	132.0	80.9	135.3	112.8	105.4	82.2	149.9
105.5	94.1	157.0	83.6	129.2	111.6	113.1	82.7	133.7
109.2	92.0	159.1	85.3	133.9	114.6	114.3	83.9	141.1
106.5	94.0	161.1	85.7	136.6	115.6	115.1	84.9	146.6
110.3	93.8	164.4	86.1	144.7	121.2	118.1	86.3	159.5
112.6	92.8	166.0	86.1	154.4	127.1	121.6	86.3	170.9
118.8	97.5	171.5	86.1	174.8	141.8	133.7	86.5	181.1
103.[illegible]	89.0	160.4	75.1	127.3	109.4	110.3	73.1	135.1
105.9	91.5	166.8	76.0	134.2	113.8	113.3	73.9	147.0
108.2	88.4	172.0	77.1	138.4	115.4	114.4	74.5	158.0
114.1	90.9	177.1	77.4	155.5	127.4	121.2	74.9	177.9
110.6	90.4	179.8	78.5	159.5	127.8	121.6	75.6	188.5
105.8	91.5	170.4	77.5	147.1	122.9	125.1	75.5	139.3
110.7	94.5	177.6	77.5	155.6	128.4	128.0	75.5	155.9
110.2	90.4	186.8	77.8	158.9	128.8	126.1	75.4	168.0
112.5	95.0	178.0	78.3	175.5	140.9	131.3	76.0	192.1
105.3	91.4	143.6	78.6	145.5	122.0	122.0	78.8	146.2
107.7	93.5	151.7	79.4	153.8	126.0	123.7	79.3	160.7
112.3	95.8	159.1	81.0	167.5	134.3	128.4	79.6	185.2
112.7	92.7	170.1	83.1	167.5	136.5	135.3	80.6	162.3
116.5	93.7	176.3	84.0	185.1	148.2	141.3	81.3	187.3
111.1	93.5	167.5	83.1	180.6	145.6	137.9	82.5	176.9
115.4	95.4	156.4	84.1	174.2	141.4	129.8	81.7	194.3

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSURE AT VALVE (PSI)
2400.8	26.76	12.23	118.18	100.76	2.27	.19	6.05	74.77	362.91
2403.9	34.75	15.91	95.56	200.82	3.66	.23	6.00	75.16	377.72
2398.2	43.04	19.66	63.00	300.01	3.60	.18	6.00	75.10	379.09
2406.6	54.98	25.20	54.28	400.33	4.14	.16	6.04	78.35	368.28
2396.8	35.32	16.13	289.86	100.48	5.55	.34	7.98	86.82	380.18
2401.9	50.71	23.20	266.96	200.70	10.21	.44	8.00	87.03	376.96
2398.4	65.21	29.79	240.73	300.59	13.78	.46	8.01	86.74	378.59
2408.2	83.54	38.32	215.60	400.06	16.43	.43	8.07	88.65	267.82
2404.0	94.81	43.41	173.36	500.55	16.53	.38	8.01	86.30	349.67
2402.2	111.71	51.11	129.82	599.54	14.83	.29	8.03	87.61	329.37
2401.3	123.25	56.37	73.07	699.73	9.74	.17	8.00	85.27	261.03
2403.2	44.13	20.20	508.82	101.84	9.87	.49	10.03	100.60	372.27
2396.3	67.03	30.59	472.22	200.43	18.03	.59	9.97	100.57	376.11
2403.5	91.33	41.81	445.88	300.91	25.56	.61	9.98	100.52	375.31
2408.6	115.50	52.99	415.76	399.04	31.66	.60	9.98	100.29	364.48
2402.0	139.23	63.70	365.38	500.87	34.88	.55	9.98	100.71	343.00
2407.1	161.57	74.08	321.65	600.15	36.77	.50	9.98	99.91	310.04
2411.0	181.25	83.24	250.95	700.07	33.46	.40	9.98	99.50	167.95
2412.8	243.28	111.81	340.68	800.12	51.92	.46	10.15	111.90	175.26
2409.3	98.42	45.17	804.08	200.53	30.71	.68	12.01	121.84	376.34
2404.9	99.55	45.60	818.95	201.14	31.38	.69	12.01	123.27	373.17
2411.6	213.96	98.28	945.56	400.47	72.13	.73	12.03	131.89	367.60
2406.1	220.46	101.04	731.55	500.68	69.77	.69	11.94	123.84	349.73
2396.6	255.62	116.69	667.26	601.28	76.65	.66	11.98	121.90	322.33
2406.2	287.19	131.63	604.03	700.71	80.63	.61	11.99	121.60	259.05
2401.2	127.99	58.54	1109.3	200.56	42.38	.72	14.03	141.06	375.67
2402.3	188.08	86.06	1114.0	301.81	64.04	.74	13.94	145.42	375.74
2400.1	238.46	109.01	1046.9	400.24	79.81	.73	13.94	143.18	356.56
2404.1	287.09	131.47	960.07	499.99	91.43	.70	13.95	141.84	316.03
2413.1	331.71	152.47	880.24	600.03	100.60	.66	14.05	141.34	195.26
2402.1	142.68	65.28	1257.2	201.31	48.21	.74	15.92	157.45	368.78
2404.8	202.30	92.66	1173.0	301.57	67.38	.73	15.92	158.15	346.09
2403.0	261.67	119.77	1100.4	401.82	84.22	.70	15.92	158.36	318.12
2417.9	314.86	145.01	1001.9	500.32	95.48	.66	16.03	157.90	167.07
2402.2	197.86	90.53	1737.0	200.90	66.47	.73	17.99	191.15	373.21
2405.3	272.61	124.90	1544.2	301.20	88.59	.71	17.88	189.91	343.43
2406.0	341.73	156.70	1350.4	401.77	103.34	.66	17.95	186.71	269.62
2402.7	326.77	147.64	1028.6	501.16	98.19	.66	17.98	164.29	167.73
2403.0	233.08	106.68	1988.9	201.45	76.32	.72	19.88	205.32	341.14
2406.2	327.23	149.98	1699.4	301.61	97.63	.65	19.88	204.65	228.97
2413.7	295.68	135.94	2307.2	200.64	88.17	.65	21.80	220.81	246.58
2407.5	323.45	148.44	1754.9	301.49	100.78	.68	21.85	204.57	317.81
2403.8	318.68	145.91	2501.4	201.54	96.03	.66	23.83	235.70	288.98

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1019.8	40.30	46.06	315.12	18.07	.62	11.36	0.00	0.00
1751.5	206.00	46.57	315.86	18.98	.50	11.36	.11	.11
2344.4	90.80	45.99	317.99	19.99	.33	11.36	0.00	0.00
3197.8	87.69	46.77	319.27	21.12	.28	11.36	0.00	0.00
985.46	50.03	45.73	319.06	20.33	1.52	11.36	0.00	0.00
1691.4	94.96	45.83	317.28	21.77	1.40	11.36	0.00	0.00
2375.6	91.53	46.10	316.29	23.55	1.26	11.36	0.00	0.00
3145.2	312.59	34.86	314.58	26.28	1.13	11.36	.64	.68
3831.6	213.43	44.96	317.93	27.63	.91	11.36	.45	.69
4351.8	142.42	46.47	317.24	31.30	.68	11.36	.11	.65
5079.2	162.00	45.49	317.36	31.87	.38	11.36	.11	.46
997.94	40.29	45.05	317.80	20.09	2.67	11.36	0.00	0.00
1704.1	100.79	45.14	318.17	23.88	2.48	11.36	.90	.75
2384.0	228.61	45.08	317.72	27.02	2.34	11.36	.89	.80
3090.6	131.60	45.56	317.43	30.99	2.17	11.36	.87	.84
3703.2	253.21	45.46	316.54	33.71	1.92	11.36	.84	.85
4442.2	291.75	44.58	315.37	38.08	1.68	11.36	.80	.86
4963.2	192.53	46.06	316.37	39.98	1.31	11.36	.67	.84
5594.2	228.43	45.90	316.80	50.36	1.78	11.36	.80	.89
1704.0	80.16	44.78	312.66	28.92	4.20	11.36	0.00	0.00
1711.0	103.70	44.48	310.67	23.65	4.29	11.36	.95	.85
3206.0	231.98	45.68	311.52	46.71	4.94	11.36	.94	.93
3625.2	272.87	45.51	309.50	46.61	3.83	11.36	.93	.93
4452.8	146.99	45.26	312.15	51.26	3.52	11.36	.92	.93
4731.0	254.56	45.51	310.34	57.15	3.16	11.36	.90	.93
1908.5	208.25	44.91	310.95	32.79	5.82	11.36	.96	.90
2798.2	218.88	44.76	310.09	41.79	5.84	11.36	.95	.93
3537.0	245.10	44.71	310.77	49.43	5.49	11.36	.94	.94
4223.0	290.74	45.37	309.46	56.52	5.03	11.36	.94	.95
4790.0	193.38	43.76	311.84	65.40	4.59	11.36	.93	.95
2139.6	120.45	43.17	312.58	34.26	6.12	10.55	.96	.92
2972.2	256.20	43.60	312.25	43.33	6.14	11.36	.95	.94
3056.2	195.00	43.51	313.09	52.79	5.77	11.36	.94	.95
4558.4	204.89	44.40	311.63	62.71	5.22	11.36	.93	.96
2712.6	219.46	42.03	317.75	43.08	6.12	7.64	.95	.94
4010.4	231.40	41.21	316.27	53.70	6.12	8.60	.94	.96
4997.4	175.22	42.07	314.63	65.52	6.12	9.84	.94	.97
4715.6	273.84	44.59	312.17	63.21	5.39	11.36	.93	.96
3445.0	190.92	41.58	317.14	48.04	6.12	6.67	.95	.95
4741.0	210.76	40.94	316.36	62.10	6.12	7.82	.74	.96
4288.4	156.47	39.60	315.62	57.01	6.12	5.78	.94	.96
5158.0	-117.0	118.27	312.23	65.22	6.12	7.58	0.00	0.00
4653.8	265.84	41.70	323.60	62.04	6.12	5.31	.94	.96

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
0.00	0.00	0.00	0.00	0.00	0.00
.84	.92	.02	0.00	.77	.02
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.91	.96	.44	.00	.87	.38
.32	.97	.31	.00	.79	.24
.62	.97	.06	0.00	.60	.04
.11	.97	.05	0.00	.10	.00
0.00	0.00	0.00	0.00	0.00	0.00
.97	.92	.67	.03	.90	.60
.97	.94	.71	.02	.91	.65
.95	.96	.74	.02	.91	.67
.94	.96	.71	.01	.90	.64
.91	.97	.69	.02	.88	.60
.64	.97	.58	.00	.82	.46
.88	.98	.72	.02	.86	.61
0.00	0.00	0.00	0.00	0.00	0.00
.98	.92	.81	.14	.90	.73
.97	.96	.88	.20	.93	.81
.96	.96	.86	.09	.92	.79
.95	.97	.85	.07	.92	.78
.94	.97	.84	.05	.91	.77
.98	.93	.86	.33	.91	.77
.97	.95	.89	.33	.92	.81
.96	.96	.89	.27	.93	.82
.96	.97	.89	.21	.93	.82
.95	.97	.88	.16	.92	.82
.97	.93	.88	.38	.91	.79
.97	.95	.89	.38	.92	.82
.96	.97	.90	.31	.93	.83
.95	.97	.89	.23	.93	.83
.97	.93	.89	.37	.90	.80
.96	.96	.90	.37	.92	.83
.95	.97	.90	.36	.92	.83
.95	.97	.90	.25	.93	.83
.96	.93	.90	.37	.90	.81
.95	.96	.90	.36	.92	.82
.76	.94	.90	.37	.90	.81
0.00	0.00	0.00	0.00	0.00	0.00
.96	.94	.90	.36	.90	.81

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
107.0	94.9	173.5	87.9	146.0	124.3	129.0	82.4	131.7
105.8	94.1	178.3	88.8	143.0	122.2	126.0	83.1	132.8
107.2	92.4	179.3	89.2	142.7	121.9	124.6	83.5	133.8
157.2	90.5	174.8	73.6	115.2	97.5	98.7	69.1	120.8
96.3	88.4	129.9	82.0	115.5	102.5	104.7	81.6	118.9
101.1	88.3	147.9	82.9	120.0	105.6	107.5	81.5	127.1
103.6	88.0	158.0	83.0	123.9	108.0	109.8	81.7	131.6
113.4	98.8	170.7	82.9	134.5	116.9	114.1	90.5	136.7
104.0	91.2	167.5	83.7	137.1	115.5	114.9	81.9	145.2
104.7	90.5	147.3	84.4	145.7	122.8	117.0	83.8	144.2
106.1	92.5	161.0	86.0	156.4	128.3	121.4	84.0	151.7
106.3	91.2	165.1	87.0	136.3	117.5	120.8	84.3	127.5
104.2	91.9	167.9	87.8	135.4	116.9	118.9	85.2	132.3
106.5	93.7	172.5	88.1	137.6	117.9	120.4	85.7	143.0
108.7	95.4	177.3	89.0	141.7	120.3	121.3	86.0	154.2
111.8	94.6	182.8	88.2	153.0	128.4	126.6	86.2	162.7
118.0	96.2	185.5	88.6	155.5	127.9	126.3	85.9	166.5
113.6	93.3	183.4	89.5	172.6	141.5	133.0	86.4	175.8
100.1	82.3	168.2	80.4	154.5	124.7	111.6	78.3	184.7
105.4	95.4	154.7	86.5	134.3	117.3	118.7	90.7	143.3
108.2	93.7	160.7	86.5	133.8	116.6	117.0	90.5	141.8
107.8	89.8	136.1	88.2	131.7	113.5	110.3	96.2	177.0
111.5	95.0	155.9	89.5	141.7	119.9	117.1	96.7	183.2
112.7	92.7	166.9	90.5	152.3	126.2	121.0	97.3	196.2
115.0	97.6	176.6	92.6	163.2	133.0	126.8	98.1	208.6
109.0	94.2	150.6	92.4	152.1	128.2	130.5	98.9	160.7
108.8	93.3	153.6	86.9	134.2	115.9	114.0	91.8	165.8
114.1	93.8	164.9	87.1	143.2	120.9	119.9	99.8	183.7
117.8	99.2	177.2	89.0	161.9	134.4	128.1	89.9	211.5
124.4	99.9	187.7	90.9	177.8	145.0	135.3	89.8	231.1
116.2	94.1	190.4	91.9	163.0	136.1	138.9	89.9	159.7
118.5	100.7	194.2	92.0	168.3	139.5	139.6	88.8	183.0
117.1	99.0	191.3	91.4	172.1	141.0	138.4	88.5	193.7
121.0	101.8	196.6	91.3	192.8	156.8	149.4	88.1	230.2
100.9	91.7	143.1	71.2	137.3	117.2	114.9	70.4	155.4
110.2	95.8	159.0	72.0	149.3	124.1	119.1	70.4	183.0
111.8	96.3	166.9	72.2	158.7	128.1	120.7	71.0	201.5
107.5	88.1	184.7	89.4	186.3	148.9	140.6	82.2	232.5
115.[illegible]	97.0	172.7	73.7	157.0	130.3	126.6	70.9	168.5
116.3	94.9	181.6	74.2	173.1	140.2	130.8	71.3	210.6
115.2	97.4	187.6	75.8	178.9	145.1	136.3	71.9	201.3
130.7	85.5	166.5	77.6	155.0	123.1	120.5	73.0	187.9
110.5	93.2	138.0	69.7	147.5	122.4	109.5	68.9	201.5

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSU. AT VALVE (PSI)
2596.5	37.01	18.31	111.43	200.45	4.25	.23	6.00	74.83	381.17
2577.3	44.99	22.27	83.77	299.23	4.77	.21	6.00	74.78	385.22
2604.5	53.16	26.37	45.54	399.16	3.46	.13	6.00	75.09	358.14
2605.2	37.41	18.56	358.52	100.98	6.90	.37	8.00	89.06	380.30
2609.1	54.07	26.87	339.79	200.76	12.99	.48	8.00	89.46	381.40
2601.3	70.40	34.88	297.95	300.17	17.04	.49	8.00	88.49	382.74
2605.0	86.85	43.10	267.45	400.08	20.38	.47	8.00	88.49	374.89
2597.8	102.10	50.52	222.79	499.29	21.19	.42	8.01	88.16	363.40
2613.7	117.02	58.26	176.97	599.63	20.21	.35	8.01	88.33	342.14
2621.0	130.92	65.36	114.74	700.06	15.30	.23	8.01	88.48	241.91
2604.0	79.57	39.46	654.55	200.37	24.98	.63	10.09	108.17	379.41
2600.6	108.03	53.51	609.78	300.18	34.87	.65	10.03	107.93	378.63
2605.3	135.21	67.10	562.01	400.69	42.89	.64	9.98	107.95	370.99
2604.6	162.80	80.77	517.21	501.91	49.45	.61	9.98	107.28	353.01
2601.3	188.31	93.30	465.50	599.81	53.18	.57	9.98	106.64	322.87
2602.1	182.15	90.28	276.71	705.39	37.18	.41	10.12	101.40	159.11
2616.1	247.86	123.51	402.70	799.45	61.32	.50	10.12	109.81	205.73
2598.1	132.16	65.40	1183.2	200.71	45.23	.69	12.03	135.36	389.47
2606.5	172.14	85.46	1088.7	299.12	62.03	.73	12.04	132.13	386.82
2607.5	209.44	104.02	993.48	399.77	75.65	.73	11.98	129.91	383.63
2592.6	230.72	113.94	826.93	501.92	79.06	.69	11.89	124.42	363.51
2607.7	242.89	120.64	669.76	600.48	76.61	.63	11.95	121.54	293.03
2610.8	393.69	195.73	947.46	699.37	126.21	.64	13.97	145.61	200.24
2600.3	147.76	73.18	1374.4	200.40	52.46	.72	14.02	156.14	385.44
2598.0	202.98	100.45	1276.3	300.96	73.16	.73	14.02	153.13	384.53
2571.5	254.32	124.57	1178.4	401.67	90.16	.72	14.00	151.20	363.34
2601.6	300.31	148.82	1111.1	501.79	106.20	.71	14.05	148.20	358.39
2598.1	345.37	170.92	999.74	600.53	114.36	.67	14.09	145.15	271.81
2673.1	279.08	142.10	555.49	699.39	74.00	.52	14.06	144.04	133.28
2602.2	136.61	67.71	1285.2	200.14	48.99	.72	15.96	149.19	375.43
2599.5	194.01	96.06	1215.8	301.25	69.76	.73	15.97	149.62	365.80
2612.3	253.86	125.83	1183.2	400.00	90.15	.72	15.97	153.57	354.62
2605.8	311.23	154.48	1117.2	500.85	106.58	.69	15.97	154.17	313.55
2614.0	362.94	180.71	1028.2	601.88	117.88	.65	15.97	153.15	206.04
2598.6	154.77	76.59	1473.0	200.83	56.35	.74	17.99	166.66	378.59
2607.9	184.21	91.50	1758.9	200.56	67.19	.73	17.98	183.95	383.43
2609.3	320.17	159.14	1423.9	400.48	108.62	.68	17.99	179.62	306.50
2605.6	330.06	188.63	1279.1	499.56	121.71	.65	17.95	177.74	223.87
2606.2	192.65	95.64	1829.3	199.90	69.65	.73	19.88	189.96	370.09
2609.5	203.56	101.18	1922.4	200.14	73.29	.72	19.91	194.47	373.78
2592.1	371.36	183.35	1549.3	399.95	118.03	.64	19.88	194.25	241.16

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1778.0	130.53	42.93	316.69	23.44	.54	11.36	.11	.11
2389.0	57.71	43.94	316.58	24.52	.41	11.36	0.00	0.00
3175.6	72.62	42.80	319.40	25.40	.22	11.36	0.00	0.00
1002.1	91.68	43.31	319.43	24.51	1.73	11.36	0.00	0.00
1652.6	141.64	43.79	317.70	26.29	1.64	11.36	.84	.59
2435.8	83.69	44.26	314.48	28.65	1.44	11.36	0.00	0.00
3079.0	167.13	43.00	317.75	31.20	1.29	11.36	.75	.73
3782.2	176.74	43.77	319.91	33.74	1.08	11.36	.65	.74
4387.8	133.36	44.52	317.82	36.44	.85	11.36	.45	.72
5039.2	294.23	43.47	316.15	38.57	.55	11.36	.11	.61
1693.7	177.92	43.50	315.86	30.25	3.16	11.36	.94	.79
2396.0	137.79	43.12	315.30	34.69	2.95	11.36	.92	.85
3082.6	224.58	43.79	316.87	39.01	2.72	11.36	.91	.87
3754.2	176.31	43.05	316.60	43.29	2.50	11.36	.90	.89
4341.2	301.81	42.75	315.59	47.13	2.25	11.36	.88	.89
4939.8	271.81	45.87	314.35	46.88	1.34	11.36	.74	.84
5963.2	-114.6	102.58	313.72	60.06	1.94	11.36	0.00	0.00
1240.4	227.82	42.60	311.52	42.09	5.73	11.36	.96	.90
2585.8	134.98	41.22	312.66	48.82	5.26	11.36	.95	.92
3271.8	225.27	42.40	312.41	55.30	4.80	11.36	.94	.93
3861.3	208.24	42.55	311.61	56.82	4.02	11.36	.93	.93
4321.4	239.28	46.26	310.21	55.55	3.23	11.36	.92	.92
6153.9	883.17	167.84	311.16	86.71	4.57	11.36	0.00	0.00
2157.9	132.39	42.14	313.05	41.28	6.12	10.45	.96	.92
2976.0	250.39	43.43	313.25	47.80	6.12	11.24	.95	.94
3761.6	248.25	43.08	314.27	56.40	5.77	11.36	.94	.95
4446.6	164.76	43.91	313.53	66.43	5.38	11.36	.94	.96
5049.6	277.31	44.10	311.06	73.31	4.84	11.36	.93	.96
5557.6	246.02	43.85	309.22	71.21	2.62	11.36	.89	.93
1995.6	75.81	45.99	309.82	38.52	6.12	11.18	0.00	0.00
2364.4	225.65	45.11	310.75	47.50	5.89	11.36	.95	.94
3792.8	195.76	46.24	312.51	57.51	5.72	11.36	.94	.95
4546.6	327.20	46.75	311.51	67.90	5.40	11.36	.94	.96
5183.8	246.28	47.08	310.83	76.89	4.95	11.36	.93	.96
2294.8	140.19	45.60	312.06	41.14	6.12	9.74	.96	.92
2726.0	191.42	45.49	312.72	46.75	6.12	8.19	.95	.93
4643.6	194.27	45.49	312.01	69.89	6.12	10.12	.94	.96
5480.8	309.65	45.69	310.93	81.95	6.12	11.25	.93	.97
2834.0	166.16	45.75	311.51	47.26	6.12	7.87	.95	.94
2958.6	253.78	46.13	312.24	49.58	6.12	7.50	.95	.94
5346.0	265.38	44.43	308.55	80.60	6.12	9.24	.93	.97

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
.87	.92	.02	0.00	.80	.01
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
.97	.72	.50	.02	.89	.44
0.00	0.00	0.00	0.00	0.00	0.00
.93	.96	.55	.00	.89	.49
.88	.97	.48	.00	.85	.41
.77	.97	.33	.00	.75	.24
.42	.97	.06	0.00	.41	.03
.98	.92	.74	.07	.90	.66
.97	.94	.78	.06	.92	.72
.96	.96	.79	.04	.92	.73
.95	.97	.80	.03	.92	.73
.94	.97	.78	.02	.91	.71
.87	.97	.62	.00	.84	.52
0.00	0.00	0.00	0.00	0.00	0.00
.98	.93	.86	.40	.71	.77
.97	.95	.88	.31	.92	.80
.97	.96	.88	.23	.93	.81
.96	.97	.87	.14	.93	.80
.95	.97	.85	.07	.92	.78
0.00	0.00	0.00	0.00	0.00	0.00
.97	.93	.88	.47	.91	.79
.97	.95	.89	.47	.92	.82
.96	.96	.90	.38	.93	.83
.96	.97	.90	.31	.93	.83
.95	.97	.89	.23	.93	.82
.93	.98	.83	.04	.90	.75
0.00	0.00	0.00	0.00	0.00	0.00
.97	.95	.89	.42	.92	.82
.96	.97	.90	.38	.93	.83
.96	.97	.90	.32	.93	.83
.95	.97	.89	.25	.92	.82
.97	.93	.88	.47	.91	.80
.97	[illegible]	.89	.47	.90	.80
.96	.97	.90	.46	.93	.83
.95	.98	.90	.45	.93	.84
.97	.93	.89	.47	.90	.80
.97	.93	.89	.47	.90	.80
.95	.97	.90	.44	.92	.83

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
103.8	92.0	155.9	72.2	129.7	112.9	114.7	69.4	124.2
104.7	92.1	166.4	72.1	132.6	114.7	116.1	69.3	128.8
106.6	88.8	174.2	72.1	136.5	116.9	117.4	69.3	131.4
104.0	87.7	147.1	71.7	125.5	110.4	111.2	70.6	118.2
104.2	89.9	159.2	72.5	126.9	111.0	113.0	70.7	127.8
107.3	89.7	167.7	72.6	130.0	112.6	114.1	71.1	136.6
108.3	88.6	172.4	72.1	133.8	114.6	115.8	71.2	142.0
107.6	73.5	177.6	72.6	141.4	119.6	117.9	70.9	151.8
109.2	88.8	179.2	72.4	145.6	121.1	119.0	70.7	152.2
110.3	89.4	178.5	73.2	158.7	131.2	123.1	70.5	162.7
103.9	88.5	157.6	74.3	134.9	116.5	117.3	71.9	134.6
108.7	92.6	172.5	73.0	139.5	119.3	120.5	72.2	157.7
112.3	91.0	179.3	74.3	144.4	122.6	122.1	72.1	167.8
111.0	90.4	182.6	74.3	148.0	124.1	123.4	72.1	171.0
111.0	94.1	184.3	74.4	156.2	128.9	125.3	72.5	182.9
105.4	82.0	191.2	85.9	180.6	144.8	140.5	79.2	199.4
101.4	87.9	170.1	76.6	167.2	133.9	123.2	69.9	203.9
95.4	80.0	141.6	64.7	101.0	89.7	88.6	60.2	157.4
105.2	79.8	159.2	67.3	113.4	97.9	97.1	61.3	174.1
102.1	81.6	168.0	69.1	121.6	102.9	101.3	62.5	184.5
105.9	81.8	175.1	71.7	136.1	113.7	110.4	64.9	199.7
136.5	85.7	198.2	91.9	168.2	136.6	133.0	83.3	221.4
116.1	89.5	177.6	73.0	163.7	130.9	117.8	64.1	267.5
111.8	78.6	149.3	73.2	111.6	97.5	96.6	70.6	168.7
112.0	82.6	157.3	75.1	119.6	102.4	100.4	70.9	182.1
117.6	79.6	167.1	77.2	134.7	113.0	109.1	71.9	209.1
111.0	82.3	140.9	81.0	129.2	107.9	105.2	77.8	214.7
132.2	83.3	164.9	83.9	158.6	129.8	119.8	78.8	255.1
138.8	86.0	187.9	87.6	176.6	142.0	129.9	79.9	273.8
138.0	84.9	206.0	94.4	158.3	131.1	133.1	85.0	185.4
138.0	87.7	209.2	95.1	159.0	130.8	131.9	86.0	202.0
130.1	84.5	187.8	94.4	150.8	123.8	121.6	88.7	198.8
138.2	85.6	194.6	94.4	156.1	125.9	125.3	89.1	222.8
142.2	84.9	200.0	95.4	172.2	137.3	129.2	89.6	264.9
140.5	86.2	208.1	97.3	159.3	131.8	134.1	90.3	199.3
124.8	84.6	156.5	89.9	118.7	102.8	100.6	89.6	176.7
147.8	86.6	178.5	91.9	156.0	128.7	119.1	89.8	255.4
139.0	86.3	192.6	94.5	161.4	128.7	119.7	90.5	267.4
145.5	86.6	210.0	98.2	159.8	131.8	132.4	91.1	202.7
143.3	84.8	184.0	95.6	147.0	123.3	120.2	92.6	206.8
142.7	91.5	195.7	96.6	157.8	125.8	122.6	92.5	249.2

PUMP INPUT SPEED (RPM)	PUMP INPUT TORQUE (FT-LB)	PUMP INPUT POWER (HP)	MOTOR OUTPUT SPEED (RPM)	MOTOR OUTPUT TORQUE (FT-LB)	MOTOR OUTPUT POWER (HP)	TRANS OVERALL EFF. (RATIO)	CONTROL VALVE VOLTAGE (VDCA)	CONTROL VALVE PRESSURE (PSI)	PRESSURE AT VALVE (PSI)
2805.5	27.28	14.58	96.98	100.32	1.85	.13	5.95	74.44	388.36
2799.0	34.52	18.40	82.24	199.34	3.12	.17	5.95	75.89	383.86
2800.0	46.46	24.78	102.04	300.25	5.84	.24	5.95	76.28	387.69
2801.2	54.62	29.14	67.83	401.88	5.19	.18	5.96	76.40	388.37
2797.0	37.56	20.01	350.78	100.63	6.72	.34	7.95	86.88	392.36
2799.5	53.18	28.36	327.08	200.49	12.49	.44	7.95	86.34	385.95
2796.0	67.97	36.20	293.97	300.58	16.83	.46	7.95	87.52	389.41
2802.3	82.44	44.01	266.11	400.20	20.29	.46	7.95	86.63	394.95
2803.3	96.57	51.57	232.65	499.05	22.12	.43	7.96	87.90	376.38
2804.7	112.04	59.85	185.62	601.38	21.26	.36	7.96	87.87	365.63
2802.1	160.90	85.88	314.10	700.09	41.89	.49	8.03	96.05	382.51
2794.2	173.04	92.10	197.36	800.28	30.08	.33	8.03	94.64	284.07
2799.4	74.82	39.90	641.74	199.85	24.43	.61	9.99	106.07	405.64
2799.2	102.96	54.89	629.03	300.76	36.04	.66	10.01	107.25	402.13
2801.0	142.41	75.98	678.24	401.57	51.88	.68	9.99	111.74	407.06
2801.5	163.47	89.90	628.33	500.97	59.96	.67	10.00	110.38	401.62
2814.6	194.51	104.28	584.87	600.87	66.94	.64	10.00	109.11	390.17
2797.3	218.44	116.39	495.56	699.71	66.05	.57	10.00	107.53	345.91
2811.4	264.27	141.52	519.70	797.74	78.97	.55	9.99	111.60	316.03
2804.4	109.53	58.51	1052.9	199.64	40.04	.68	11.89	126.33	402.46
2810.0	146.50	78.41	989.68	300.02	56.56	.72	12.02	125.81	402.10
2809.5	184.59	98.75	938.87	400.51	71.62	.73	12.03	125.33	404.49
2805.3	220.17	117.67	885.04	500.17	84.32	.72	12.03	124.08	393.50
2811.7	257.06	137.67	823.79	601.55	94.39	.69	12.04	124.85	362.66
2811.4	290.55	155.59	770.07	698.42	102.44	.66	12.04	123.45	342.34
2820.5	317.31	170.47	684.08	797.89	103.97	.61	12.05	122.47	175.08
2803.3	158.78	84.78	1627.9	200.20	62.08	.73	14.08	167.67	408.01
2797.3	210.54	112.18	1465.8	300.43	83.88	.75	14.02	160.23	402.58
2796.3	263.05	140.11	1354.2	400.42	103.29	.74	14.03	158.02	388.41
2805.5	314.74	168.19	1267.8	500.85	120.95	.72	14.05	156.06	364.86
2805.8	149.91	80.12	1544.3	201.38	59.24	.74	15.98	160.89	399.87
2801.9	208.60	111.33	1452.2	301.47	83.39	.75	15.99	161.27	399.84
2807.0	260.22	139.23	1342.1	399.15	102.04	.73	16.00	158.49	372.24
[illegible]	314.98	168.58	1237.7	501.12	118.14	.70	16.00	157.45	343.10
2792.5	364.73	174.01	1125.5	602.76	129.22	.67	16.02	155.17	236.07
2805.1	188.11	100.51	1959.0	201.16	75.06	.75	17.89	186.02	402.13
2807.8	253.45	135.55	1747.5	300.72	100.10	.74	17.91	180.77	375.54
280[illegible]	315.71	168.47	1565.9	400.51	119.46	.71	17.92	177.37	361.38
2778.5	193.11	102.94	1794.7	200.28	76.09	.74	19.87	188.53	398.94
2793.3	267.93	143.62	1819.6	300.48	104.14	.73	19.90	187.47	376.65
2814.9	330.77	181.65	1594.0	399.93	121.43	.67	19.91	186.98	263.71
2807.0	211.77	113.23	2159.6	199.45	82.04	.72	21.93	199.33	375.41

FWD MOTOR PRESS (PSI)	REV MOTOR PRESS (PSI)	CASE DRAIN PRESS (PSI)	DISP PRESS (PSI)	FUEL FLOW RATE (LB HR)	CALC PUMP DISPL (IN3-REV)	CALC MOTOR DISPL (IN3-REV)	CALC PUMP VOL EFF (RATIO)	CALC PUMP MECH EFF (RATIO)
1017.8	60.61	47.92	312.83	27.46	.44	11.36	0.00	0.00
1744.3	179.63	48.14	313.46	27.93	.37	11.36	.11	.11
2449.6	169.13	48.06	315.39	31.45	.46	11.36	.11	.11
3188.2	193.42	47.32	314.40	31.64	.30	11.36	.11	.11
988.12	24.15	47.32	316.45	27.99	1.58	11.36	0.00	0.00
1659.5	159.53	46.67	315.49	30.71	1.47	11.36	.83	.55
2306.8	166.67	47.03	315.28	34.69	1.32	11.36	.79	.66
3080.4	237.62	47.76	316.44	37.22	1.20	11.36	.75	.70
3771.0	245.72	47.46	315.21	39.81	1.04	11.36	.67	.73
4435.2	323.35	46.22	313.65	42.43	.83	11.36	.50	.71
5496.4	1087.1	191.62	318.24	54.84	1.41	11.36	0.00	0.00
6182.8	772.13	179.83	317.83	62.31	.89	11.36	0.00	0.00
1903.1	694.26	45.02	316.64	37.14	2.89	11.36	0.00	0.00
2647.7	695.41	122.04	316.01	42.77	2.83	11.36	0.00	0.00
3362.9	897.69	115.57	313.92	50.26	3.05	11.36	0.00	0.00
4698.7	930.46	72.13	316.33	55.50	2.82	11.36	0.00	0.00
4778.9	1036.9	77.14	317.35	61.04	2.62	11.36	0.00	0.00
5454.7	945.96	174.80	317.79	64.45	2.23	11.36	0.00	0.00
6104.5	845.28	193.48	315.09	70.92	2.33	11.36	0.00	0.00
1996.4	687.24	70.13	312.48	38.25	4.73	11.36	0.00	0.00
2726.2	607.13	98.81	310.70	48.20	4.43	11.36	0.00	0.00
3447.2	691.84	100.81	308.84	54.15	4.21	11.36	0.00	0.00
4149.7	680.07	212.73	309.21	59.49	3.97	11.36	0.00	0.00
4852.6	697.88	149.80	311.61	66.47	3.69	11.36	0.00	0.00
5486.0	748.78	139.76	312.73	73.11	3.45	11.36	0.00	0.00
5943.7	531.77	74.90	313.91	79.22	3.95	11.36	0.00	0.00
2573.3	716.36	209.71	311.22	51.51	6.12	9.51	0.00	0.00
3350.4	692.59	194.46	310.78	58.39	6.12	10.54	0.00	0.00
4236.0	674.51	147.69	311.83	67.99	6.10	11.36	0.00	0.00
5003.5	688.01	71.55	310.27	78.11	5.69	11.36	0.00	0.00
2475.8	677.93	153.36	307.74	48.64	6.12	10.04	0.00	0.00
3378.5	708.57	100.50	310.54	58.09	6.12	10.66	0.00	0.00
4212.0	652.24	129.35	310.33	67.79	6.02	11.36	0.00	0.00
5004.1	624.22	53.53	309.85	79.10	5.55	11.36	0.00	0.00
5720.1	620.03	152.76	308.83	91.96	5.07	11.36	0.00	0.00
3071.4	681.53	121.89	311.45	56.75	6.12	7.91	0.00	0.00
4058.9	758.34	189.83	311.35	67.90	6.12	8.87	0.00	0.00
5027.3	663.45	225.00	310.60	81.16	6.12	9.88	0.00	0.00
3156.2	775.43	212.86	311.73	55.56	6.12	7.75	0.00	0.00
4355.1	829.55	209.17	313.23	70.75	6.12	8.48	0.00	0.00
5337.0	779.59	239.65	311.46	86.98	6.12	9.75	0.00	0.00
3486.8	904.15	196.85	313.03	60.22	6.12	7.18	0.00	0.00

[illegible] OF 42 RUNS.

CALC MOTOR VOL EFF (RATIO)	CALC MOTOR MECH EFF (RATIO)	CALC PUMP OVERALL EFF (RATIO)	CALC LINE POWER LOSS (HP)	CALC MOTOR OVERALL EFF (RATIO)	CALC TRANS OVERALL EFF (RATIO)
0.00	0.00	0.00	0.00	0.00	0.00
.78	.92	.02	0.00	.72	.01
.77	.95	.02	0.00	.73	.01
.28	.96	.02	0.00	.26	.00
0.00	0.00	0.00	0.00	0.00	0.00
.97	.72	.45	.02	.89	.40
.95	.94	.52	.01	.90	.47
.93	.96	.53	.00	.89	.47
.89	.96	.49	.00	.86	.42
.80	.97	.35	.00	.78	.27
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00

PAGE # 4 OF 4 OF 42 RUNS.

WATER INLET (TEMP)	WATER OUTLET (TEMP)	ENGINE OIL (TEMP)	FUEL INTER (TEMP)	OIL COOLER INLET (TEMP)	OIL COOLER OUTLET (TEMP)	OIL RES (TEMP)	DYNO OUTLET (TEMP)	AIR BOX (TEMP)
92.0	78.8	157.2	86.7	133.2	113.8	116.7	84.2	[illegible]
91.8	82.6	166.6	87.0	131.5	112.2	114.9	84.5	154.5
87.9	81.0	135.4	81.4	117.3	102.2	101.9	81.2	[illegible]
93.3	83.6	153.4	83.4	123.9	106.6	106.6	81.2	161.0
97.0	79.9	166.5	85.4	122.0	105.7	108.3	81.6	155.9
96.4	82.7	170.8	86.2	122.8	106.2	108.2	81.8	158.7
97.9	85.1	175.3	86.9	125.1	107.6	109.2	82.2	167.2
99.2	82.5	177.3	87.5	126.8	108.4	109.2	82.5	172.1
100.2	84.3	188.7	88.7	134.5	113.4	113.2	83.1	192.7
101.8	85.0	190.4	89.6	137.5	114.6	114.0	83.5	191.2
85.8	76.6	120.3	61.3	112.9	93.7	91.9	58.6	168.1
98.5	79.2	151.4	64.1	147.8	120.2	110.3	58.8	194.3
95.0	79.9	172.3	68.7	124.2	104.4	105.5	61.0	147.8
93.4	81.8	165.2	70.4	126.2	106.3	107.3	63.9	172.7
92.0	77.2	141.5	56.8	106.1	91.8	90.3	61.9	157.5
101.8	83.1	163.7	58.0	123.4	104.4	101.4	60.7	189.5
99.2	80.7	170.3	59.8	126.6	104.4	102.9	60.5	187.2
104.9	85.7	181.3	60.3	148.5	121.3	113.7	60.4	208.7
105.2	81.2	150.1	60.7	146.0	119.8	108.1	59.2	229.7
101.3	82.3	165.1	62.6	127.4	108.1	109.1	59.6	169.2
89.9	81.0	134.9	61.0	126.2	107.1	106.2	62.8	161.2
100.3	81.4	155.2	63.6	135.7	113.9	112.3	62.8	194.8
101.7	85.4	166.6	63.7	138.8	114.3	113.8	63.2	199.0
106.6	86.1	176.2	63.4	151.4	123.7	118.8	62.8	223.6
106.6	84.0	183.0	63.7	156.0	125.1	120.4	63.0	229.3
114.6	88.1	191.0	64.7	177.5	142.6	129.8	63.0	257.3
89.6	82.0	109.8	69.6	103.4	91.9	88.4	68.0	162.2
114.3	87.7	142.6	72.5	127.7	109.0	105.8	68.4	216.9
103.2	89.4	159.5	75.3	138.1	114.7	111.1	69.1	230.7
107.8	87.1	167.2	77.7	147.6	120.4	115.4	70.9	248.7
95.7	85.7	145.5	79.7	135.6	115.0	114.3	76.7	183.0
106.3	89.4	166.8	81.7	146.0	121.8	120.6	76.9	222.1
113.7	92.7	183.3	84.7	160.9	132.4	128.7	77.7	252.4
115.4	95.5	195.5	87.9	174.7	141.8	135.5	78.6	279.1
109.3	85.6	193.6	91.8	181.8	143.6	135.7	83.1	283.4
105.0	85.9	140.8	82.1	124.0	106.6	103.7	80.4	211.1
107.1	90.9	158.8	84.6	140.4	116.9	113.3	80.9	236.1
106.3	91.0	170.0	86.9	152.6	123.8	119.1	81.7	261.1
114.2	87.5	188.7	90.9	155.4	128.6	128.3	82.4	222.1
107.5	92.1	191.3	92.1	161.9	131.3	130.1	83.2	236.5
121.3	96.0	202.1	94.6	187.9	151.8	142.1	84.9	298.3
105.7	92.2	204.3	97.2	176.4	143.9	142.8	85.5	233.9

APPENDIX D

F/D CONVERTOR AND PWM CARD DESCRIPTIONS

DESCRIPTION OF FREQUENCY/DIGITAL CONVERTER CARD

The frequency-to-digital converter board (F/D) is a single, stitch-welded, circuit board whose function is to perform an interval or frequency measurement on four incoming pulse streams. The selection of interval or frequency measurement is entirely determined by software resident on this circuit board. Intended as an intelligent slave to the SC-1 computer, the F/D converter card is itself microprocessor controlled using CMOS logic elements.

As can be seen in Figures D1 through D5, the schematic diagrams of the F/D card, the heart of this system is the 8085, 8-bit monolithic microprocessor. The processor is supported 1K byte of static RAM, shown as U8 on the reference schematic diagrams, and 2K bytes of EPROM memory implemented as device U4 on the drawings. Individual assembly language instructions steps are stored in the EPROM memory device where program stack and measurement data are stored in the volatile RAM device mentioned earlier as U8.

The 8085 microprocessor acquires the measurement of interval or frequency from either of the two 82C54 timer devices shown in the reference drawings as U5 and U12. Seen on sheet 2 of the schematic diagrams, the incoming pulse streams are buffered and debugged before being presented as inputs to one of the two timer devices. The 8085 has then only to make direct leads of the contents of the two 82C54s to measure interval or frequency.

If the 8085 is programmed to make a measurement of interval of the incoming pulse streams, it performs this function by reading the contents of the individual counters until a change in count is sensed. Once this change has been seen the 8085 takes a "snapshot" of its master time counter which is implemented in U12 counters 1 and 2. The microprocessor will then look for a second change in count and when detected, take a second snapshot of the master time counters. By performing arithmetic difference between the first and second contents of the master timer the 8085 is able to derive the value of the interval between the two successive pulses to any one of the four timers. This same basic operation of sensing a change in a counter's value, recording the master timer's contents, then sensing a subsequent change in the same timer and performance arithmetic difference is maintained for all four timers on a continuous basis.

As the SC-1 wishes to read the interval measurement data from the 8085 microprocessor located on the F/D card it does so by performing an I/O read to the card address of the F/D converter. This read process causes a hardware interrupt to be generated to the 8085. Responding to this interrupt the 8-bit microprocessor fetches data from the 1K-byte RAM mentioned earlier and presents it to the data interface devices shown as U1 and U3 on sheet 4 of the reference schematics. In order to maintain hardware synchronization a transfer acknowledge signal is generated by the 8085 back to the SC-1 to indicate that the requested data is available and stable on the bus. This transfer acknowledge signal can be seen on sheet 3 of the schematics as the signal "XACK/". In order that the F/D card can identify which of the four channels for which data is requested a read is made by the 8085 of device U4 and its Port A input bits. As can be seen on sheet 1 of the reference schematics, the Port A connections from U4 are actually connected to the eight low-order address bits on the SC-1 expansion chassis backplane. By inspecting the low-order 2 bits, ADR00 and ADR01, the 8085 is able to discern which of the four channels the SC-1 is asking for data from.

In normal operation, the F/D card does not have data written to it by the SC-1. For purposes of future growth however, the capability has been designed into this board to allow the 8085 to be interrupted by the assertion of a write command to the F/D card. As seen on sheet 3 of the schematics, device U10B, a signal labeled RST6-5 is generated as the SC-1 attempts to write to this card. Such command capability can be used to implement any number of special functions for future application.

In summary the frequency-to-digital converter card, designed, fabricated and tested under this project, is actually a stand-alone 8-bit microprocessor which uses general purpose interval timers/event counters to make a software determined measurement of interval or frequency on four incoming pulse streams. The F/D card continuously measures the interval or frequency on a free-running basis. Data can be delivered from the F/D card to the SC-1 in response to a I/O read from the SC-1 to the physical address of the F/D card in the backplane of the I/O expansion chassis. The card is designed with expansion capability for future applications and uses CMOS logic to minimize power consumption and maximum and maximize noise immunity.

DESCRIPTION OF THE PWM CONTROLLER CARD

A 300 Hz pulse width modulator controller card has been designed and developed under this project for use in the SC-1's expansion chassis. This card is intended to replace an analog subsystem used in an earlier configuration. The basic function of the PWM card is accept a 16-bit binary command from the SC-1 and to convert this command into a pulse width modulated output signal. Because of the fact that a 16-bit wide command word is used for control purposes, the resolution of this card is essentially one part in 65,535.

Seen in Figures D6 through D9, the schematic diagrams for the referenced pulse width modulator controller card, the PWM card uses an array of 8-bit synchronous binary counters to perform the pulse width modulation function. These counters have each 8-bit preload capability. Counters are always used in pairs in order to generate the 16-bit functionality described earlier.

During operation the SC-1 performs an I/O write operation to the physical address of the PWM card in the I/O expansion chassis. As seen in sheet 1 of the referenced schematics, the SC-1 determines which counter is being preset by the value contained on its four least significant address bits. The specified counter pair are then jam-loaded with the 16-bit value. The counters are controlled by the MSI combinatorial logic shown on sheets 4 and 5 of the schematics. A 300 Hz master timer clock pulse is generated by the circuitry shown on sheet 5 and this master clock oscillator is used to control the start of the 3.33 millisecond interval corresponding to the 300 Hz control function. Once the timers have been started by the 300 Hz master oscillator, they will continue counting down until they have reached their preset value at which point the outputs will go back to a zero state. The period time in which the counters are actually counting thus determines the pulse width of the output signal.

In summary, the pulse width modulator cards developed for this project provide the basic functionality of generating four 300 Hz pulse width modulated outputs per card. Absolute accuracy of the timing signals generated by this card are controlled by a crystal clock oscillator seen in the referenced schematic diagrams. The SC-1 is able to preset any of the four 16-bit pulse width modulated controllers under software control. The basic resolution of the this system is one part in 65,535.

In normal operation, the F/D card does not have data written to it by the SC-1. For purposes of future growth however, the capability has been designed into this board to allow the 8085 to be interrupted by the assertion of a write command to the F/D card. As seen on sheet 3 of the schematics, device U10B, a signal labeled RST6-5 is generated as the SC-1 attempts to write to this card. Such command capability can be used to implement any number of special functions for future application.

In summary the frequency-to-digital converter card, designed, fabricated and tested under this project, is actually a stand-alone 8-bit microprocessor which uses general purpose interval timers/event counters to make a software determined measurement of interval or frequency on four incoming pulse streams. The F/D card continuously measures the interval or frequency on a free-running basis. Data can be delivered from the F/D card to the SC-1 in response to a I/O read from the SC-1 to the physical address of the F/D card in the backplane of the I/O expansion chassis. The card is designed with expansion capability for future applications and uses CMOS logic to minimize power consumption and maximum and maximize noise immunity.

DESCRIPTION OF THE PWM CONTROLLER CARD

A 300 Hz pulse width modulator controller card has been designed and developed under this project for use in the SC-1's expansion chassis. This card is intended to replace an analog subsystem used in an earlier configuration. The basic function of the PWM card is accept a 16-bit binary command from the SC-1 and to convert this command into a pulse width modulated output signal. Because of the fact that a 16-bit wide command word is used for control purposes, the resolution of this card is essentially one part in 65,535.

Seen in Figures D6 through D9, the schematic diagrams for the referenced pulse width modulator controller card, the PWM card uses an array of 8-bit synchronous binary counters to perform the pulse width modulation function. These counters have each 8-bit preload capability. Counters are always used in pairs in order to generate the 16-bit functionality described earlier.

During operation the SC-1 performs an I/O write operation to the physical address of the PWM card in the I/O expansion chassis. As seen in sheet 1 of the referenced schematics, the SC-1 determines which counter is being preset by the value contained on its four least significant address bits. The specified counter pair are then jam-loaded with the 16-bit value. The counters are controlled by the MSI combinatorial logic shown on sheets 4 and 5 of the schematics. A 300 Hz master timer clock pulse is generated by the circuitry shown on sheet 5 and this master clock oscillator is used to control the start of the 3.33 millisecond interval corresponding to the 300 Hz control function. Once the timers have been started by the 300 Hz master oscillator, they will continue counting down until they have reached their preset value at which point the outputs will go back to a zero state. The period time in which the counters are actually counting thus determines the pulse width of the output signal.

In summary, the pulse width modulator cards developed for this project provide the basic functionality of generating four 300 Hz pulse width modulated outputs per card. Absolute accuracy of the timing signals generated by this card are controlled by a crystal clock oscillator seen in the referenced schematic diagrams. The SC-1 is able to preset any of the four 16-bit pulse width modulated controllers under software control. The basic resolution of the this system is one part in 65,535.

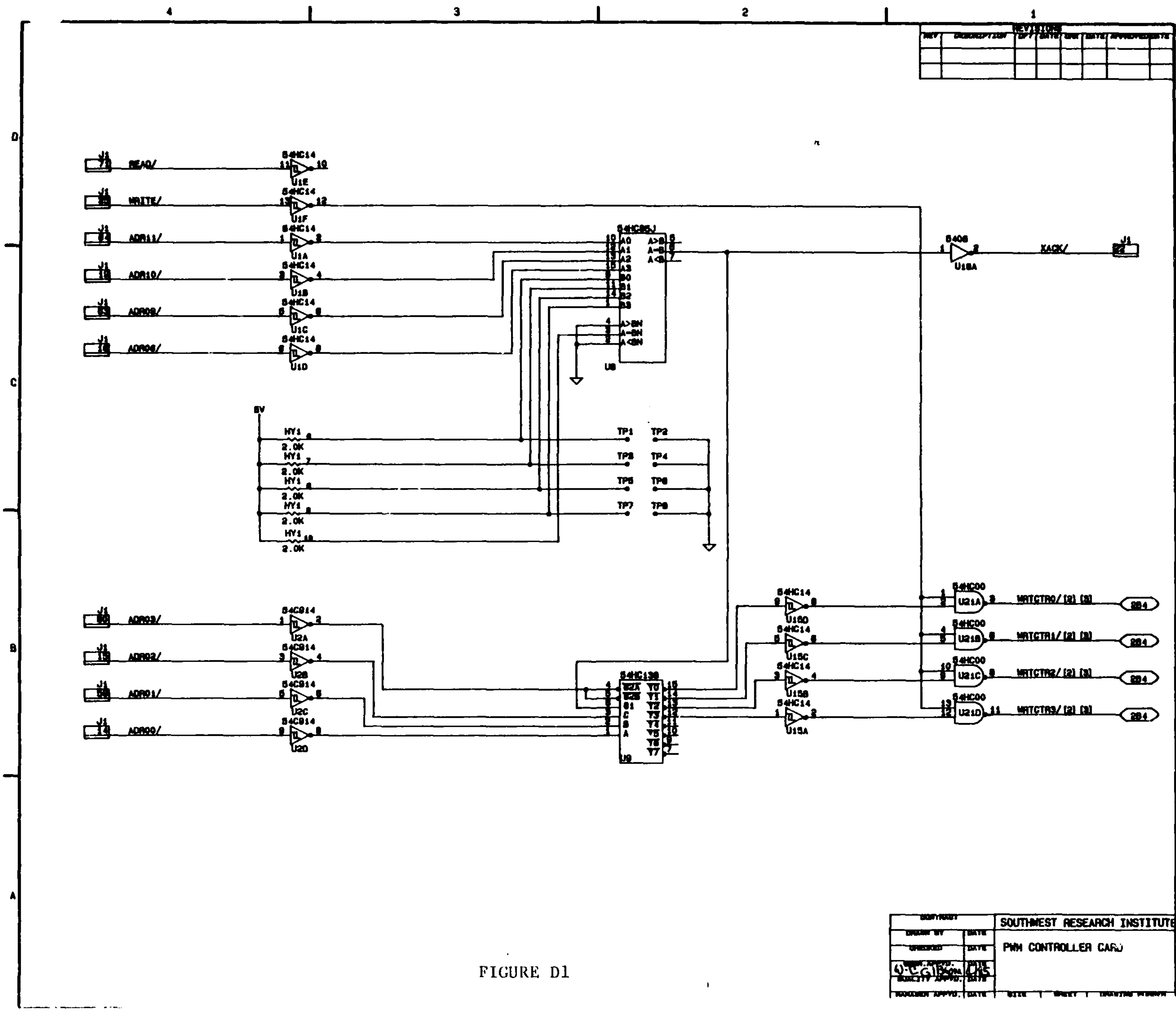

REVISIONS
READ/
WRITE/
ADR11/
ADR10/
ADR09/
ADR08/
54HC14
54HC85J
S406
XACK/
5V
2.0K
TP1
TP2
TP3
TP4
TP5
TP6
TP7
TP8
ADR03/
ADR02/
ADR01/
ADR00/
54C914
54HC138
54HC00
WRTCTR0/ (2) (3)
WRTCTR1/ (2) (3)
WRTCTR2/ (2) (3)
WRTCTR3/ (2) (3)
SOUTHWEST RESEARCH INSTITUTE
PWM CONTROLLER CARD

FIGURE D1

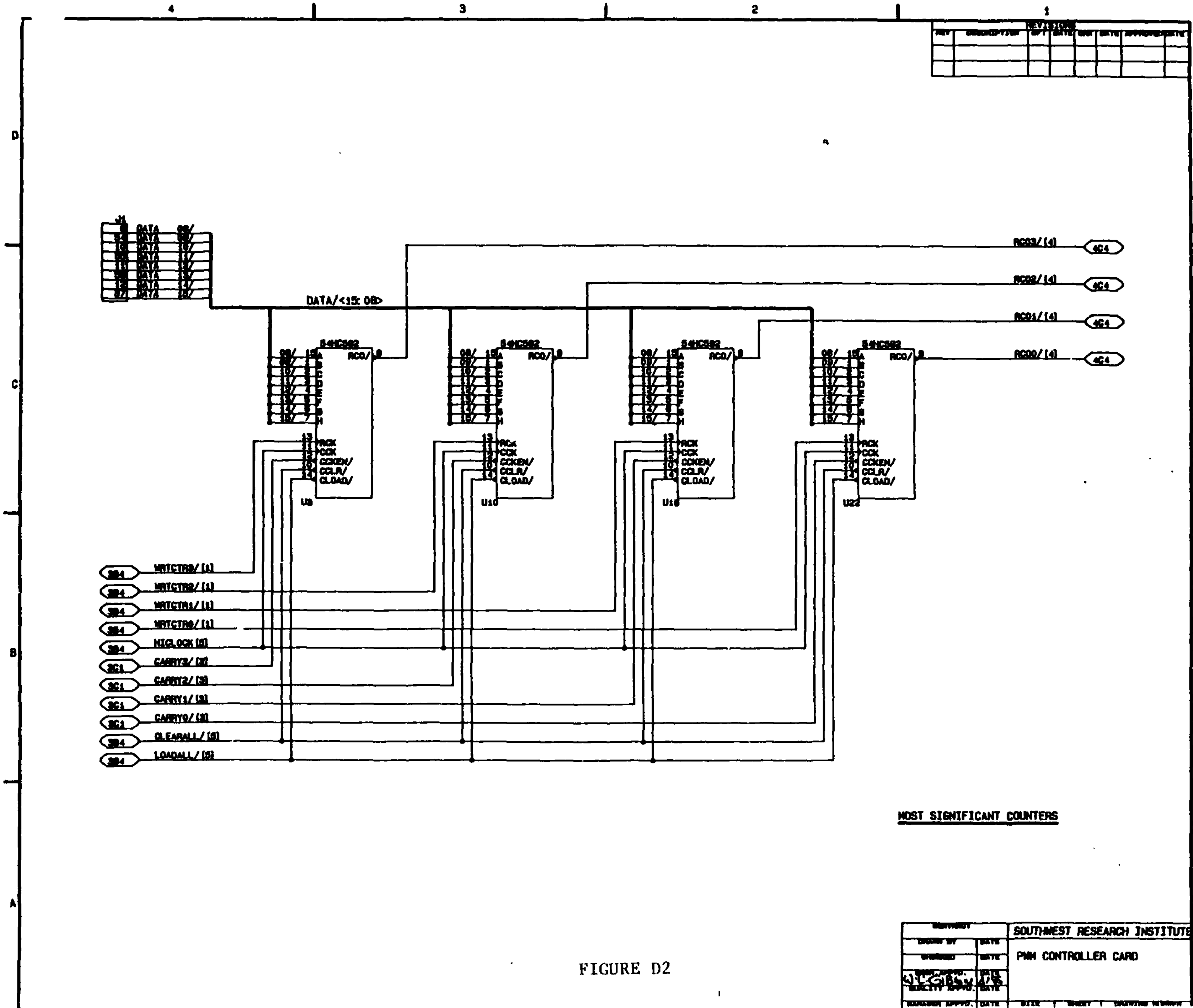
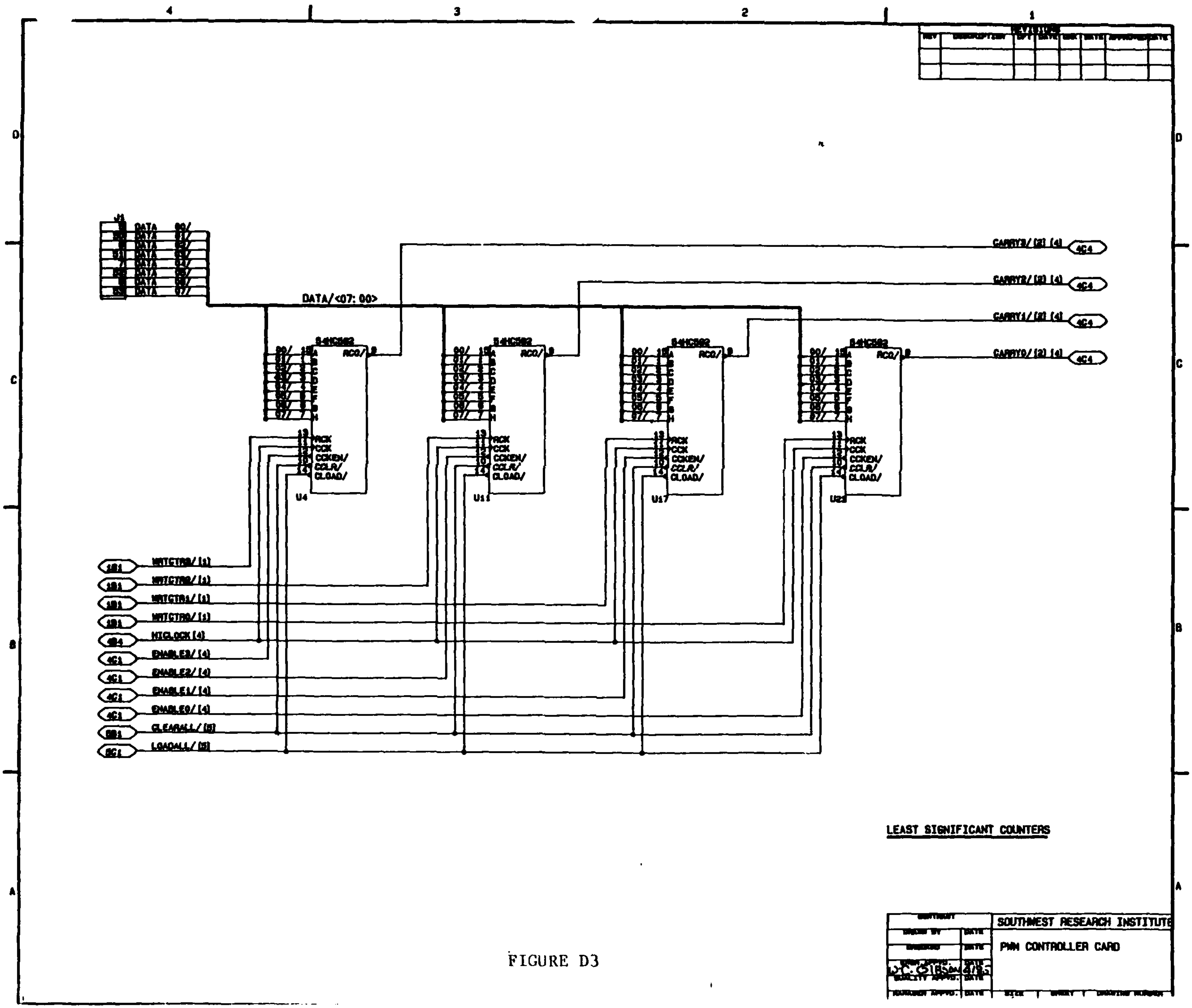

REVISIONS
DATA/<15:08>
54HC592
RCO/
RCK
CCK
CCKEN/
CCLR/
CLOAD/
U9
U10
U16
U22
RCO3/(4)
RCO2/(4)
RCO1/(4)
RCO0/(4)
4C4
WRTCTR3/(1)
WRTCTR2/(1)
WRTCTR1/(1)
WRTCTR0/(1)
HICLOCK(5)
CARRY3/(2)
CARRY2/(3)
CARRY1/(3)
CARRY0/(3)
CLEARALL/(5)
LOADALL/(5)
3B4
3C1
MOST SIGNIFICANT COUNTERS
SOUTHWEST RESEARCH INSTITUTE
PWM CONTROLLER CARD

FIGURE D2



DATA/<07:00>
54HC592
RCO/
RCK
CCK
CCKEN/
CCLR/
CLOAD/
U4
U11
U17
U23
CARRY3/ [2] [4]
CARRY2/ [2] [4]
CARRY1/ [2] [4]
CARRY0/ [2] [4]
WRTCTR3/ [1]
WRTCTR2/ [1]
WRTCTR1/ [1]
WRTCTR0/ [1]
HICLOCK [4]
ENABLE3/ [4]
ENABLE2/ [4]
ENABLE1/ [4]
ENABLE0/ [4]
CLEARALL/ [5]
LOADALL/ [5]
LEAST SIGNIFICANT COUNTERS
SOUTHWEST RESEARCH INSTITUTE
PWM CONTROLLER CARD

FIGURE D3

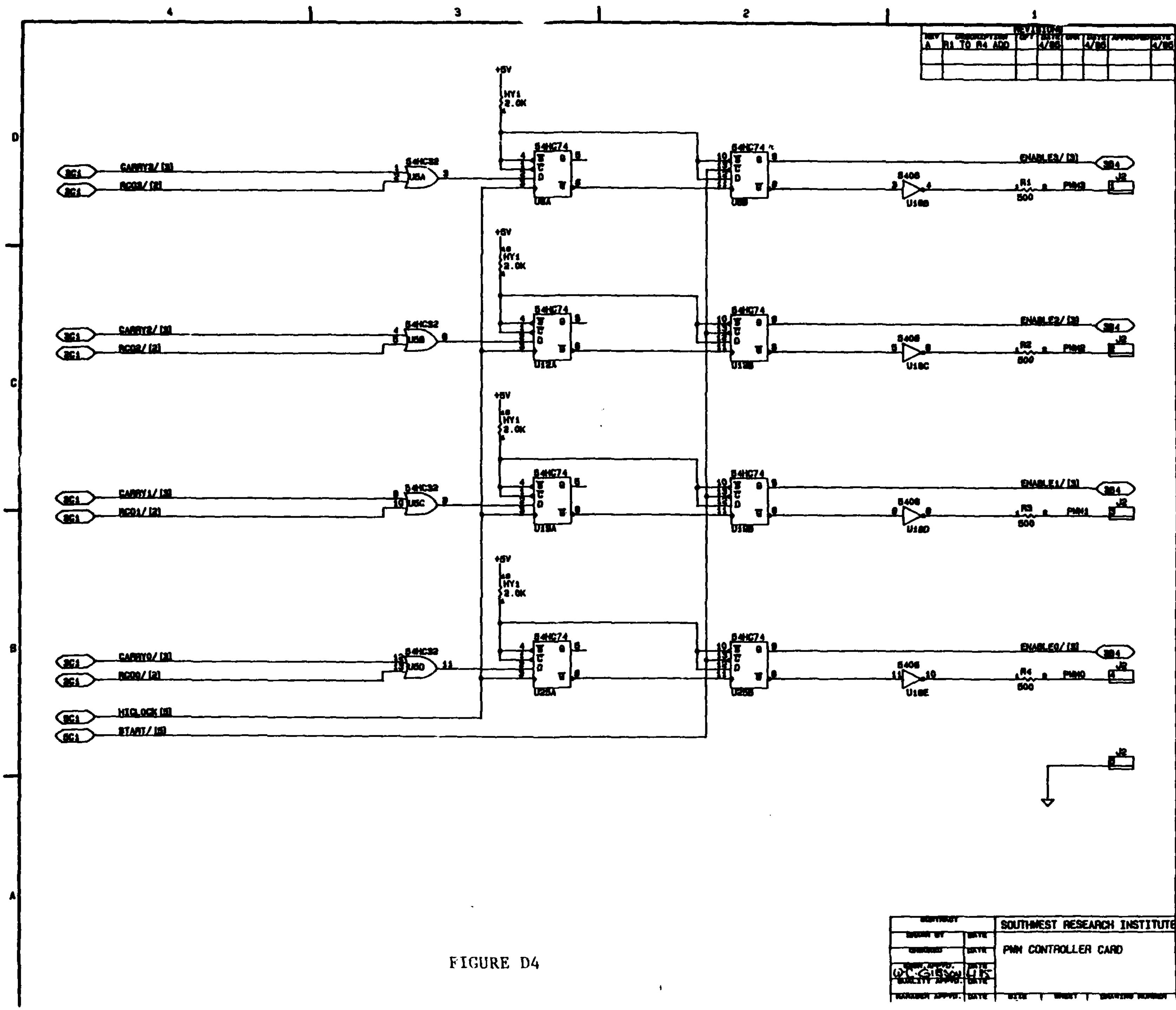
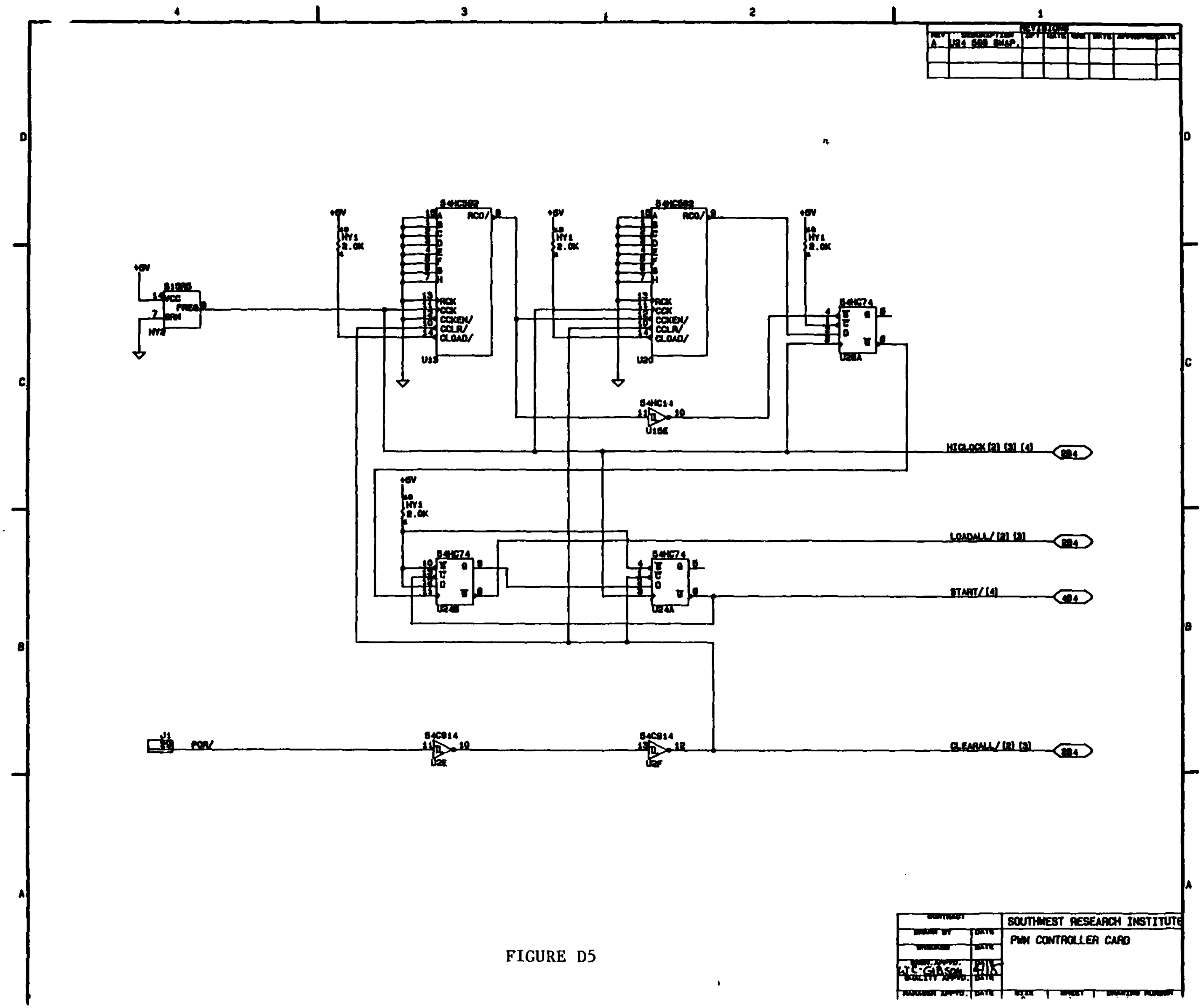
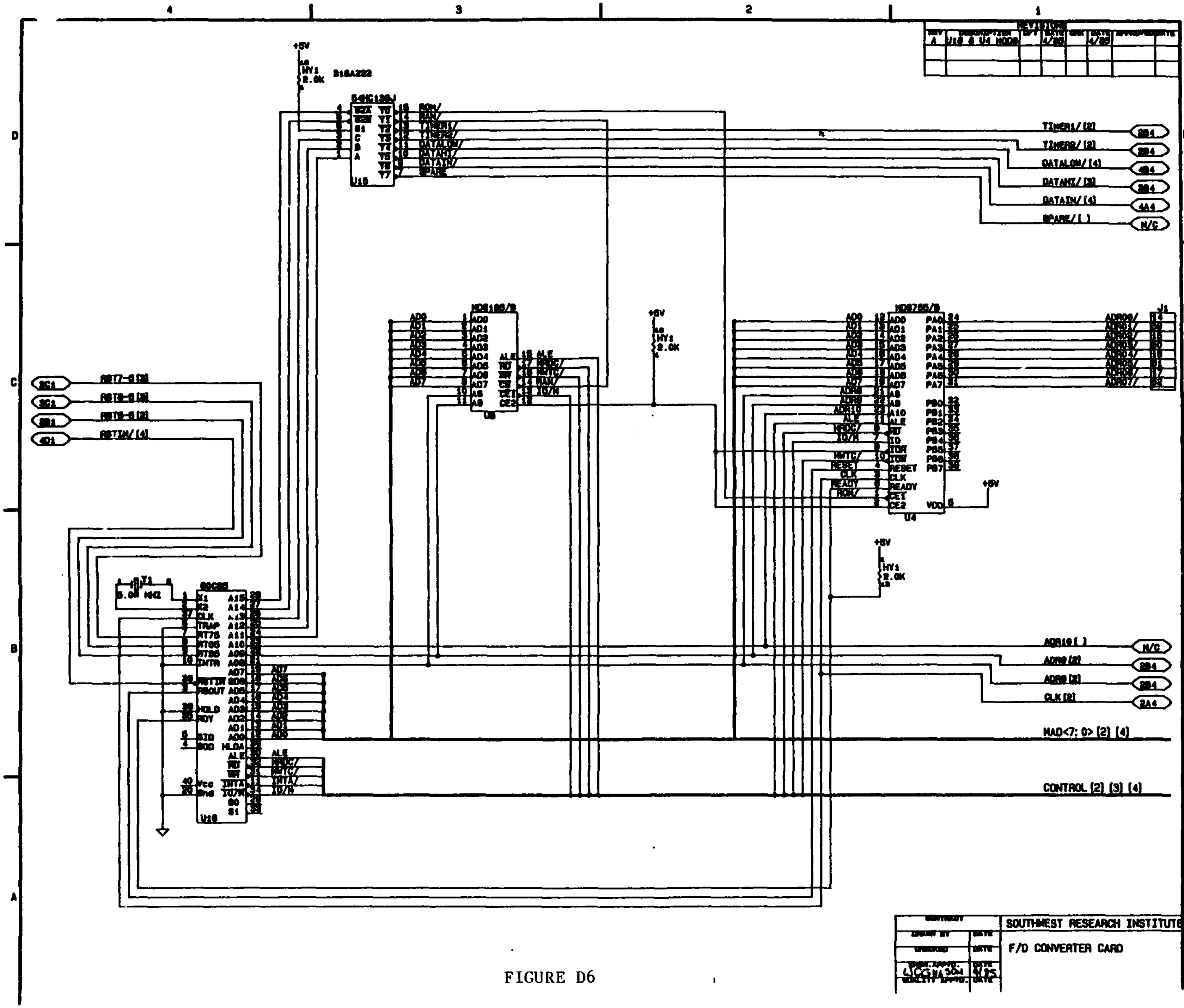

SOUTHWEST RESEARCH INSTITUTE
PWM CONTROLLER CARD
R1 TO R4 ADD
+5V
2.0K
54HC74
54HC32
5406
CARRY3/ [3]
RCO3/ [2]
ENABLE3/ [3]
CARRY2/ [3]
RCO2/ [2]
ENABLE2/ [3]
CARRY1/ [3]
RCO1/ [2]
ENABLE1/ [3]
CARRY0/ [3]
RCO0/ [2]
ENABLE0/ [3]
HICLOCK [3]
START/ [3]
PWM0
PWM1
PWM2
500
R1
R2
R3
R4
J2

FIGURE D4



REVISIONS
REV DESCRIPTION
A U24 SSS SWAP.
54HC592
RCO/
RCK
CCK
CCKEN/
CCLR/
CLOAD/
U13
U20
54HC74
U23A
U24A
U24B
54HC14
U15E
54CS14
U2E
U2F
+5V
HY1
2.2K
FREQ
VCC
GND
HY2
J1
POR/
HICLOCK [2] [3] [4]
LOADALL/ [2] [3]
START/ [4]
CLEARALL/ [2] [3]
SOUTHWEST RESEARCH INSTITUTE
PWM CONTROLLER CARD

FIGURE D5



SOUTHWEST RESEARCH INSTITUTE
F/D CONVERTER CARD
REVISIONS
U16 & U4 MODS
74HC138J
U15
HD8155/8
U8
HD8755/8
U4
80C85
U16
5.0M MHZ
TIMER1/ [2]
TIMER2/ [2]
DATALOW/ [4]
DATAHI/ [3]
DATAIN/ [4]
SPARE/ [ ]
ADR10 [ ]
ADR9 [2]
ADR8 [2]
CLK [2]
MAD<7:0> [2] [4]
CONTROL [2] [3] [4]
RST7-5 [3]
RST6-5 [3]
RST5-5 [2]
RSTIN/ [4]
+5V
2.0K

FIGURE D6

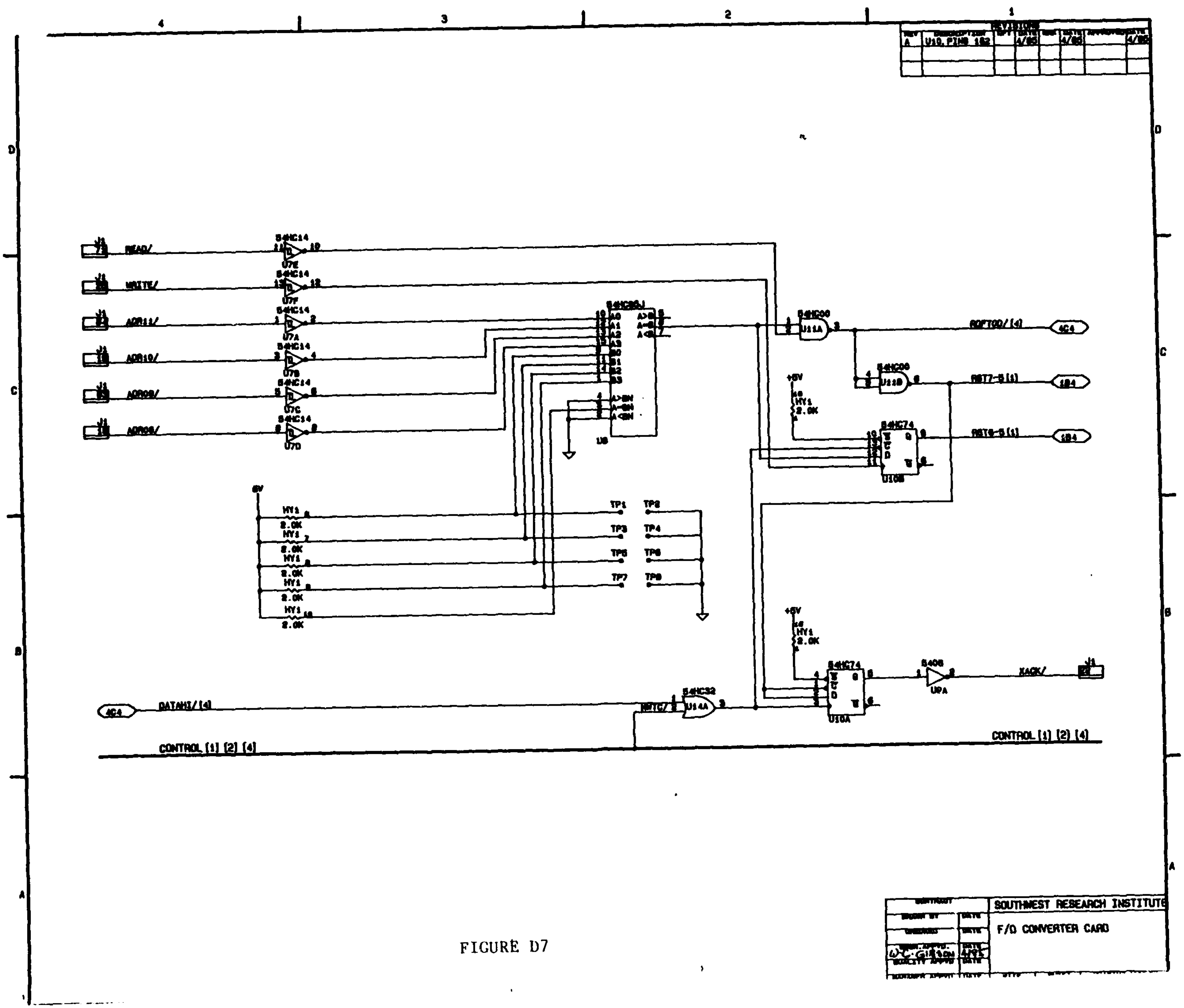
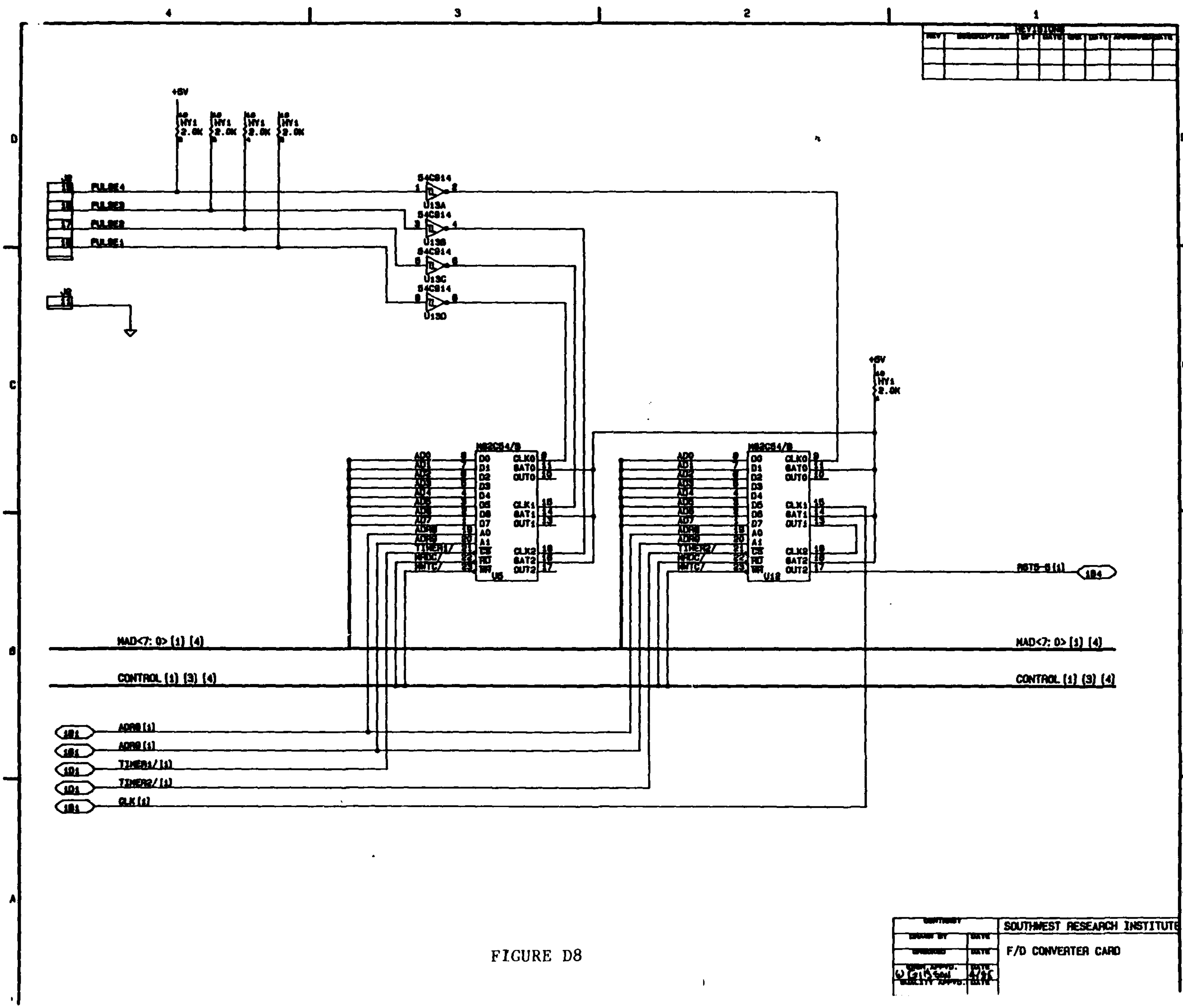
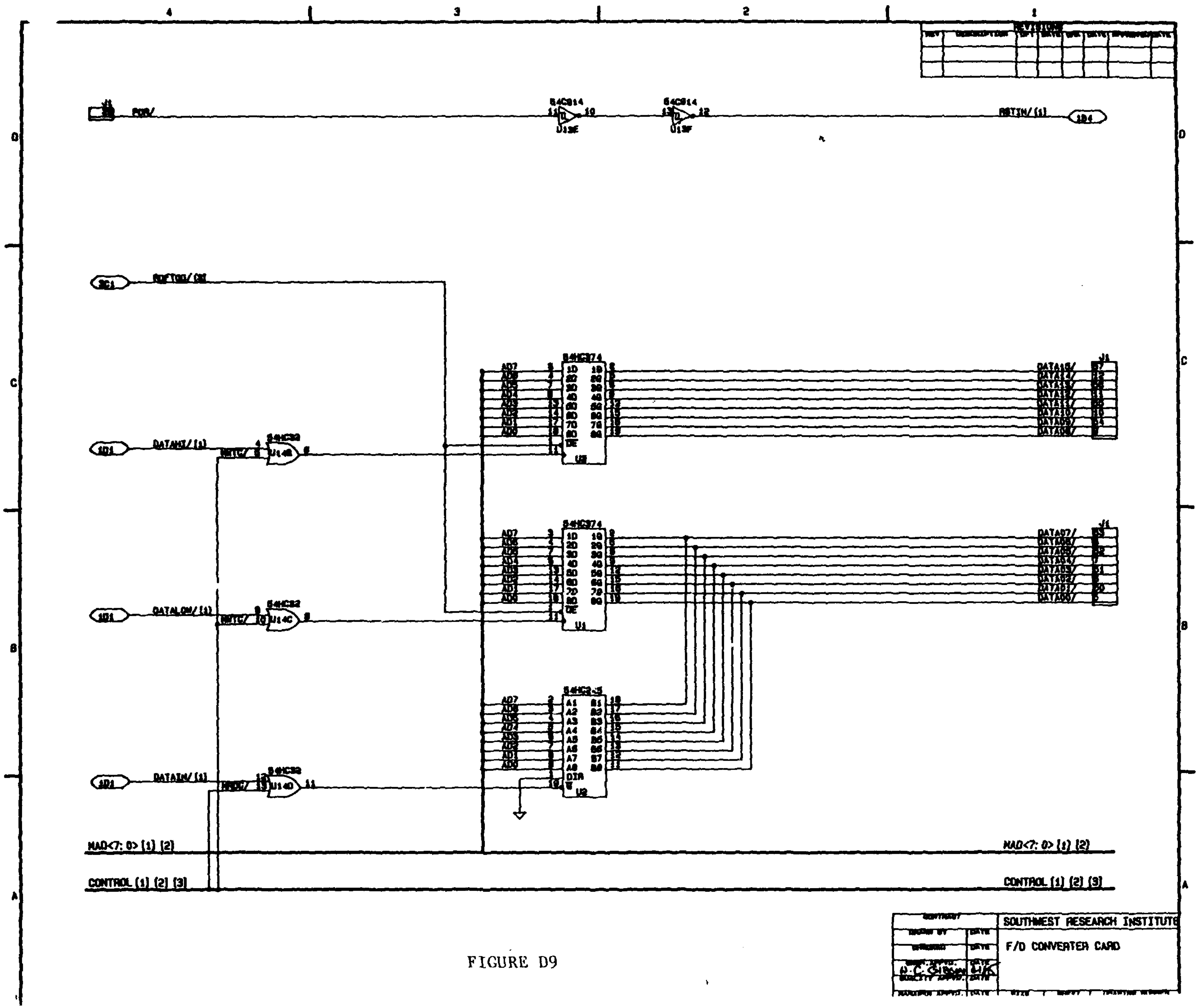

SOUTHWEST RESEARCH INSTITUTE
F/O CONVERTER CARD
READ/
WRITE/
ADR11/
ADR10/
CONTROL [1] [2] [4]
DATAHI/[4]
XACK/

FIGURE D7



+5V
PULSE4
PULSE3
PULSE2
PULSE1
54C914
U13A
U13B
U13C
U13D
U5
U12
MAD<7: 0> (1) (4)
CONTROL (1) (3) (4)
ADR8 (1)
ADR9 (1)
TIMER1/ (1)
TIMER2/ (1)
CLK (1)
CLK0
GAT0
OUT0
CLK1
GAT1
OUT1
CLK2
GAT2
OUT2
REVISIONS
SOUTHWEST RESEARCH INSTITUTE
F/D CONVERTER CARD

FIGURE D8



POR/
54C914
U13E
U13F
RSTIN/(1)
MAD<7: 0> (1) (2)
CONTROL (1) (2) (3)
DATAHI/(1)
DATALOW/(1)
DATAIN/(1)
54HC32
54HC374
U1
U2
U8
SOUTHWEST RESEARCH INSTITUTE
F/D CONVERTER CARD

FIGURE D9

APPENDIX E

HTP Computer Program Listing

Please contact the following for program listing:

Commander, David Taylor Research Center
Code 1240: MAG
Bethesda, MD 20084

APPENDIX F

VARIABLES RECORDED BY MILTOPE RECORDER

Variables recorded by the Miltope recorder.

Channel 10 Longitudinal Acceleration (LONACL)

Voltage - 2.5 volts + 2.5 (volts/gee) * Longit (gees)
Recorded # - 4095 / 5 volts * Voltage on A/D
- 2162 + 2162 * Longit (gees)
-1 gee < Longit < 1 gee

Channel 11 Latteral Acceleration (LATACL)

Voltage - 2.5 volts + 2.5 (volts/gee) * Latter (gees)
Recorded # - 4095 / 5 volts * Voltage on A/D
- 2162 + 2162 * Latter (gees)
-1 gee < Latter < 1 gee

Channel 12 Pitch Inclinometer (PITCHA)

Voltage - 2.5 volts + 0.0556 (volts/degree) * Pitch
Recorded # - 4095 / 5 volts * Voltage on A/D
- 2162 + 46 * Pitch (degrees)
- 45 degrees < Pitch < 45 degrees (bow up)

Channel 13 Roll Inclinometer (ROLLAN)

Voltage - 2.5 volts + 0.833 (volts/degree) * Roll
Recorded # - 4095 / 5 volts * Voltage on A/D
- 2162 + 68 * Roll
- 30 degrees < Roll < 30 degrees (starboard)

Channel 14 Hydraulic Oil Temp (OILTMP)

UNUSED AT THIS TIME

Channel 15 Vertical Acceleration (YAWACL)

Voltage - 2.5 volts + 2.5 (volts/gee) * Yaw (gees)
Recorded # - 4095 / 5 volts * Voltage on A/D
- 2162 + 2162 * Yaw (gees)
-1 gee < Yaw < 1 gee

Channel 16 Load Cell for Towing (LODCEL)

Voltage = 0.00025 (volts/pound) * Force (pounds)
Recorded # = 4095 / 5 volts * Voltage on A/D
= 0.20475 * Force (pounds)
0 pounds < Force < 20,000 pounds

Channel 17 Doppler Radar Vehicle Speed (DOPSPD)

Voltage = 0.10 (volts/mph) * Speed (mph)
Recorded # = 4095 / 5 volts * Voltage on A/D
= 82 * Speed (mph)
0 mph < Speed < 50 mph

Channel 18 Right Track Speed (RTS)

ARSS (rpm) = .7313 (rpm/cps) * ARSS (cps)
V_{ARSS} = ARSS (cps) * (5 volts / 5000 cps)
IARSS = V_{ARSS} * (4095 / 5 volts)
RTS = (IARSS * .59897 rpm/unit) / 17.5 rpm/mph

Channel 19 Left Track Speed (LTS)

ALSS (rpm) = .7313 (rpm/cps) * ALSS (cps)
V_{ALSS} = ALSS (cps) * (5 volts / 5000 cps)
IALSS = V_{ALSS} * (4095 / 5 volts)
LTS = (IALSS * .59897 rpm/unit) / 17.5 rpm/mph

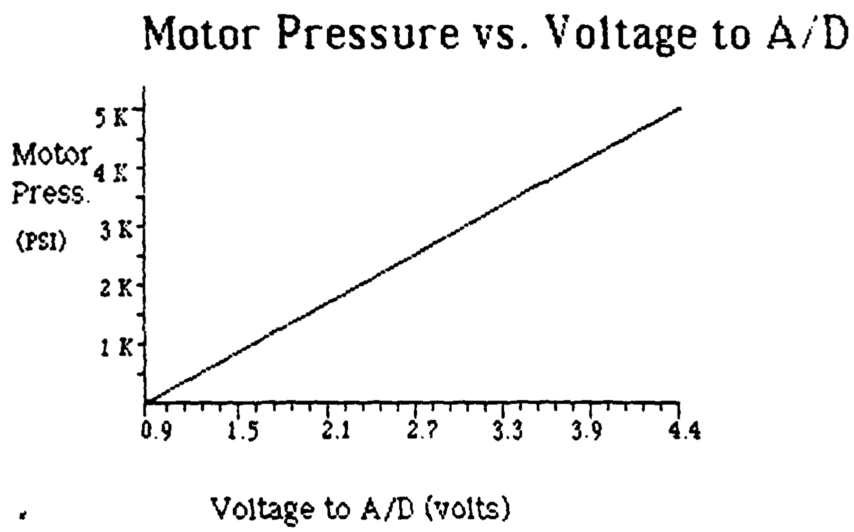
Channel 20 Right Sprocket Torque (RST)

RST = ((RFMP-RRMP)*RMD - 1874.4) / 75.396 * FDGR

Channel 21 Left Sprocket Torque (LST)

LST = ((LFMP-LRMP)*LMD - 1874.4) / 75.396 * FDGR

Channel 22 Right Forward Motor Pressure (RFMP)



Cur_{RFMP} = (16mA)/(5000 psi) * (Actual Motor Pressure) + 4 mA

Through a 226 ohm resistor, this current causes

V_{RFMP} = Cur_{RFMP} * 226 ohms * (1 Amp / 1000 mAmp)

After the A/D converter, the variable stored is

IRFMP = V_{RFMP} * (4095 / 5 Volts)

RFMP = 1.688 * IRFMP - 1249

Channel 23 Left Forward Motor Pressure (LFMP)

LFMP - please see above

Channel 24 Right Reverse Motor Pressure (RRMP)

RRMP - please see above

Channel 25 Left Reverse Motor Pressure (LRMP)

LRMP - please see above

Channel 26 Right Motor Displacement (RMD)

RMD = AES / ARMS * (6.12) * (.95) * (.95)

(* Minimum Motor Displacement *)
IF RMD < 3.37 THEN RMD = 3.37

(* Maximum Motor Displacement *)
IF RMD > 11.36 THEN RMD = 11.36

Channel 27 Left Motor Displacement (LMD)

LMD = AES / ALMS * (6.12) * (.95) * (.95)

(* Minimum Motor Displacement *)
IF LMD < 3.37 THEN LMD = 3.37

(* Maximum Motor Displacement *)
IF LMD > 11.36 THEN LMD = 11.36

Channel 28 Actual Right Motor Speed (ARMS)

ARMS (rpm) = 1.4286 (rpm/cps) * ARMS (cps)
V_{ARMS} = ARMS (cps) * (5 volts / 5000 cps)
IARMS = V_{ARMS} * (4095 / 5 volts)
ARMS = 1.7443 * IARMS

Channel 29 Actual Left Motor Speed (ALMS)

ALMS (rpm) = 1.4286 (rpm/cps) * ALMS (cps)
V_{ALMS} = ALMS (cps) * (5 volts / 5000 cps)
IALMS = V_{ALMS} * (4095 / 5 volts)
ALMS = 1.7443 * IALMS

Channel 30 Right Pump Displacement (RPD)

RPD = ARMS / AES * 11.36 /((.95)*(.95))

(* Maximum Pump Displacement *)
IF RPD > 6.12 THEN RPD = 6.12

Channel 31 Left Pump Displacement (LPD)

LPD = ALMS / AES * 11.36 /((.95)*(.95))

(* Maximum Pump Displacement *)
IF LPD > 6.12 THEN LPD = 6.12

Channel 32 Actual Engine Speed (AES)

AES (rpm) = 0.4762 (rpm/cps) * AES (cps)
V_{AES} = AES (cps) * (5 volts / 10000 cps)
IAES = V_{AES} * (4095 / 5 volts)
AES = IAES * 1.1628

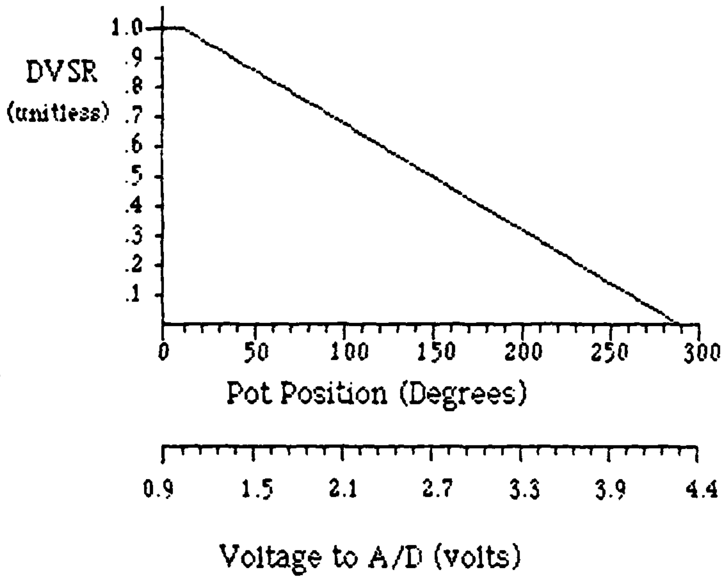
Channel 33 Final Drive Gear Ratio (FDGR)

FDGR = 0, 4100, or 10877

Corresponding to Neutral, Low, and High respectively.

Channel 34 Desired Vehicle Speed Ratio (DVSR)

DVSR vs. Potentiometer Position



The current loop transmitter measures the potentiometer position, 0 degrees displacement corresponds to 4 mAmps while 300 degrees is 20 mA.

$Cur_{DVSR} = (16mA)/(300\ degrees) \times (Pot\ Displacement) + 4\ mA$

Through a 226 ohm resistor, this current causes

$V_{DVSR} = Cur_{DVSR} \times 226\ ohms \times (1\ Amp\ /\ 1000\ mAmp)$

After the A/D converter, the variable stored is

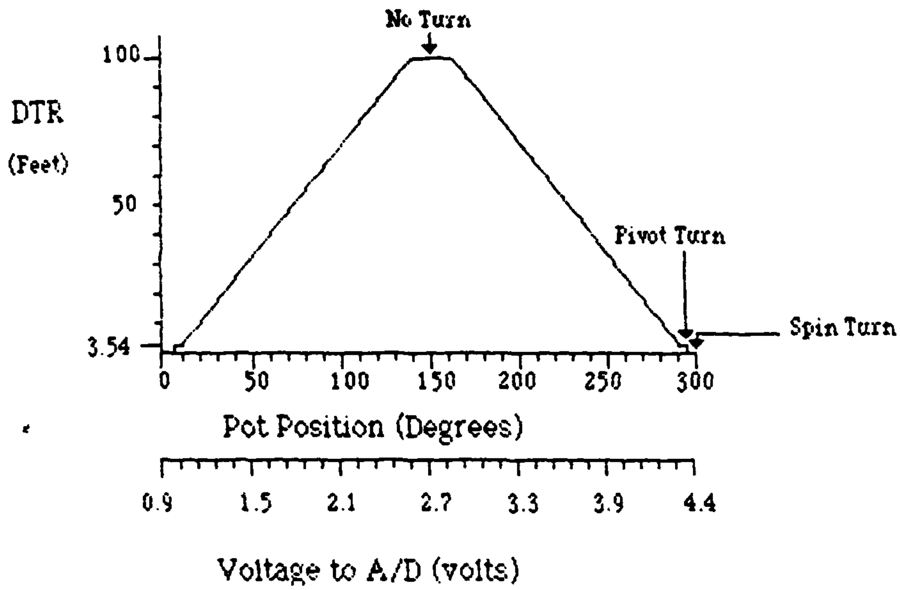
$IDVSR = V_{DVSR} \times (4095\ /\ 5\ Volts)$

$IDVSR = 9.87 \times Pot\ Displacement\ (in\ degrees) + 740$

$$DVSR = 1.2765 - IDVSR \times .0003591$$

Channel 35 Desired Turn Radius (DTR)

DTR vs. Potentiometer Position



The current loop transmitter measures the potentiometer position, 0 degrees displacement corresponds to 4 mAmps while 300 degrees is 20 mA.

Cur_{DTR} = (16mA)/(300 degrees) * (Pot Displacement) + 4 mA

Through a 226 ohm resistor, this current causes

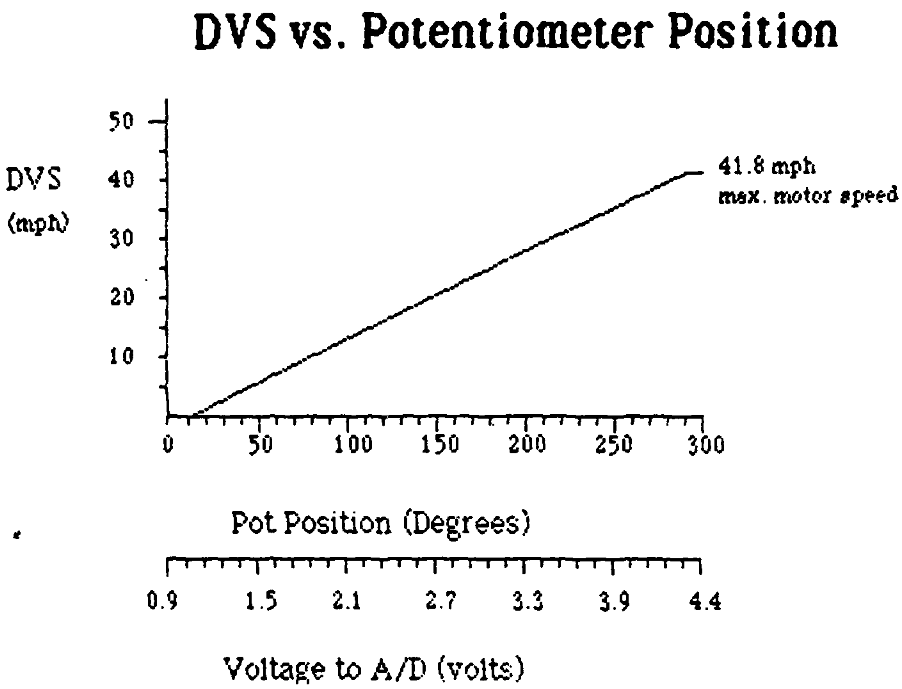
V_{DTR} = Cur_{DTR} * 226 ohms * (1 Amp / 1000 mAmp)

After the A/D converter, the variable stored is

IDTR = V_{DTR} * (4095 / 5 Volts)

IDTR = 9.87 * Pot Displacement (in degrees) + 740

Channel 36 Desired Vehicle Speed (DVS)



The current loop transmitter measures the potentiometer position, 0 degrees displacement corresponds to 4 mAmps while 300 degrees is 20 mA.

Cur_{DVS} = (16mA)/(300 degrees) * (Pot Displacement) + 4 mA

Through a 226 ohm resistor, this current causes

V_{DVS} = Cur_{DVS} * 226 ohms * (1 Amp / 1000 mAmp)

After the A/D converter, the variable stored is

IDVS = V_{DVS} * (4095 / 5 Volts)

IDVS = 9.87 * Pot Displacement (in degrees) + 740

DVS = IDVS * .015 - 11.56

note: The maximum value for DVS is scaled from 41.8 mph to 15.8 mph in low gear.

Channel 37 Desired Right Brake Pressure (DRBP)

```
BPS = -20 * DTR + 2000              (* Brake Pressure for Steering *)
BPB = (1-DVSR)*(1500psi - BPS)      (* Brake Pressure for Braking *)
HBP = BPS + BPB                     (* High Brake Pressure *)
LBP = BPB                           (* Low Brake Pressure *)

IF (DTD = RIGHT)     THEN
                 DRBP = HBP
                     ELSE
                 DRBP = LBP
                     END IF
```

Channel 38 Desired Left Brake Pressure (DLBP)

```
BPS = -20 * DTR + 2000              (* Brake Pressure for Steering *)
BPB = (1-DVSR)*(1500psi - BPS)      (* Brake Pressure for Braking *)
HBP = BPS + BPB                     (* High Brake Pressure *)
LBP = BPB                           (* Low Brake Pressure *)

IF (DTD = RIGHT)     THEN
                 DLBP = HBP
                     ELSE
                 DLBP = LBP
                     END IF
```

Channel 39 Total Required Engine Power (TREP)

$$TREP = EPLM + EPRM + .000006 * AES^2 - .00077 * AES$$

Channel 40 Right Motor Power (RMP)

$$RMP = RST * DRMS$$

Channel 41 Engine Power for Right Motor (EPRM)

$$\begin{aligned} EPRM &= RMP / RTE \\ &= RMP / SQRT(SQRT(RMP/249)) \end{aligned}$$

Channel 42 Left Motor Power (LMP)

$$LMP = LST * DLMS$$

Channel 43 Engine Power for Left Motor (EPLM)

$$\begin{aligned} EPLM &= LMP / LTE \\ &= LMP / SQRT(SQRT(LMP/249)) \end{aligned}$$

Channel 44 Desired Engine Speed (DES)

$$\begin{aligned} DES = {} & 1100 + .3666 * HighMotorSpeed + 8.5 * TREP - \\ & .00185 * TREP * HighMotorSpeed \end{aligned}$$