DEVELOPMENT OF A 55kW DIESEL POWERED AUXILIARY POWER UNIT FOR HYBRID ELECTRIC VEHICLES

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TFLRF No. 328

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13. ABSTRACT (Maximum 200 words)

Three auxiliary power units (APU) were developed for military hybrid vehicle applications with funding from DARPA. One APU was for the electric M113 troop carrier originally converted to electric power in the 1960's. The other two APU's developed during this project were for hybrid electric High Mobility Multipurpose Wheeled Vehicle (HMMWV) projects. For this APU design a Volkswagen 1.5-l diesel engine drives a permanent magnet generator, that with associated inverter produces 55 kW of DC power at 380 volts. Overall thermal efficiencies of 33 % were observed.

The controller for the APU's was based on the personal computer (PC) CPU. Basing the controller on the PC allowed flexibility in meeting the individual requirements of the different vehicles. Given a power level request from the vehicle controller, the APU controller set the engine speed for optimum thermal efficiency. The generator electronics adjusts the voltage and thus the current output from the inverter to deliver the requested power to the vehicle's electrical bus.

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EXECUTIVE SUMMARY

The initial purpose of this project was to develop an Auxiliary Power Unit (APU) for use in a High Mobility Multi-purpose Wheeled Vehicle (HMMWV) that was being converted to a hybrid electric configuration. Later, the project scope was increased to add an APU for another electric HMMWV and another APU for a hybrid electric M113 Troop Carrier. The project involved selecting the engine and generator, developing the APU control system, and testing the completed APU. The project was divided into four phases: (1) selection of engine and generator, (2) design and construction of the APU, (3) APU control system development, and (4) APU testing.

The first phase involved reviewing the specifications of each vehicle integrator to select an appropriate engine and generator that would meet the size, weight, and power requirements and be able to operate underwater. The engine chosen, the new Volkswagen 1.9L, turbo-charged, direct injected diesel, is a state-of-the-art, high-efficiency, low emissions design. The generator selected is a permanent magnet alternator with inverter electronics to provide the requested power at the prevailing bus voltage. This electric machine is a state-of-the-art design with an overall efficiency in excess of 94 percent at most operating conditions.

The second phase involved the design and construction of the three APUs. Design of the APUs was a joint effort with SwRI and McKee Engineering. In order to fit the APU into the space available under the hood of the HMMWV, it was necessary to turn the engine on its side. Lubrication by means of the stock oil sump would no longer be functional, therefore the engine was modified to a dry sump configuration. McKee Engineering was selected for this task because of their extensive experience doing this engine modification.

The third phase of the project involved designing and developing an APU controller. The controller receives a power request from the vehicle and provides engine and generator management to meet the requested power. The APU controller was based on a personal computer (PC) platform. In order to meet the differing requirements of the M113 and the HMMWV vehicle projects, individual software programs were developed for each vehicle.

The fourth phase of the project consisted of the debugging and performance testing of the APU in the laboratory. During this testing, the output of the generator was absorbed by a battery pack and a resistive load bank that simulated the vehicle power bus. Documentation of the complete control system was prepared to assist the vehicle integrators.

FOREWARD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI), San San Antonio, TX performed this work, under contract no. DAAK70-92-C-0059. Work was funded by the Defense Advanced Research Projects Agency (DARPA) with Mr. R. Rosenfeld (DARPA) and Mr. T. Bagwell (TARDEC) serving as technical monitors, and Mr. L. Villahermosa (TARDEC) serving as the contracting officer's representative.

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1.0 BACKGROUND

1.1 Technical Background

Three hybrid vehicle auxiliary power units (APU) for hybrid vehicle applications were developed with DARPA funding at Southwest Research Institute (SwRI) for use in military vehicles. One APU design was for the electric M113 Troop Carrier. This vehicle is an electric conversion of the diesel-powered production M113. The conversion was completed in the 1960's. The installation of the SwRI APU was an upgrade funded by the Defense Advanced Research Projects Agency (DARPA). The other two APUs are for hybrid electric High Mobility Multipurpose Wheeled Vehicle (HMMWV) projects.

1.1.1 Engine

At the start of the APU development project, only one APU was to be delivered. The APU was for a HMMWV being converted to a hybrid by Pentastar Electronics Corporation. Pentastar's APU requirement became the basis for the initial APU design. Later in the project the second APU request, again for a HMMWV, required changes in the mechanical design. Requirements for the third APU for the M113 troop carrier were much different from the HMMWV, requiring a different engine/generator layout and APU controller hardware and software.

All three APUs used the Volkswagen 1.9L, direct injected, turbocharged, intercooled, four-cylinder engine. This is a modern-design diesel engine selected for its high efficiency, good power-to-weight ratio, quiet operation, and ability to maintain power with altitude. The engine also produces low emissions, although this was not a requirement for the current application. The engine was modified with a dry sump lubrication system, which allowed it to be mounted in the vehicle on its side. The lower height permitted the APU to be located between the battery pack and the hood of the HMMWV. The dry sump system also insured proper engine lubrication over the vehicle's extreme grade and slope operating range.

1.1.2 Generator

All three APUs used a Unique Mobility SR218H Brushless DC motor, normally used as a vehicle drive motor. For this application, the motor was operated in the regenerative braking mode. The motor controller effectively served as a boost rectifier to elevate the generator's output voltage to deliver the requested power to the vehicle bus. The generator also served as the engine starter under the SwRI APU controller. The APUs did not require the stock 12-volt starter motor, which resulted in a weight and space claim reduction.

1.1.3 Controller

The controller for the APUs is based on a personal computer (PC) CPU. Basing the controller on the PC allowed flexibility in meeting the requirements of the different vehicles. For example, the M113 controller used discrete digital and analog lines for communication with the M113 vehicle controller. The HMMWV APU employed RS232 serial data link to communicate a list of commands and status information. Different software environments were also required to meet the vehicle's communication requirements.

Given a power request from the vehicle controller, the APU controller set the engine speed for optimum thermal efficiency. The generator power electronics adjusted the voltage and current output from the generator to deliver the developed power to the vehicle's electrical bus.

2.0 TECHNICAL DISCUSSION

2.1 APU Design and Development

The developmental process of the APUs consisted of the following components: design discussions with Pentastar and McKee about fitting the APU into the hybrid HMMWV; converting the engine to the dry sump lubrication system; mating the engine to the generator; providing mounting points for the engine and generator assembly; providing adequate heat exchangers to cool the engine and generator; designing and constructing the APU controller hardware; adapting existing SwRI software code for the APU controller; and testing of the APU in the laboratory. The details of the APU development are described in this section. Figure 1 and 2 show the HMMWV APU and the M113 APU, respectively. The engine was mounted in the normal orientation for the M113 application.

2.1.1 Engine Selection

The APU specifications, as given by Pentastar, provided the criteria for the engine selection. The requirement for diesel or JP-8 operation (55 kW electrical output, high power density, quiet and efficient operation) led to the selection of a turbo-charged, direct injected, water cooled diesel engine. Other prime mover types such as diesel rotary engines (RPI), fuel cells or gas turbines (Alturdyne) were not available as off-the-shelf items. Development of these different prime mover types was beyond the scope of this project.

Power Systems Research (PSR) conducted a survey of their database of available engines (provided in the appendix). The survey did not include the new Volkswagen turbo-charged, intercooled, 1.9L engine, which was not available at the time of the survey. The Volkswagen engine had the lightest weight of any engine in the upper-60 kilowatts of power output. Also, the double fuel injection scheme reduced the noise and improved the efficiency. The engine specifications are given in the appendix.

2.1.2 Generator Selection

The following manufacturers of permanent magnet motors and generators were contacted with the request for a 55 kW continuous output generator: Onan, Kaman, Fisher Electric Motor, Unique Mobility (UQM), and Overland Technology. Onan and Kaman did not have a suitable unit. The Fisher design would have involved the development of a boost rectifier. SuperPower was contacted for an estimate to develop the boost rectifier. The total Fisher/Kaman system was heavier and more costly than the UQM system (an off-the-shelf item) with some modifications. The UQM system could also serve as the engine starter. A design from Overland Technology, which consisted of an

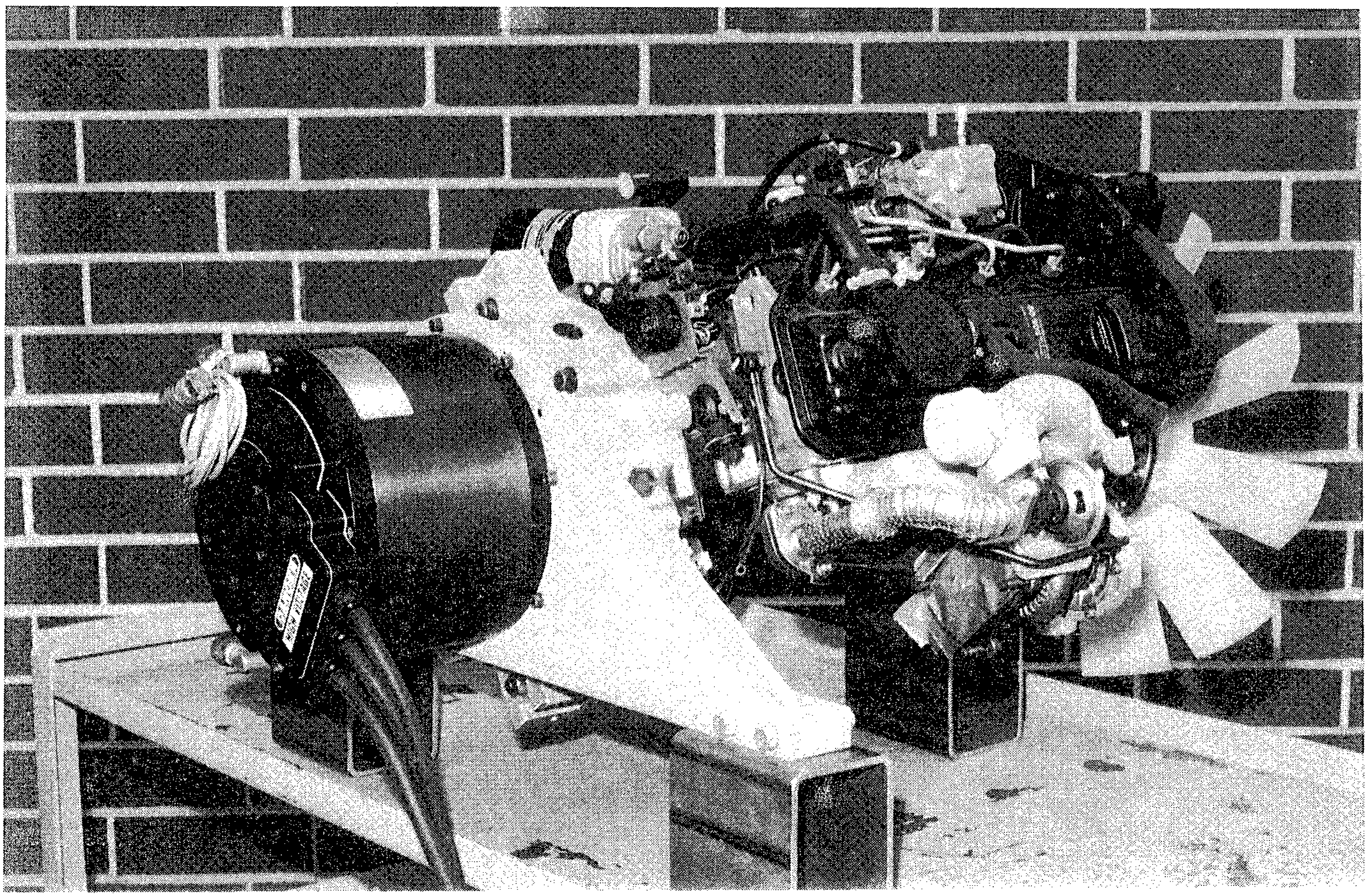


Figure 1. HMMWV APU

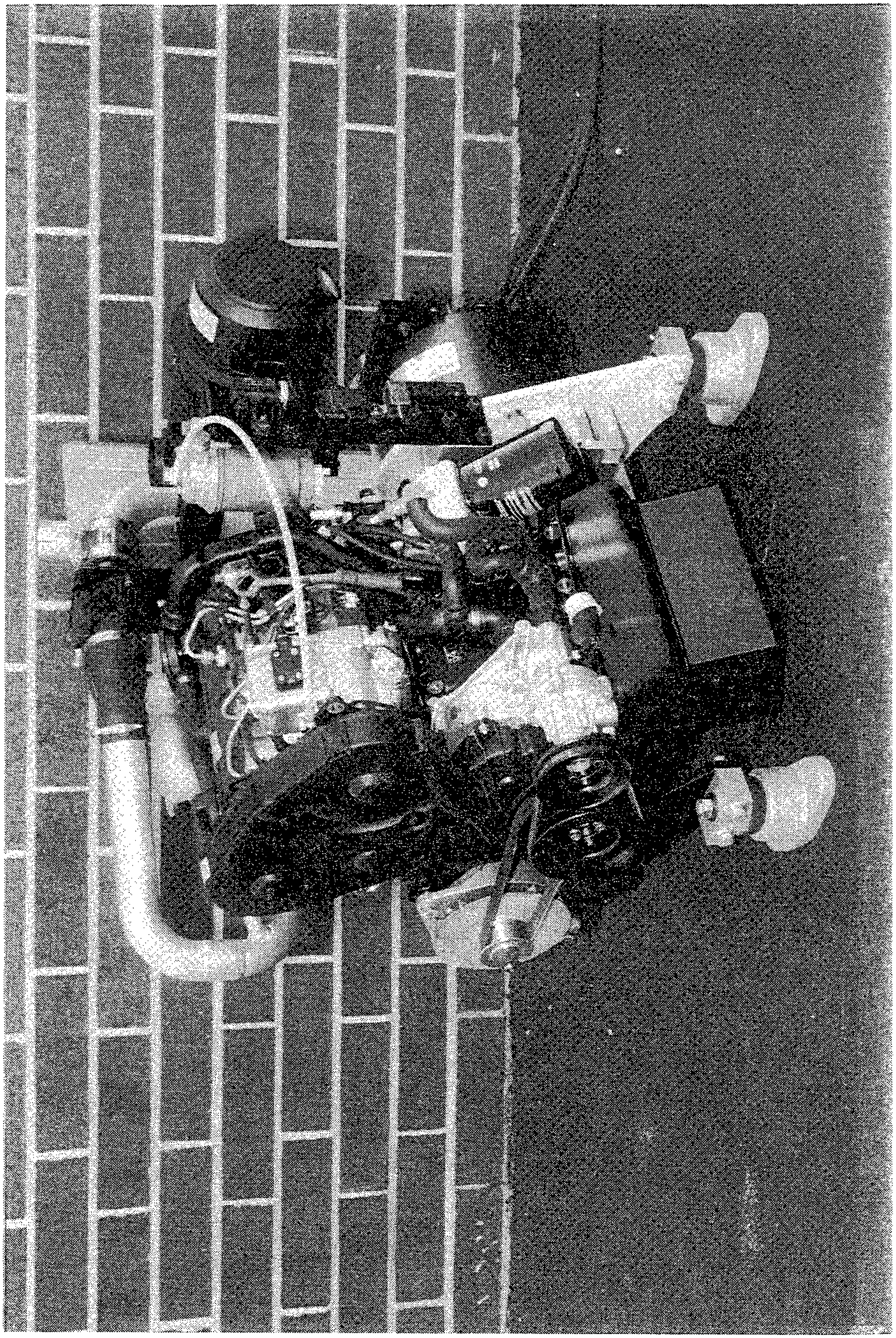


Figure 2. M113 APU

eight-disk generator, (the output from each disc would be switched between parallel and series in order to stepwise vary the output voltage as required) was also considered. However, it would have been necessary to develop the controller for switching the windings. The UQM Model 218H was selected because it did not require a development effort for the power controller.

2.1.3 Generator to Engine Coupling

The generator-to-engine coupling design and fabrication was tasked to McKee Engineering. Discussions with Pentastar and McKee concluded that the adapter plate at the engine generator interface would also serve as the rear mounting points for the APU. Since the Pentastar HMMWV was located at the McKee facility, the design of the APU mounting was conducted there.

The original coupling supplied by McKee utilized a hard nylon disc as the coupling material. The coupling was a KTR-BoWex model FLE-48-T. During APU testing, a torsional resonance was discovered at 2200 RPM. This resonance fatally overloaded the nylon sline teeth of the coupling. Figure 3 is a photograph of the fractured nylon slines after an hour of operation. McKee redesigned the coupling by replacing the nylon disc with an all-steel disc. SwRI performed a torsional analysis of the new design that predicted the second order critical speed to be 4200 rpm, which was below the 4000 rpm maximum operating speed of the engine. During testing, torsional vibrations were apparent at 1400 rpm and 2100 rpm, which corresponded to the fourth and sixth order excitations of the coupling system. However, it was decided that the vibrations were not severe enough to prohibit further debugging of the APU controller. Debugging of the APU controller continued with the hard steel disc, avoiding the resonant conditions, while SwRI redesigned the coupling.

The final coupling was a KTR BoWex design (model 48 HE with a Shore 50 elastomer) utilizing a compliant elastomer. The coupling is shown in Figure 4. McKee originally considered using this coupling with the stiffer Shore 60 elastomer, but discarded the design because KTR predicted a torsional vibration in the operating speed range. SwRI determined that by going to a more compliant elastomer and raising the idle setpoint to 1000 rpm, the resonance would drop below the operation range of the engine.

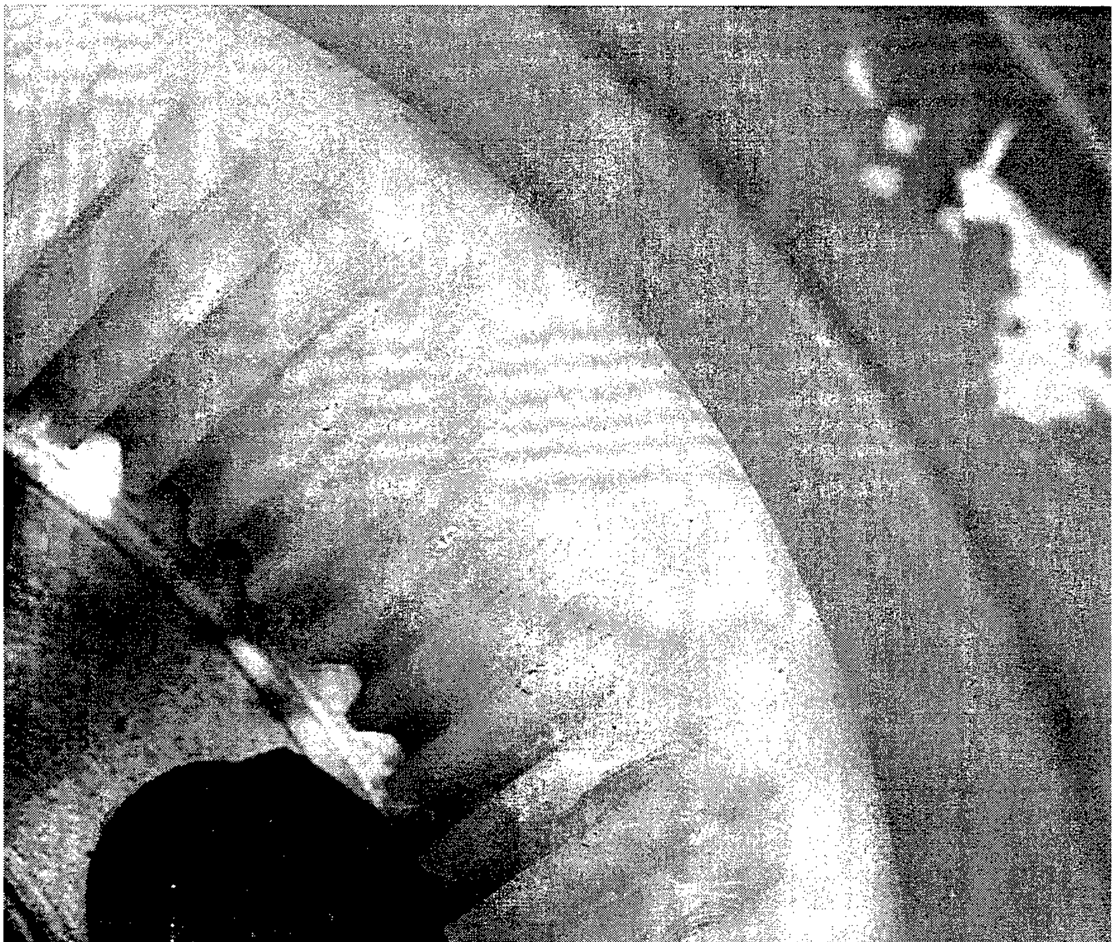


Figure 3. Fractured nylon slines after an hour of operation.

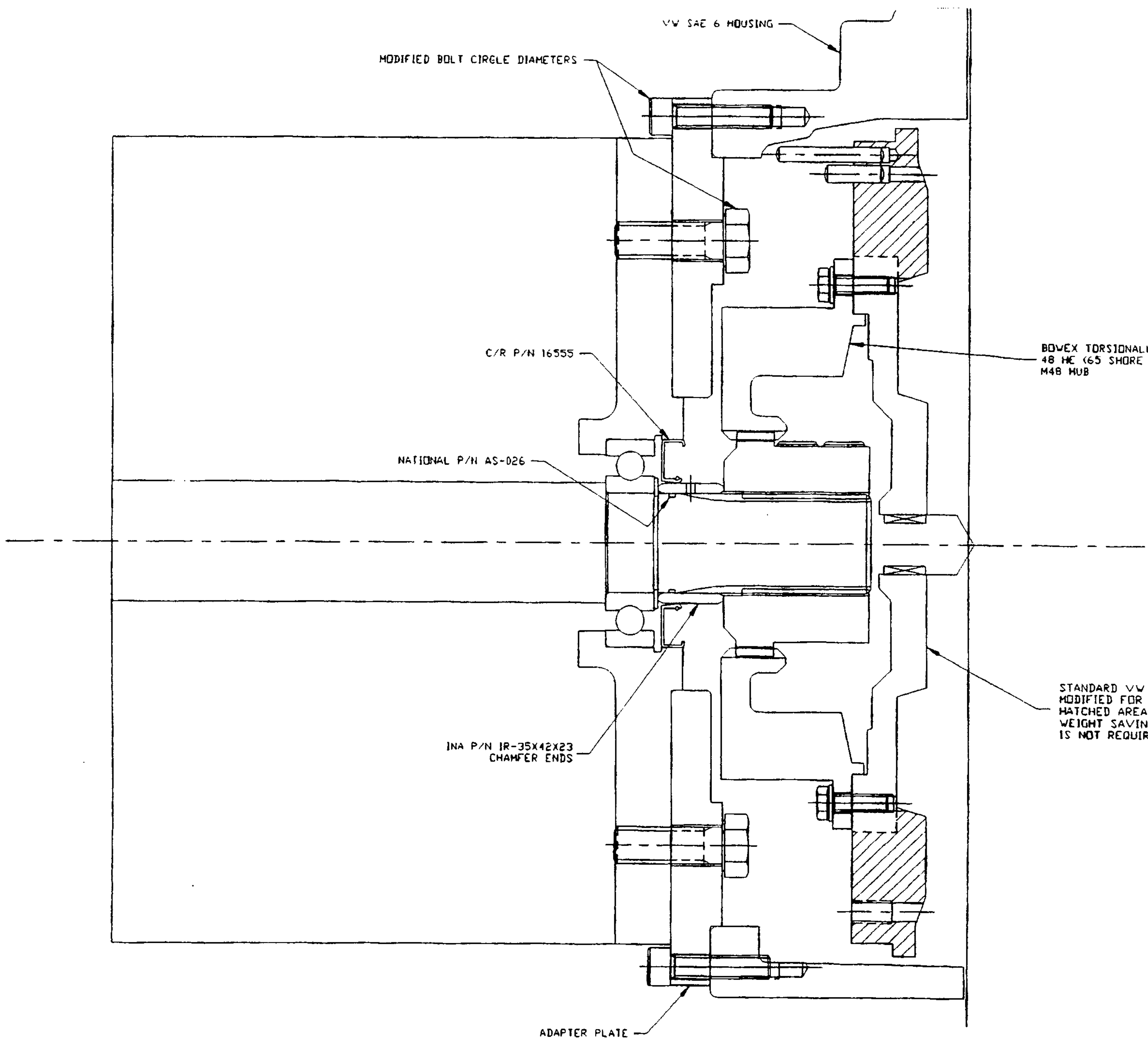


Figure 4. Final Engine-to-Generator Coupling

2.1.4 Engine Dry Sump Lubrication System

During the initial design discussions with Pentastar and McKee it was decided to lay the engine on its side, which involved lowering the height of the APU, allowing it to be mounted in the space available in the HMMWV. Because the oil sump was no longer located at the lowest point, a dry sump lubrication system was required. This change produced the following advantages: an increase in the oil capacity of the engine; reduced engine friction losses; and the ability of the engine to meet the wide range of operating angles of the HMMWV.

Using the assembled engine generator with cardboard mockups of the UQM drive motors, and later the Kaman drive motor in the case of the CTC APU, McKee determined that the best location for the scavenge pumps, which are belt driven, to be the front of the engine. The system is shown in Figure 5. A toothed belt drives two Bertel pumps on the front of the engine. These pumps draw oil from the lowest points on the engine and return it to an external reservoir. An oil-air separator is located at the inlet of the reservoir, and the air is directed to the vent system. The stock engine oil pump draws oil from this reservoir and pressurizes the oil galleries in the normal manner.

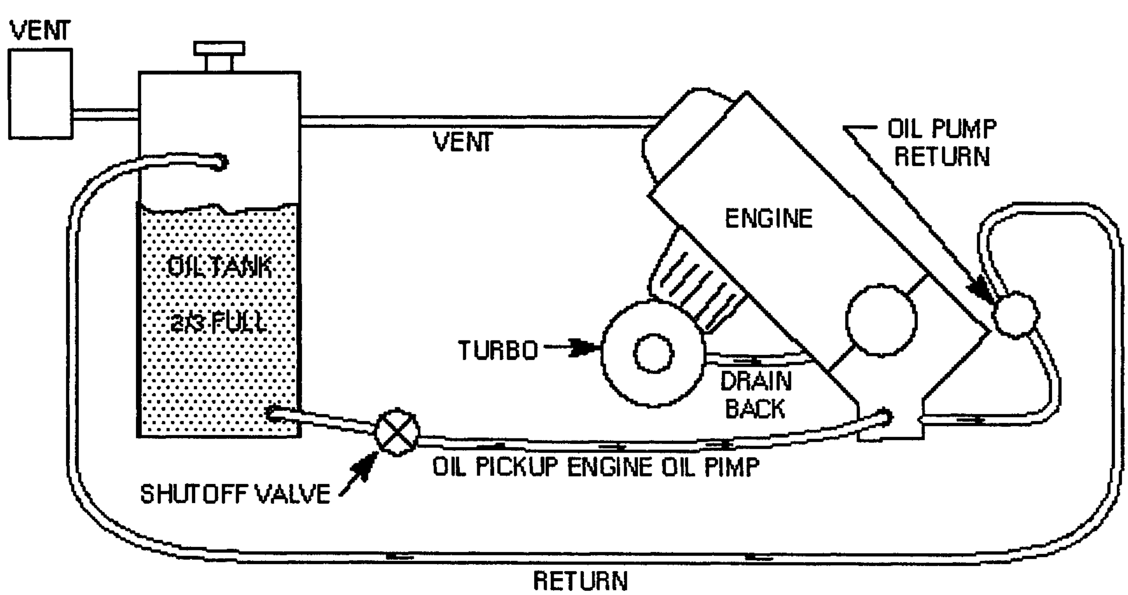


Figure 5. Dry Sump Lubrication System

2.1.5 Engine and Generator Cooling

Three heat exchangers were required for the APU, with each mounted behind the other in front of the engine, as illustrated in Figure 6. The first heat exchanger (from the front) was for the electronics cooling loop. This was an aluminum radiator, the core dimensions being 3-1/2" thick x 13" high x 24" wide. The stock Volkswagen intercooler was mounted behind the electronics heat exchanger. Behind the intercooler, an aluminum core radiator was mounted which measured 3-1/2" thick x 15" high x 24" wide. A 50/50 water/antifreeze mixture was used in both liquid cooling loops. A pump in the electronics loop recirculated the coolant at 5 gallons per minute. A shroud was constructed around the three heat exchangers and the engine-driven cooling fan.

2.2 APU Control System Development

An APU control system was developed to provide control of the engine operating point. SwRI designed and constructed a PC-based APU control system to accomplish this function. The SwRI controller design was based on its Rapid Prototyping Electronic Control System (RPECS) platform. The RPECS is a highly flexible, PC-based prototyping tool used for real-time control in a variety of applications, such as engine and power-train control and test-cell control.

2.2.1 Control Functions

The SwRI APU controller was designed to provide numerous control functions as related to the APU components. Fundamentally, the APU controller provided control of the APU operating point through manipulation of the throttle and control of the generator output via the voltage boost unit. The APU controller was also responsible for the engine start and stop functions.

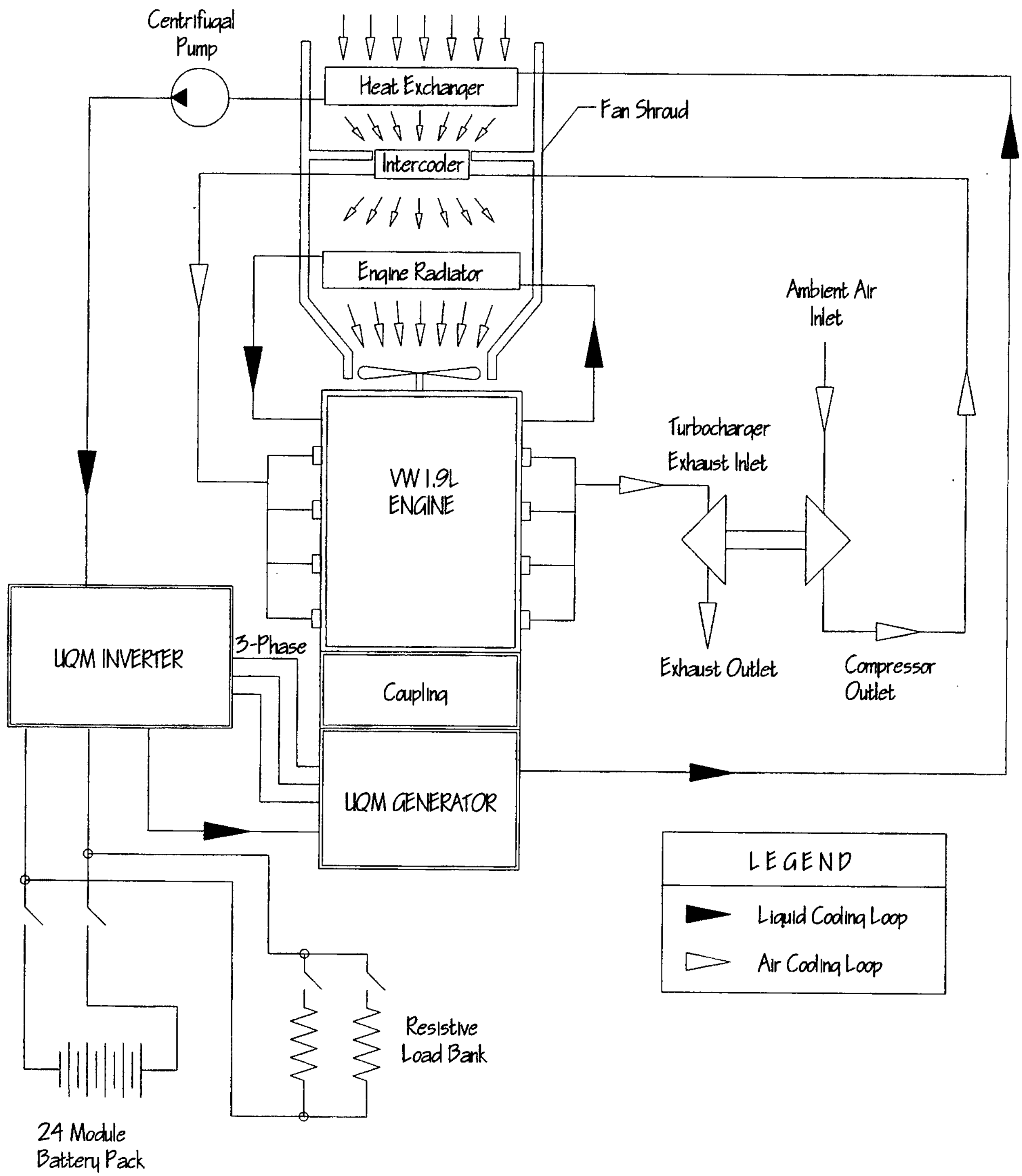


Figure 6. <u>APU Test Setup</u>

2.2.2 Controller Hardware Platform

As previously noted , the APU controller platform was based on an industrial PC. The controller utilized a commercially available 486, 66-Mhz CPU card, with a 1.44 Mb solid state RAM disk emulator as the primary memory device. The controller utilized commercially available data acquisition and control cards, as well as a commercial watchdog timer board for protection. The controller enclosure for the APU is shown in Figure 7. In order to provide the necessary signal conditioning and driver circuitry for interfacing with the APU hardware, a custom interface enclosure was designed and constructed by SwRI. Electrical power for the control system was provided via a converter that stepped the vehicle bus voltage down to 12 Vdc.

2.2.3 Control Software/Algorithm Descriptions

The APU control software was written in C language and executed in the MS DOS environment. The control software was written to utilize floating point arithmetic to allow modifications to be made to the algorithms with minimum development time. The 486 processor adequately executed all control equations in a time-based interrupt drier routine operating at 100 Hz. Because the system was built around the existing SwRI RPECS platform, built-in functions such as real-time plotting and data logging were easily integrated into the control system. The following is a detailed description of the APU control algorithms.

The APU controller's most fundamental function was to control the power output of the APU. APU power output was commanded from the vehicle controller.

Given the desired APU power output, the engine speed and throttle set point were computed via a programmable engine operation trajectory. The engine trajectory was calibrated to maximize the APU efficiency. Therefore, the engine operation trajectory programmed into the APU controller entailed transitioning the engine to the wide open rack point at the lowest engine speed and running at the maximum rack up to the maximum power point of the engine (4000 rpm).

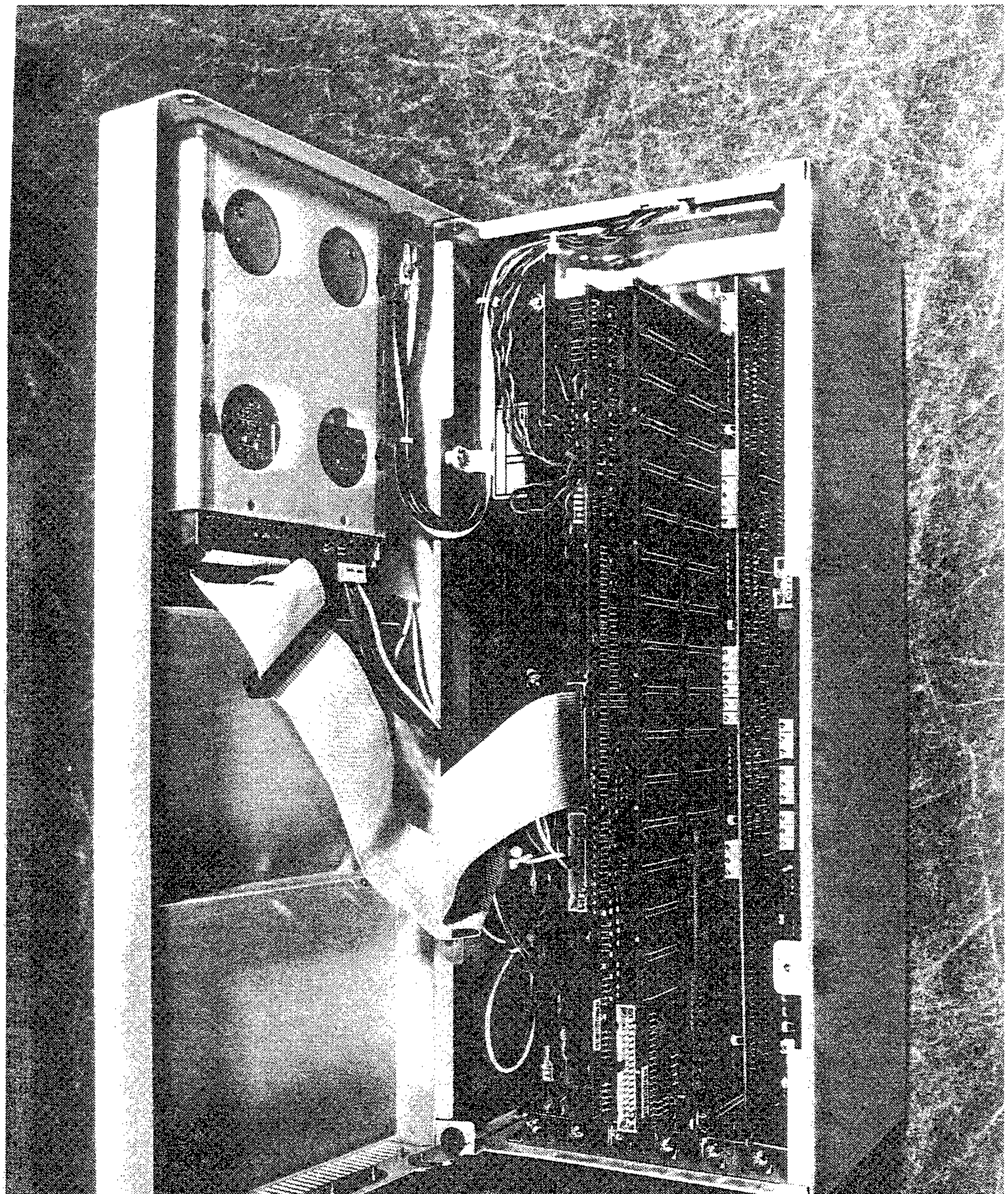


Figure 7. <u>APU Controller</u>

Having computed the desired engine speed and throttle position, the APU controller first provided the necessary rpm signal to the engine ECU. In order to achieve the desired engine speed, the APU controller utilized information from an engine-speed sensor for the feedback control. In order to control engine speed, the APU controller modulated the load applied to the engine via the generator. The generator control was provided through the UQM inverter and its throttle signal. The APU control functions are shown in Figure 8.

In addition to the APU power output control function the controller also provided control of the engine start and stop functions. The engine start function was accomplished by using the generator as a motor.

In conjunction with the control functions and algorithms previously described, the APU controller was also designed with a limited set of diagnostics. Out-of-range diagnostics for each of the sensors used by the APU controller were implemented to detect and react to sensor failures. Furthermore, system level diagnostics and protection were built into the APU controller to detect and prevent APU operation that could damage the unit (engine protection). The diagnostic functions of the APU were designed to prevent operation that could cause permanent damage to the unit, and to provide valuable information for diagnosing problems.

2.3 APU Testing

Testing was performed at SwRI to verify the performance of the HMMWV APU prior to shipment. The M113 APU controller was tested with the HMMWV engine-generator since the M113 engine-generator was located at the McKee Engineering facility. The testing was broken down into two specific areas: stand alone testing of the APU controllers, and integrated testing of the APU controllers and the engine generator. The performance of the APU controllers was found to be satisfactory during all testing. Testing of the integrated APU package revealed problems with limited transient response of the APU and over-heating of the generator rotor with prolonged operation at full power. The following paragraphs detail the APU controller testing.

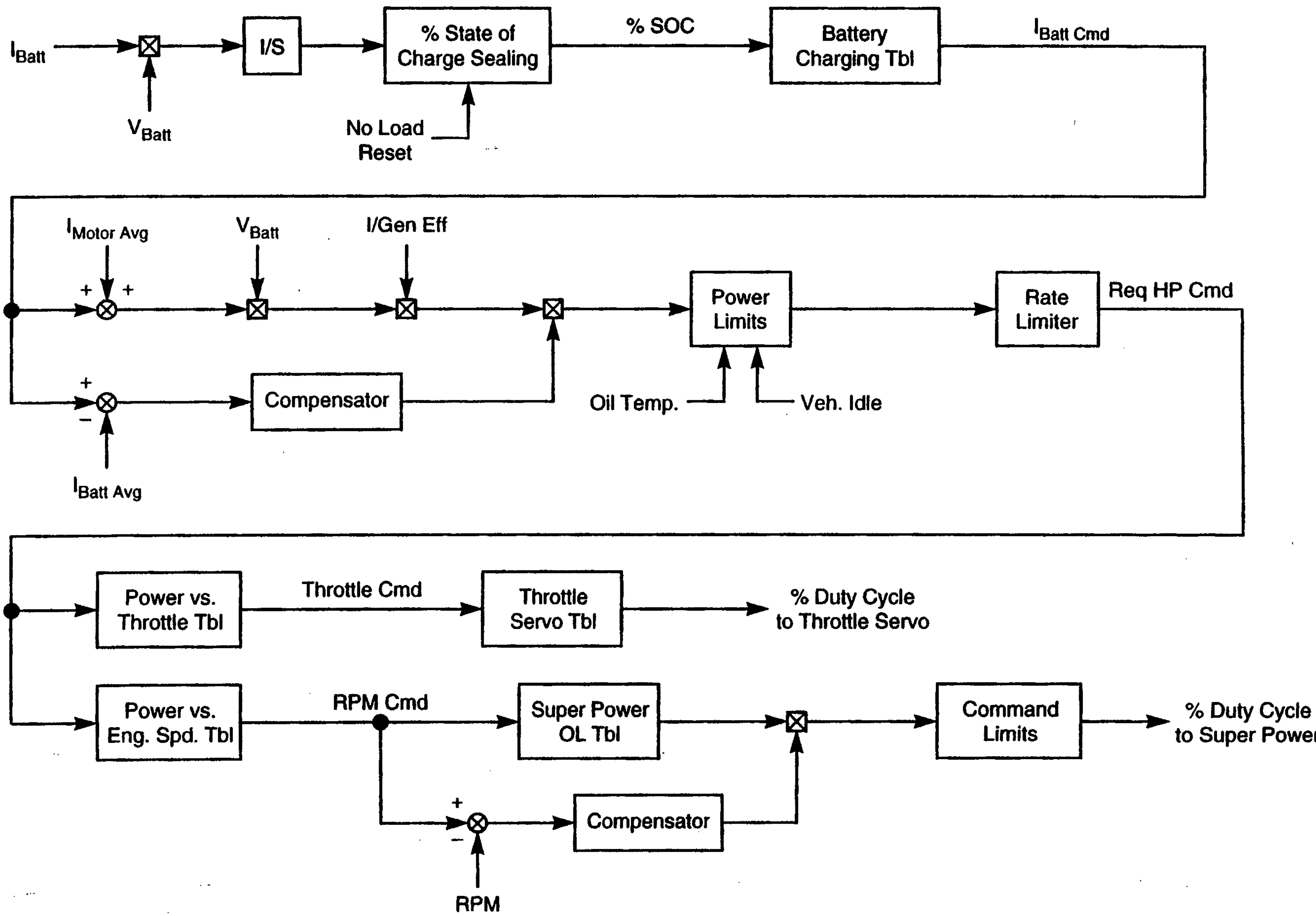


Figure 8. APU Control Functions

2.3.1 M113 APU Controller Stand Alone Testing

For the stand-alone testing, the APU controller was not interfaced with any other control systems or sensors that make up the APU system. Rather, the APU controller was isolated on the test bench with power supplied from a 12-VDC source and the first-stage, DC-to-DC converter bypassed. Signals from sources such as adjustable power supplies and function generators were used as input to the APU controller. Output signals were measured via oscilloscope and multi-meter instrumentation. The purpose of the APU controller stand-alone testing was to verify that all analog and digital signal I/O was functioning properly. This included all wiring and signal conditioning circuitry between the APU control computer (the appropriate analog to digital converter [ADC], digital to analog converter [DAC], digital input and digital output) and the interface connector on the exterior of the APU controller enclosure. A list of the APU controller I/O signals (by signal type) is shown in Table 1.

All controller I/O was tested on the bench environment and performed as expected. As a result of the bench testing, the controller was installed in the test laboratory for APU-integrated testing. The complete wiring diagram for the M113 and HMMWV APUs is given in the appendix.

Table 1. APU Controller Signal I/O

Analog Input Signals		
ADC channel #:	Description:	From:
0	APU Power Request	Vehicle Controller
1	Coolant Temperature	APU Sensors
2	Oil Temperature	APU Sensors
3	Oil Pressure	APU Sensors
4	Bus Voltage	UQM Control
5	Generator Current	UQM Controller
6	Engine Speed	APU Sensors
7	Barometric Pressure	APU Sensors

Table 1. APU Controller Signal I/O		
Analog Output Signals		
DAC Channel #:	Description:	To:
0	ECU Pedal Command	Engine Controller
1	UQM Brake command	UQM Controller
2	Coolant Temperature Signal	Vehicle Controller
3	Engine Speed Signal	Vehicle Controller
4	APU Power Output	Vehicle Controller
5	UQM Accel Command	UQM Controller
Digital Input Signals		
Dig In Bit #:	Description:	From:
0	APU On/Off	Vehicle Controller
1	UQM Over Temp	UQM Controller
Digital Output Signals		
Dig Out Bit #:	Description:	To:
0	Engine On/Off	Vehicle Controller
1	APU Fault	Vehicle Controller
2	UQM Enable	UQM Controller
3	UQM Direction	UQM Controller
4	Idle Validation	Engine Controller
5	UQM Over Temp	Vehicle Controller
6	ECU On/Off	APU Power Relay

2.3.2 CTC Engine-Generator/ M113 APU Controller Integrated Testing

The CTC engine-generator was mounted to a wooden pallet using three jackstands at the mounting points provided by the McKee interface plate between the engine and generator and a bracket on the front of the engine. The stock VW intake air filter assembly, which also houses the mass air flow sensor, was used.

2.3.2.1 Heat Exchangers

Volumetric air flow through the heat exchanger was determined using a hand-held anemometer to measure the air velocity at six points at the face of the heat exchanger pack. The six velocity measurements were averaged, and the heat exchanger core area was used to calculate the volumetric air flow. Using ambient temperature and pressure, the mass air flow was also calculated.

As shown in Figure 6, a centrifugal pump powered by the 120 VAC mains was used to circulate the coolant through the Unique Mobility inverter and the generator. The pump output was measured to be five gallons per minute by disconnecting the discharge line from the generator and timing the filling of a one-gallon container. The capacity of the electronics cooling loop was 4.2 gallons of water/anti-freeze mixture. The coolant was routed from the heat exchanger to the pump inlet, to the inverter then the generator, and returned to the heat exchanger. The heat exchanger header space served as the reservoir. Thermocouples were installed at the coolant flow into the inverter, and at the coolant discharge at the generator.

2.3.2.2 Power Absorption

The electrical output of the inverter was connected to a switchable resistive load bank and to the battery pack through a manual breaker. The battery pack consisted of twenty-four 12-volt, group-31 modules of lead acid batteries. Overall, battery pack and power cable DC impedance was determined to be 0.9 ohms using the Thevenin equivalent method.

2.3.2.3 Fuel Supply

The engine was operated on a low-sulfur, number 2 diesel fuel. The fuel was assigned the number AL-24507F at the TACOM Fuel and Lubricants Research Facility where the gross heat of combustion was determined to be 19,571 BTU/lb, and the net heat of combustion was found to be 18,377 BTU/lb. Fuel flow rate to the engine was measured gravimetrically using a one-gallon container on an electronic digital scale, and timed using a stopwatch.

2.3.2.4 Power Measurement

Direct current electric power output from the inverter was calculated from averaged current and voltage measurements. The current was measured using a DC clamp-on-type current probe. The voltage was measured with a digital voltmeter. Prior to these measurements the inverter output was examined using an oscilloscope and found to be free of any large voltage variations. There were voltage noise spikes of 30 volts and a few microsecond duration superimposed on the nominal 280 volt base DC voltage, which occurred at the inverter frequency of approximately 20 khz. The absence of periodic voltage variations of significant duration permitted accurate power measurements using the average values of voltage and current.

2.3.2.5 Vehicle Control

Since a vehicle controller was not part of the test setup, a potentiometer was installed to provide a 0-to-5v analog signal input to simulate the APU power request signal from the vehicle controller. Similarly, a toggle switch was also installed to simulate the APU on/off signal from the vehicle controller. The APU system was tested over a variety of operating conditions with various electrical load settings on the load bank. Details of the final testing are contained in the following paragraphs.

2.3.2.6 HMMWV Controller/M113 APU Start/Stop Testing

The APUs ability to respond to a normal start/stop command, as well as a mission disabling failure condition was tested. In order to test the normal start/stop sequencing, the APU on/off switch was toggled on, allowing the APU to start. Then, the switch was toggled off, stopping the APU. Similarly, a loss of the APU start/stop signal was simulated by disconnecting the APU on/off switch input to the APU controller. The APU, as expected, shut down immediately during this simulated failure. The system was also tested for an open circuited APU power request signal. Removing the APU power request signal connection to the APU controller simulated the failure. As expected, the APU changed from its initial operating condition to an idle condition. Multiple conditions were designed to shut down the APU to prevent damage. These engine protection faults included oil pressure low/high, oil temperature high, coolant temperature high, and APU overspeed. APU controller response to these fault conditions were also tested during the course of the APU development effort.

2.3.2.7 HMMWV Controller/M113 APU Steady-State Testing

APU steady-state performance tests were designed to verify acceptable system performance at various power levels. Acceptable system performance was defined as stable operation at the desired power level, resulting in no-fault conditions. During the test, data was collected at discrete APU output power steps of 10, 25, 35, 45 and 55 kW. A tabulation of the data and calculated results is provided in the appendix. Figure 9 is plot of the APU efficiency versus the electrical power out. Efficiency was calculated as the electrical power out over the fuel energy in (lower or net heating value). The peak efficiency of 33.2 percent was observed at 25 kW, dropping to 30.7 percent at 55 kW. Figure 10 shows the efficiency of the generator/inverter only (based on the heat rejection to the coolant) versus the electrical power out.

APU performance was found to be acceptable at all operating conditions except 55 kW. After prolonged operation (greater than five minutes) at the 55kW point, the Unique Mobility controller set a fault indicating excessively high rotor temperatures on the UQM generator. Under the fault condition, the APU power output was reduced and the APU control system transitioned into an overspeed protection mode, which dithered the ECU pedal command in order to prevent engine overspeed. This condition remained until the rotor temperatures decreased below the fault threshold, where normal operation was again restored.

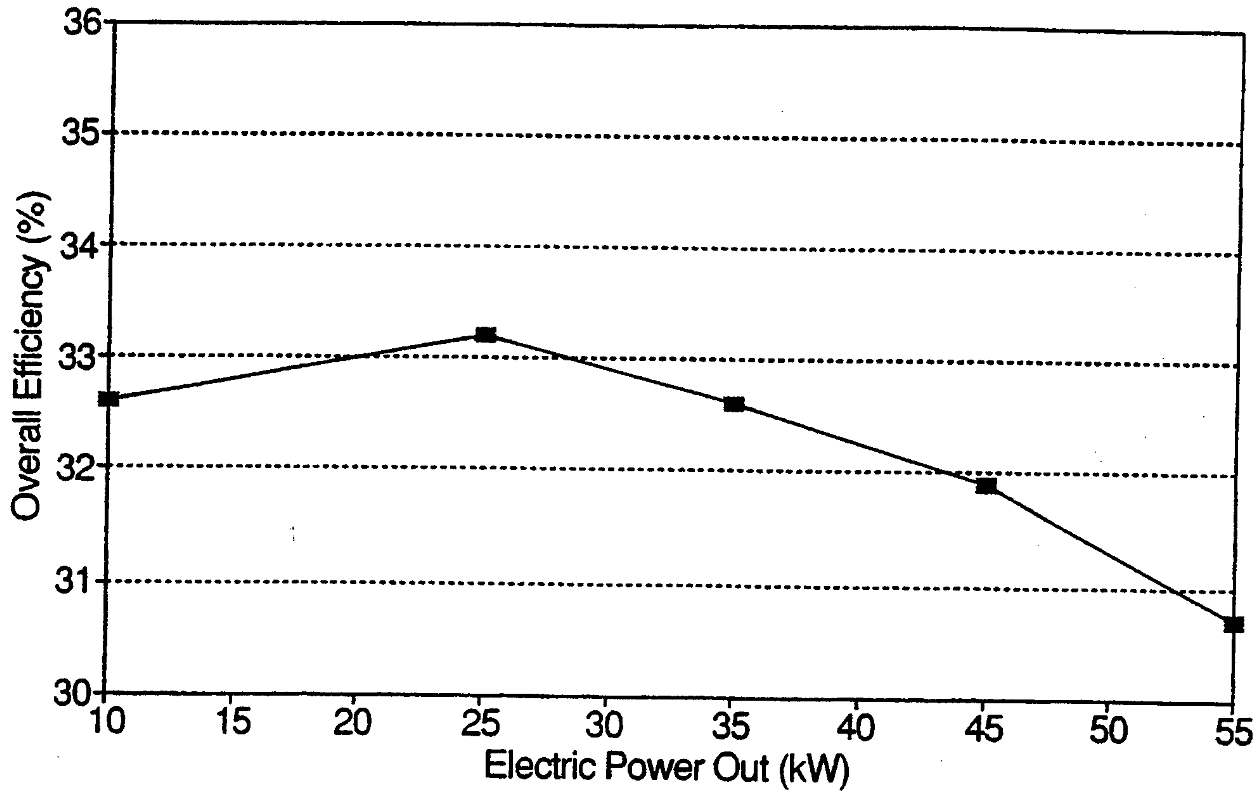


Figure 9 **APU Efficiency vs. Electrical Power Out**

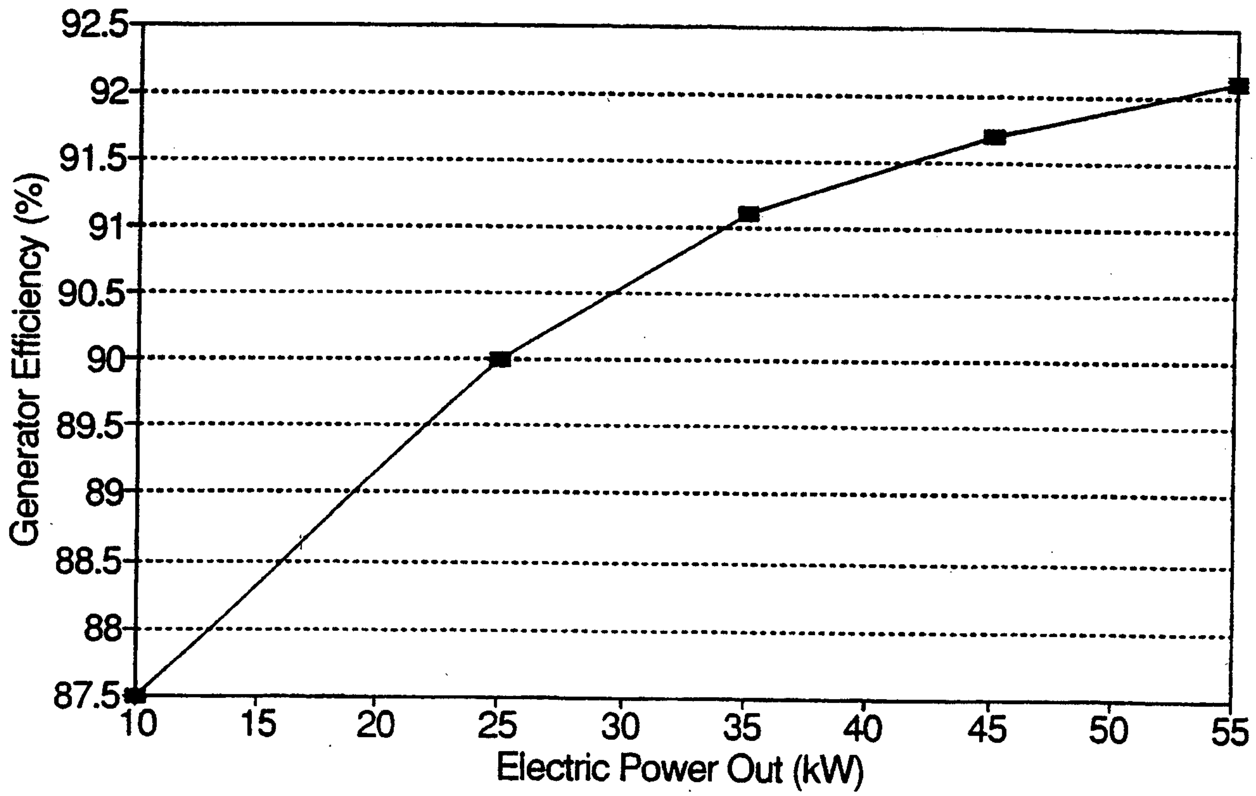


Figure 10. **Generator Efficiency vs. Electrical Power Out**

2.3.2.8 HMMWV Controller/M113 APU Transient Testing

APU performance data was gathered during power command transient conditions. The following data are shown for four different transient conditions:

1. Power ramp up/ramp down from 0 kW to 55 kW to 0 kW over 60 seconds (Figures 11a and 11b)
2. Power command step response from 0 kW to 30 kW to 0 kW over 30 seconds (Figures 12a and 12b)
3. Power command step response from 27.5 kW to 55 kW to 27.5 kW over 30 seconds (Figures 13a and 13b)
4. Power command step response from 0 kW to 55 kW to 0 kW over 30 seconds (Figures 14a and 14b)

The "a" figures show the desired and measured APU power output and the DC bus voltage. The "b" figures show the desired and measured engine speed, and the UQM brake command signal. It should be noted that the desired APU power (labeled PwrCmd in the legend) is the command signal after passing through the software rate limiter. Thus, even in a step response scenario, the maximum rate of change of this signal is 6 kW/sec. As shown in the figures, adequate APU control performance was obtained. Small overshoots in measured power of brief time duration (five seconds or less) were observed during the step response tests. The responses were found to be adequately dampened on achieving the desired output power level. As a result of the transient testing, it was determined that the power command rate limiter within the APU controller must be set at 6 kW/sec in order to achieve the responses shown in the figures. Rate limit values of more than 6 kW/sec produced uncontrollable results on the 0-to-55 kW step response. Analysis of the results showed that the UQM brake command signal from the APU controller (to the UQM controller) was reaching its upper limit of 4.5V. This indicated that the UQM controller was applying the maximum torque to the engine via the generator. Subsequent tests revealed that by lowering the APU power command rate limiter to 6 kW/sec, adequate control could be maintained without saturation of the brake command signal.

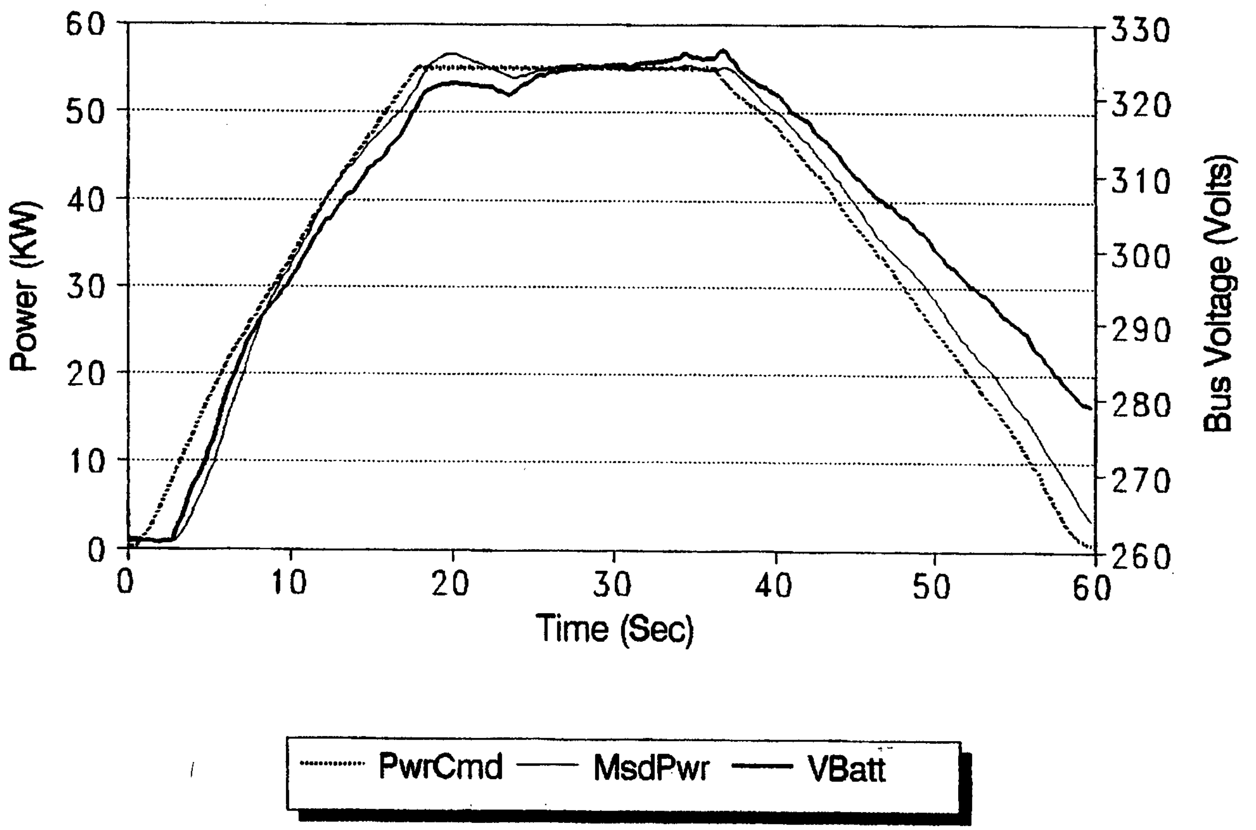


Figure 11a. Power Ramp Up/Down (Power and Bus Voltage)

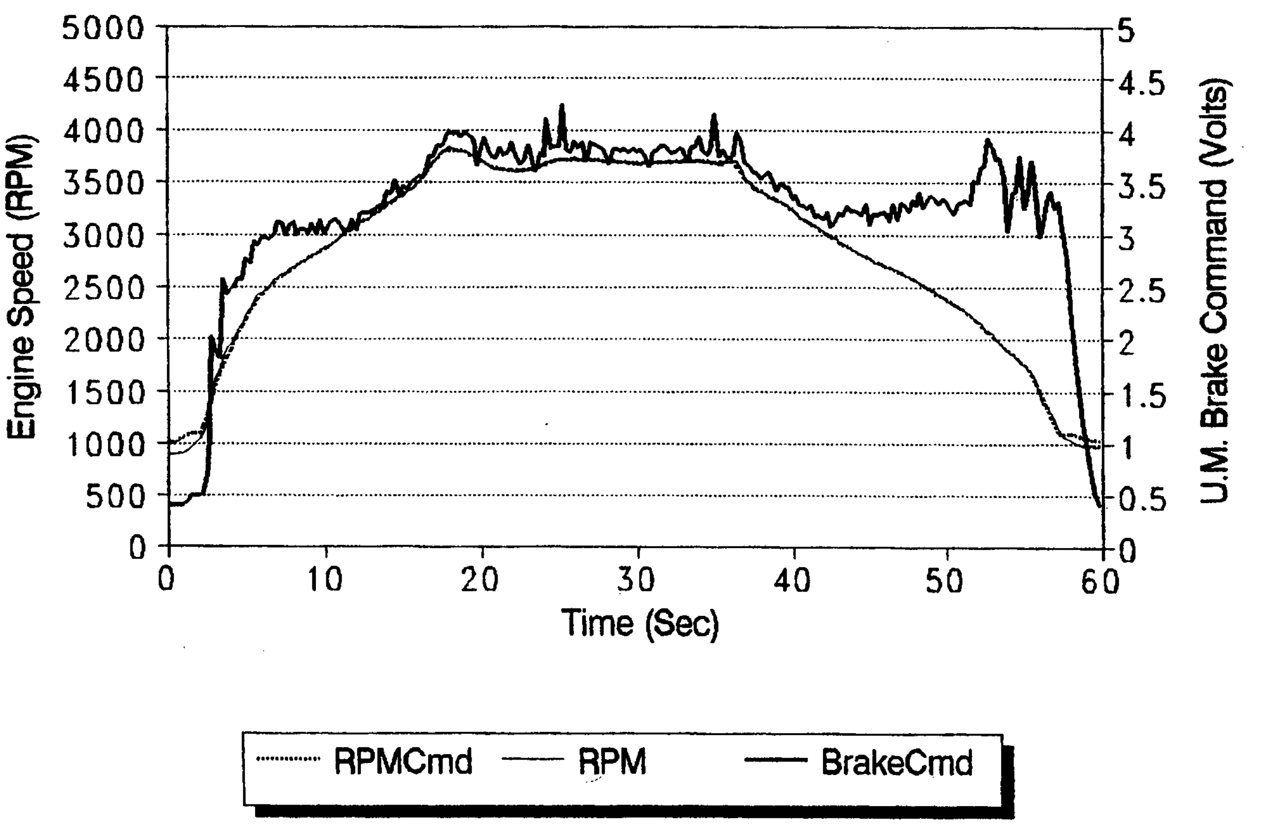


Figure 11b. Power Ramp Up/Down (Engine Speed & U.M. Brake Command)

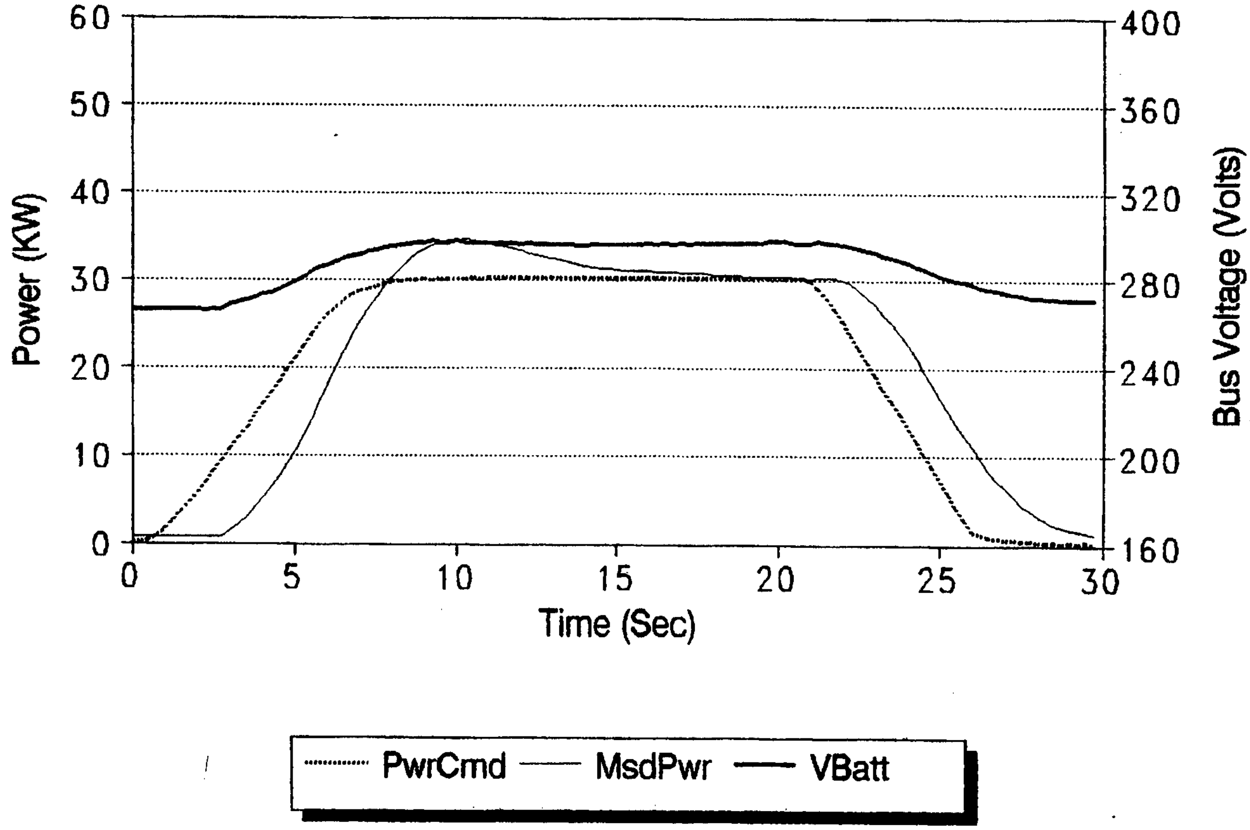


Figure 12a. APU Power Transient Response (Power and Bus Voltage)

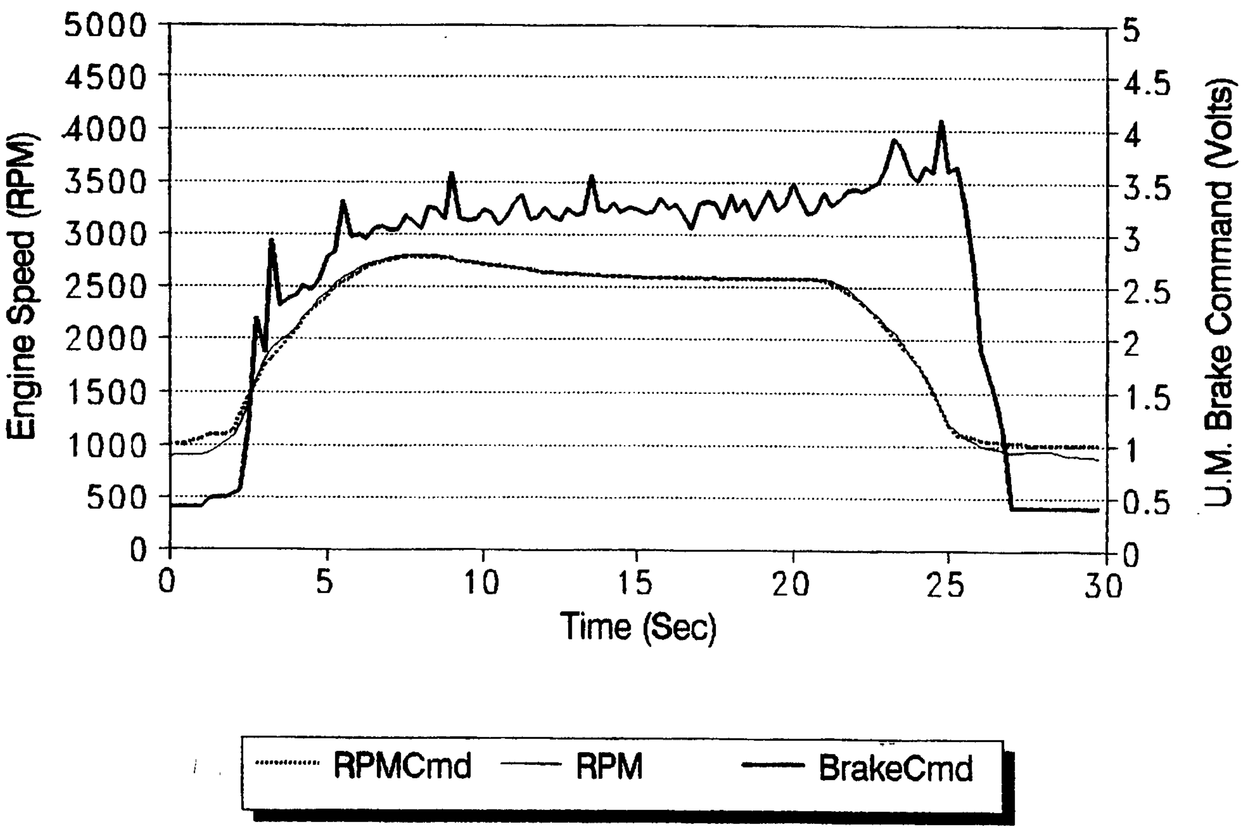


Figure 12b. APU Power Transient Response (Engine Speed & U.M. Brake Command)

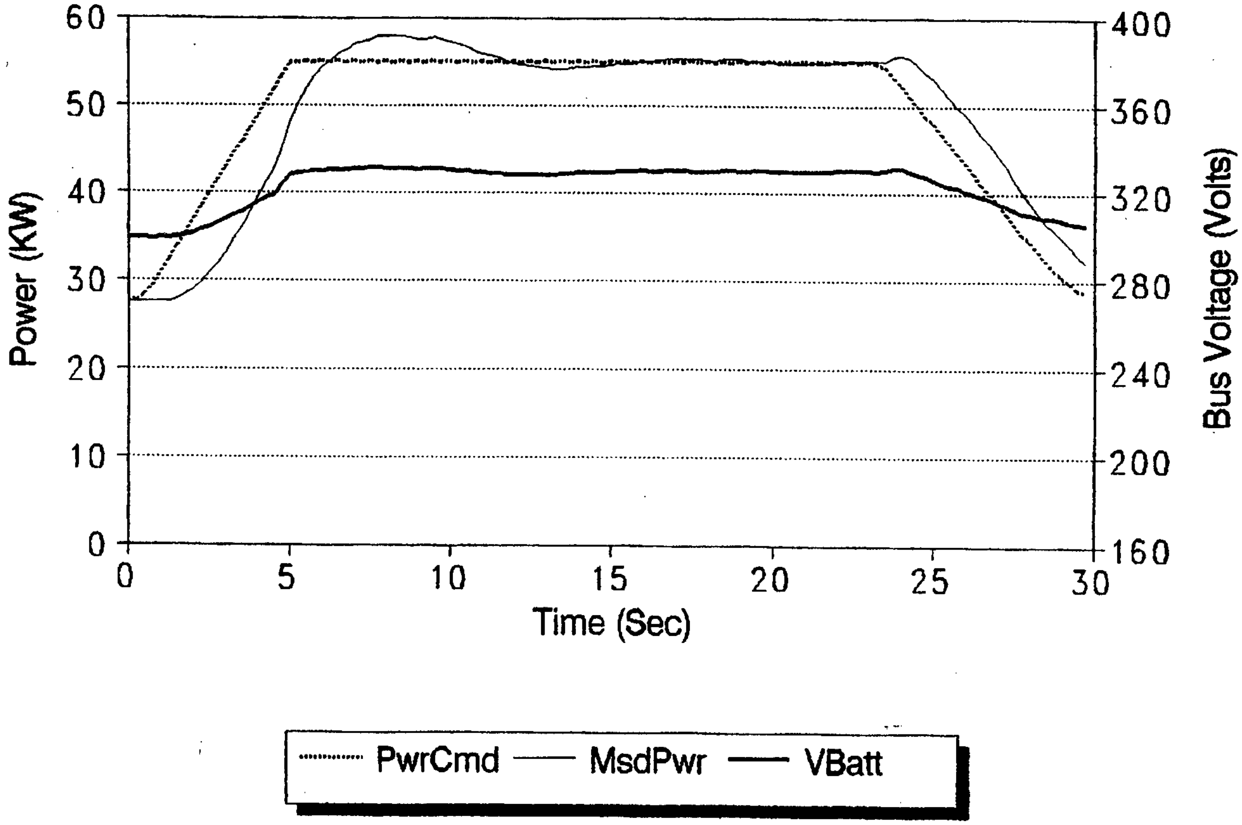


Figure 13 a. <u>APU Power Transient Response (Power and Bus Voltage)</u>

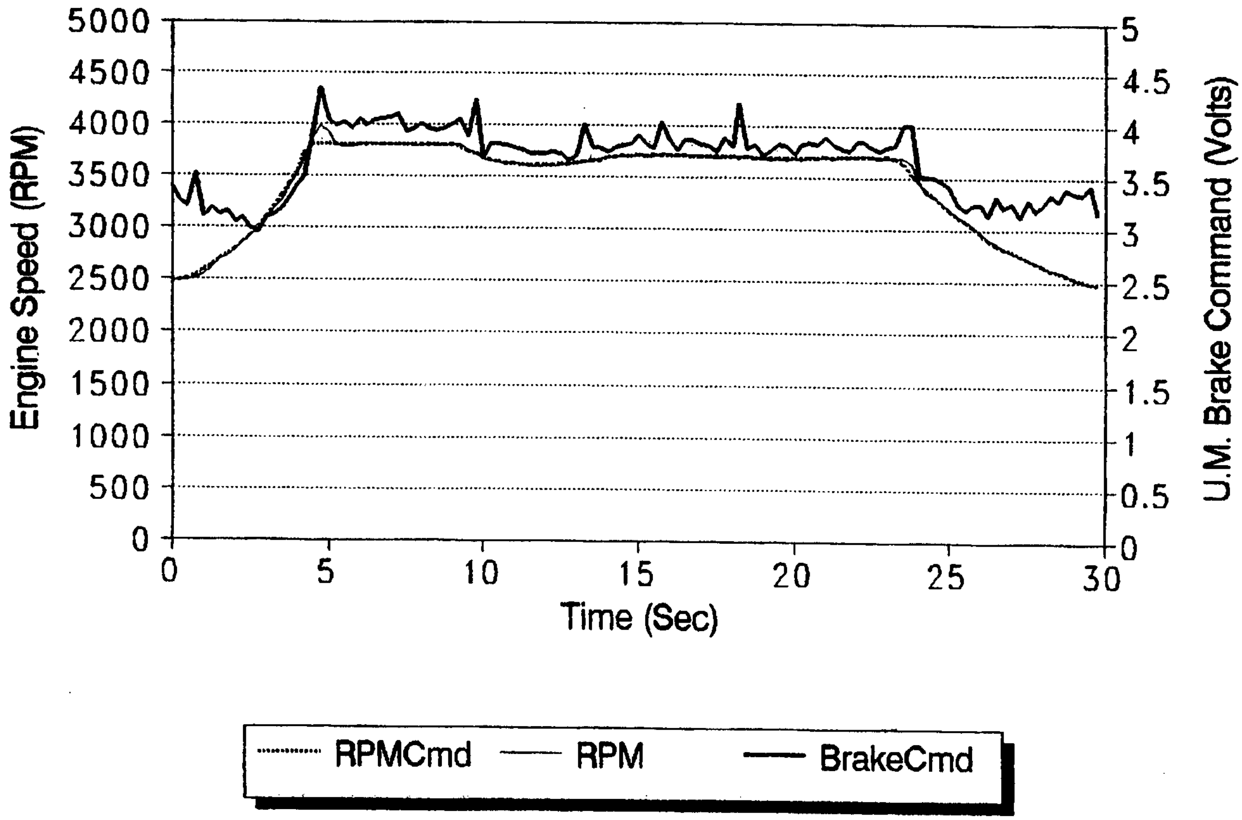


Figure 13b. <u>APU Power Transient Response (Engine Speed and U.M. Brake Command)</u>

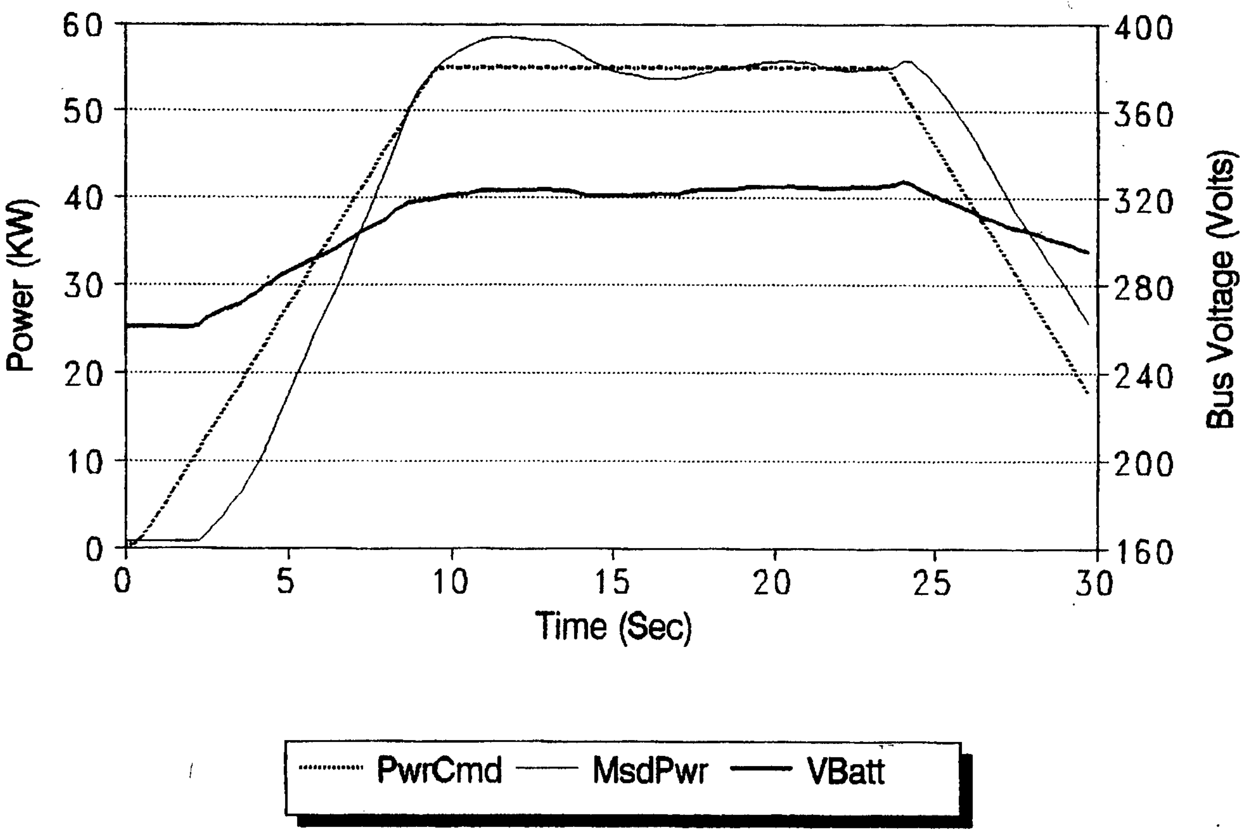


Figure 14a. APU Power Transient Response (Power and Bus Voltage)

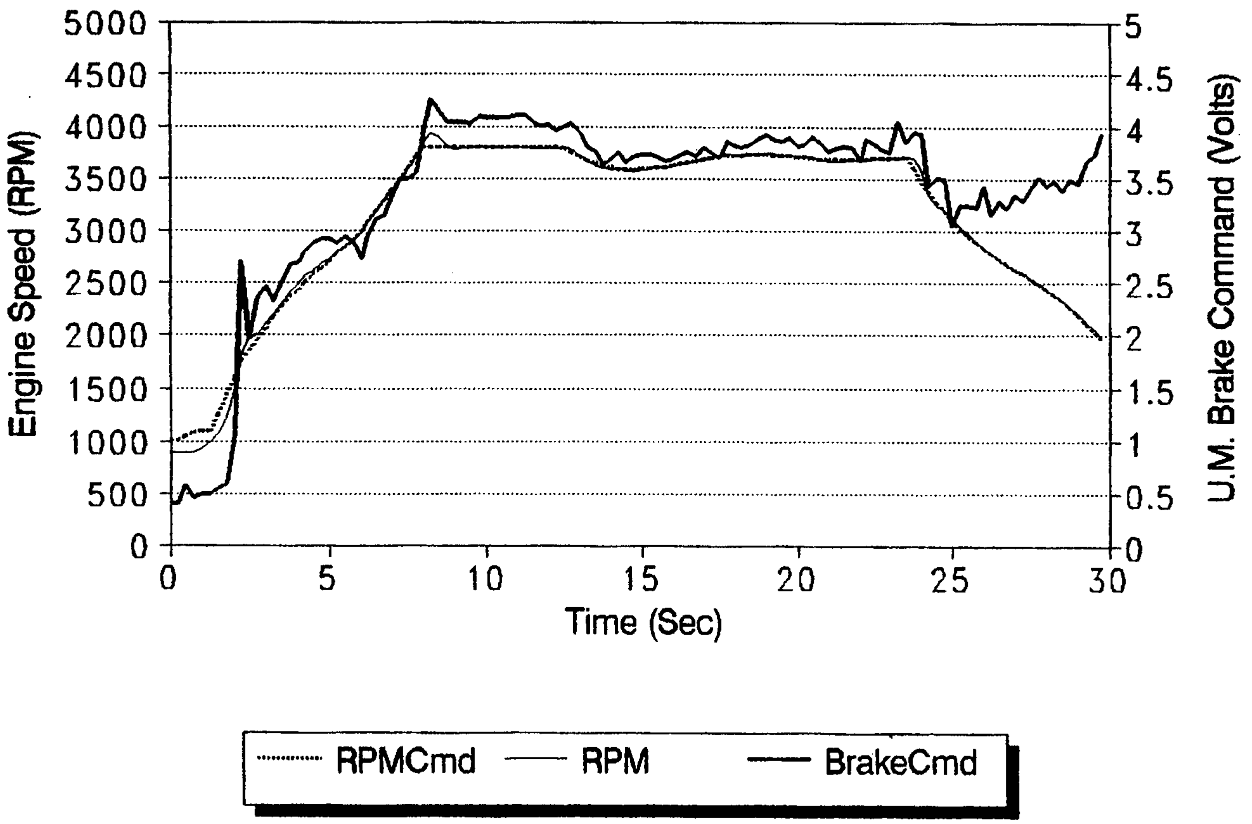


Figure 14b. APU Power Transient Response (Engine Speed and U.M. Brake Command)

2.3.3 Testing of the HMMWV Engine Generator/HMMWV APU Controller

Performance tests on the APU were conducted at SwRI prior to shipment. Testing was broken into two phases: 1) verifying proper functionality of the individual hardware components, and 2) verifying the integrated controller/engine/generator package. The performance of the APU controller was found to be satisfactory during all phases of testing.

2.3.3.1 Stand-Alone HMMWV Controller Testing

Stand-alone testing was conducted to verify proper functionality of the PC hardware, analog and digital I/O circuitry, and serial interface. I/O circuitry includes all wiring and signal conditioning circuits between the APU computer and the interface connector on the exterior of the APU controller enclosure. The APU controller was not interfaced with any of the other controller systems or sensors that make up the APU package during this testing. Instead, the APU controller was isolated on a test bench and powered by a 12-volt DC source. The first stage of the DC-to-DC converter was also bypassed. A mock-up KEC Battery Regulator-to-APU Controller link was established via a laptop computer and a standard RS-232 serial interface. The mock-up provided a means of verifying message parsing correctness and controller logic.

Signals from adjustable power supplies and function generators were used as APU controller inputs. APU controller outputs were measured with an oscilloscope and multi-meter. All I/O was tested on the bench and performed as designed. The mock-up serial tests were conducted by simulating link between the battery regulator and the SwRI APU controller. A list of the APU controller I/O signals by signal type is provided in Table 2.

TABLE 2. APU Controller I/O Signals			
Signal Type	**Channel**	**Description**	**From/To**
Analog Input	0.00	Engine Coolant Temperature	APU Sensor
	1	Engine Oil Temperature	APU Sensor
	2	Engine Oil Pressure	APU Sensor
	3	Bus Voltage	UQM Controller
	4	Generator Current	UQM Controller
	5	Engine Speed	APU Sensor
	6	Barometric Pressure	APU Sensor
Analog Output	0.00	ECU Pedal Command	Engine Controller
	1	UQM Brake Command	UQM Controller
Digital In Bit	0.00	APU Silent Override	Vehicle Controller
	1	UQM Over Temperature	UQM Controller
	2	APU Kick Down Power Override	Vehicle Controller
Digital Out Bit	2	UQM Enable	UQM Controller
	3	UQM Direction	UQM Controller
	4	Idle Validation	Engine Controller
	6	ECU On/Off	APU Power Relay
PWM Output	2	UQM Accelerator Command	UQM Controller

A program was written in QBasic for the mock-up serial link tests. The QBasic program utilized a 13-byte message and the protocol specification listed in Table 3. The first two bytes (not listed in Table 3) functioned as sync bytes to notify the APU controller that the succeeding 11 bytes comprised a message following the format listed in Table 3. A value of 77 hex was given to the two sync bytes for this version of the program and will be updated to a new value in each subsequent version of the APU controller software. The APU power request is a 16-bit word and was therefore broken into two bytes, the first byte indicating the most significant byte. The checksum, byte 9, was calculated as an 8-bit unsigned summation of bytes 0 to 8, and overflow was ignored.

TABLE 3. SERIAL LINK PROTOCOL SPECIFICATION				
BYTE	DESCRIPTION	MESSAGE SIZE	UNIT/LSB	LIMIT/RANGE
0.00	Message Header	1 Byte	-	01 hex
1	Sequence Number	1 Byte	-	0 - 255
2, 3	APU Power Request: Broken into 2 bytes; most significant byte in byte #2	2 Bytes	10 Watts	0 - 120 kW
4	APU Enable: Bit 0 Enables if True. Bits 1-7 are Spares.	1 Byte	-	Off (False) = 0 On (True) = 1
5, 6, 7, 8	Spare	1 Byte	-	0.00
9	Checksum	1 Byte	-	0 - 255
10	End of Message	1 Byte	-	03 hex

The QBasic program was installed on the laptop and simulated requests to enable the APU and power requests. The power requests were incrementally increased/decreased and observed to change as requested. All other bytes were visually monitored at each end of the serial link on either the laptop or a monitor coupled to the APU controller and were correct. Serial link outputs from the APU controller were analyzed with another program and computer that displayed the entire message output from the APU controller. The message structure, message values, and sequence of the messages were correct. As a result of the successful bench tests, the SwRI APU controller was installed in the test laboratory and electronically integrated into the engine/generator package. The KEC Battery Regulator simulation program and laptop were also coupled to the APU. The return messages from the APU controller were not displayed.

2.3.3.2 HMMWV APU Start/Stop Testing

The APUs ability to respond to commands via the mock-up KEC Battery Regulator-to-APU Controller link, as well as mission disabling conditions, was tested. The engine started appropriately and quickly when the Enable APU byte of the simulator program was changed from 0 to 1 (byte #4) via the laptop keyboard. The engine stopped when instructed to do so when the Enable APU byte was changed from 1 to 0. Also, the engine stopped when the silent mode override was true (5 volts) even though the APU was receiving Enable APU and power requests via the serial link.

Simply disconnecting the RS-232 cable between the APU controller and the laptop computer simulated loss of communication between the KEC Battery Regulator-to-APU Controller mock-up. If communication was not re-established after one second, a serial link fault was set and the engine shut down. Other fault conditions, called engine protect faults, can also shut down the engine to prevent damage. The engine protect faults included oil pressure high/low, oil temperature high, engine coolant temperature high, and engine overspeed. APU controller response to these fault conditions was also tested during the APU development effort.

2.4 APU Testing Conclusions

Based on these results, it was concluded that the APU and the APU controllers were functioning as intended with the exception of the limited operating time at full power. The manufacturer of the generator proposed that software changes to the inverter could be made to remedy this problem and that the testing of these changes will be made at their test facility.

3.0 SUMMARY

Three different configurations of a state-of-the-art APU for hybrid electric vehicles were developed. The APU utilized the following: the Volkswagen 1.9 l, direct injected, turbo-charged, intercooled, electronically controlled, injected diesel engine; the UQM model 218H drive motor as a generator; and an APU controller developed at SwRI. The APU develops 55 kW of DC output at 30.7 percent between 130 and 380 volts for charging the vehicle power pack. The peak efficiency of 33.2 percent (occurring at 25kW) is believed to be unprecedented.

A prototype APU control system was developed by SwRI for the control of the APU power output. The prototype controller was designed around a personal computer platform for maximum flexibility in control algorithm development, control system calibration, and sensor and actuator flexibility.

APPENDIX A
Power System Research Engine Survey

Request: SWEST

Diesel Specs 55 to 70 kW

Page 1

Manufacturer	Mfr Model	Int HP	Kw Rating	Cool	Asp	Inter-cool	Valve Cam	Fuel Distr	Bore	Stroke	Displace	Weight
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
BORGWARD	HR492HT	90.0	67.0	W	T	N	V	I	92	90	2.39	220
DEERE	4239D	78.0	58.0	W	N	N	V	D	106	110	3.92	386
DEUTZ	F4L913	87.0	65.0	A	N	N	V	D	102	125	4.09	0
INARMO	CIMMARRON 220	88.0	66.0	W	N	N	V	D	103	108	3.61	560
IVECO	CO3	90.0	67.0	W	N	N	V	D	110	130	4.94	0
PERKINS	6305	92.0	69.0	W	N	N	V	D	91	127	5.00	0
SEVEL	XD2S	80.0	60.0	W	T	N	V	I	94	83	2.30	0
SEVEL	XD3P	75.0	56.0	W	N	N	V	I	94	90	2.49	203
SEVEL	XUD7TE	91.0	68.0	W	T	A	C	I	80	88	1.77	150
ZANELLO	SUN4105	90.0	67.0	A	N	N	V	D	105	115	3.98	380
BMW	1.7L4ITI	90.0	67.0	W	T	A	C	I	80	83	1.67	0
STEYR	WD611	85.0	63.0	W	N	N	V	D	100	110	5.18	538
GM-BRAZIL	3-53	92.0	69.0	W	N	N	V	D	98	114	2.61	0
IVECO	CO3	90.0	67.0	W	N	N	V	D	110	130	4.94	0
MERCEDES BNZ	OM364	90.0	67.0	W	N	N	V	D	98	133	3.97	335
MWM MOTORES	4.07	85.0	63.0	W	N	N	C	D	93	103	2.80	193
MWM MOTORES	D229-4	75.0	56.0	W	N	N	V	D	102	120	3.92	345
PERKINS	4236	80.0	60.0	W	N	N	V	D	98	127	3.86	341
PERKINS	4248	81.0	60.0	W	N	N	V	D	101	127	4.07	257
PERKINS	6357	92.0	69.0	W	N	N	V	D	104	118	5.85	0
VAMMO	4236	80.0	60.0	W	N	N	V	D	98	127	3.86	341
BEIJING	F4L912	79.0	59.0	A	N	N	V	D	100	120	3.77	0
SHANGHAI DIESEL	4135	80.0	60.0	W	N	N	V	D	135	140	8.02	1288
AVIA	712	83.0	62.0	W	N	N	V	D	102	110	3.59	310
CKD PRAHA	6S110	89.0	66.0	W	N	N	V	I	110	150	8.55	0
ZETOR BRNO	1001T	89.0	66.0	W	T	N	V	D	105	120	4.16	425
ZETOR BRNO	7701T	76.0	57.0	W	T	N	V	D	102	120	3.92	410
ZETOR BRNO	8401	80.0	60.0	W	N	N	V	D	110	120	4.56	0
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
VALMET	311DS	76.0	57.0	W	T	N	V	D	108	120	3.30	280
VALMET	320DS	81.0	60.0	W	T	N	V	D	108	120	3.30	280
VALMET	411D	83.0	62.0	W	N	N	V	D	108	120	4.39	335
DEERE	3029T	80.0	60.0	W	T	N	V	D	106	110	2.94	0
DEERE	4039D	80.0	60.0	W	N	N	V	D	106	110	3.92	422
PSA	DJ5	86.0	64.0	W	N	N	C	I	92	92	2.45	177
PSA	XD3P	76.0	57.0	W	N	N	V	I	94	90	2.49	203
PSA	XUD11A	79.0	59.0	W	N	N	C	I	86	92	2.14	156
PSA	XUD11AT	86.0	64.0	W	T	N	C	I	85	92	2.09	167
PSA	XUD7T	78.0	58.0	W	T	N	C	I	80	88	1.77	150
PSA	XUD7TE	90.0	67.0	W	T	A	C	I	80	88	1.77	150
PSA	XUD9TE	93.0	69.0	W	T	A	C	I	83	88	1.91	0

Manufacturer	Mfr Model	Int HP	Kw Rating	Cool	Asp	Inter-cool	Valve Cam	Fuel Distr	Bore	Stroke	Displace	Weight
RENAULT	F8Q706T	94.0	70.0	W	T	A	C	I	80	93	1.87	155
RENAULT	G8	85.0	63.0	W	N	N	C	I	0	0	2.19	0
RENAULT	J8S814	88.0	66.0	W	T	A	C	I	86	89	2.07	170
CASE	4B3.9	76.0	57.0	W	N	N	V	D	102	120	3.92	266
DEUTZ	BF4M1012	84.0	63.0	W	T	N	V	D	94	115	3.19	380
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
DEUTZ	F4L912F	84.0	63.0	A	N	N	V	D	102	125	4.09	307
DEUTZ	F4L913	87.0	65.0	A	N	N	V	D	102	125	4.09	307
DEUTZ	F5L912W	79.0	59.0	A	N	N	V	I	100	120	4.71	380
DEUTZ	F6L912W	94.0	70.0	A	N	N	V	I	100	120	5.65	410
DEUTZ-MWM	D226-4	82.0	61.0	W	N	N	V	D	105	120	4.16	340
DEUTZ-MWM	D226B-3	74.0	55.0	W	N	N	V	D	105	120	3.12	0
DEUTZ-MWM	TD226B-3	88.0	66.0	W	T	N	V	D	105	120	3.12	345
DMS MOTOREN	3VD14.5 SRW	84.0	63.0	W	N	N	V	D	120	145	4.92	530
DMS MOTOREN	4VD SRL	91.0	68.0	A	N	N	V	D	120	145	6.56	550
HATZ	4L/M40	80.0	60.0	A	N	N	V	D	102	105	3.43	291
MERCEDES BNZ	OM364	90.0	67.0	W	N	N	V	D	98	133	3.97	335
MERCEDES BNZ	OM601D2.3	78.0	58.0	W	N	N	C	I	89	92	2.30	155
MERCEDES BNZ	OM602D2.5	90.0	67.0	W	N	N	C	I	87	84	2.49	189
MERCEDES BNZ	OM602D2.9	92.0	69.0	W	N	N	C	I	89	92	2.87	186
MERCEDES BNZ	OM604	94.0	70.0	W	N	N	D	I	87	89	2.16	0
MERCEDES BNZ	OM617	75.0	56.0	W	N	N	C	I	91	92	2.99	235
MWM	D225-6	94.0	70.0	W	N	N	V	D	95	120	5.10	445
THURINGER	4D13.5	86.0	64.0	W	N	N	V	D	118	135	5.91	0
VOLKSWAGEN	028.C	74.0	55.0	W	T	N	C	I	80	96	1.89	140
VOLKSWAGEN	028.D	90.0	67.0	W	T	N	C	D	80	96	1.89	142
VOLKSWAGEN	068.E	80.0	60.0	W	T	A	C	I	77	86	1.59	134
VOLKSWAGEN	075.1	82.0	61.0	W	N	N	C	I	77	86	2.38	191
VOLKSWAGEN	2.4L5	81.0	60.0	W	N	N	C	I	80	96	2.37	0
ASHOK LEYLAND	8040.05	88.0	66.0	W	N	N	V	D	104	115	3.91	415
ASHOK LEYLAND	WO4D	80.0	60.0	W	N	N	V	D	104	118	4.01	341
EICHER MOTORS	4D31	78.0	58.0	W	N	N	V	D	100	105	3.29	285
KIRLOSKAR-CUMM	4B3.9	76.0	57.0	W	N	N	V	D	102	120	3.92	266
MAHINDRA-NISSAN	SD25	77.0	57.0	W	N	N	V	I	89	100	2.49	208
RUSTON &HORNSBY	3YDX	77.0	57.0	W	T	N	V	D	111	127	3.70	605
RUSTON &HORNSBY	4YDA	75.0	56.0	A	N	N	V	D	111	127	4.93	620
SIMPSON & CO	6305	92.0	69.0	W	N	N	V	D	91	127	5.00	0
SWARAJ-MAZDA	3.4L4	86.0	64.0	W	N	N	V	D	100	110	3.45	0
TATA (TELCO)	OM314	76.0	57.0	W	N	N	V	D	97	128	3.78	325
ISUZU	4JA1	79.0	59.0	W	N	N	V	D	93	92	2.50	215
MIT MOTORS	4D31	78.0	58.0	W	N	N	V	D	100	105	3.29	285
PERKINS	4236	80.0	60.0	W	N	N	V	D	98	127	3.86	257
IDEM (IRAN DSL)	OM314	76.0	57.0	W	N	N	V	D	97	128	3.78	325
FIAT AUTO	1.9L4TI-DI	89.0	66.0	W	T	A	C	D	83	90	1.93	165
FIAT AUTO	230A4.000	79.0	59.0	W	T	N	C	I	83	90	1.93	0
FIAT AUTO	F280A1000	92.0	69.0	W	T	A	C	I	83	90	1.93	0
IVECO	8140.07	75.0	56.0	W	N	N	C	D	93	92	2.50	220
IVECO	8144.67	84.0	63.0	W	N	N	C	I	93	92	2.50	220
LAMBORGHINI	1000.4W	80.0	60.0	W	N	N	V	D	105	116	4.00	0
LOMBARDINI	DS4004	82.0	61.0	A	N	N	V	D	105	114	3.95	380

Manufacturer	Mfr Model	Int HP	Kw Rating	Cool	Asp	Inter-cool	Valve Cam	Fuel Distr	Bore	Stroke	Displace	Weight
SAME	1000.4A	85.0	63.0	A	N	N	V	D	105	116	4.00	0
SAME	1000.4AT	94.0	70.0	A	T	N	V	D	105	116	4.00	0
SAME	1054P	79.0	59.0	A	N	N	V	D	105	120	4.16	385
SAME	1054PT	84.0	63.0	A	T	N	V	D	105	120	4.16	397
SLANZI	DS4000TB	88.0	66.0	A	T	N	V	D	105	114	3.95	384
VM	HR392SHI	84.0	63.0	W	T	A	V	I	92	90	1.78	185
VM	HR494HPT	88.0	66.0	W	T	N	V	I	94	100	2.78	230
VM	SUN4105	90.0	67.0	A	N	N	V	D	105	115	3.98	381
DAIHATSU MTR	DL	82.0	61.0	W	N	N	V	I	92	104	2.77	236
DAIHATSU MTR	DL-T	94.0	70.0	W	T	N	V	I	92	104	2.77	240
HINO	WO4C	88.0	66.0	W	N	N	V	D	104	113	3.84	314
ISUZU	4BD1	82.0	61.0	W	N	N	V	D	102	118	3.86	316
ISUZU	4EE1-TC	86.0	64.0	W	T	A	C	I	79	86	1.69	146
ISUZU	4FG1	79.0	59.0	W	N	N	C	I	89	95	2.38	192
ISUZU	4JA1	79.0	59.0	W	N	N	V	D	93	92	2.50	215
ISUZU	4JB1	88.0	66.0	W	N	N	V	D	93	102	2.77	220
ISUZU	C223T	75.0	56.0	W	T	N	V	I	88	92	2.24	221
KOMATSU	4D95L-1	81.0	60.0	W	N	N	V	D	95	115	3.26	235
KUBOTA	V4000/4300-B	80.0	60.0	W	N	N	V	D	109	115	4.29	382
MAZDA	HA	90.0	67.0	W	N	N	V	I	95	105	2.98	235
MAZDA	M4-182(HA)	80.0	60.0	W	N	N	V	I	95	105	2.98	235
MAZDA	RF-PWS	82.0	61.0	W	S	W	C	I	86	86	1.99	189
MAZDA	RFT	76.0	57.0	W	T	N	C	I	86	86	1.99	172
MAZDA	XA	77.0	57.0	W	N	N	V	I	89	102	2.52	235
MIT MOTORS	4D31	78.0	58.0	W	N	N	V	D	100	105	3.29	285
MIT MOTORS	4D56T	88.0	66.0	W	T	N	C	I	91	95	2.48	199
MIT MOTORS	4D56TI	94.0	70.0	W	T	W	C	I	91	95	2.48	199
MIT MOTORS	4D65T	76.0	57.0	W	T	N	C	I	81	88	1.79	149
MIT MOTORS	4D68T	88.0	66.0	W	T	N	C	I	83	93	1.99	167
MIT MOTORS	4DR6A	94.0	70.0	W	T	N	V	D	92	100	2.66	265
MIT MOTORS	6DR5	90.0	67.0	W	N	N	V	I	92	100	3.98	370
MITSUBISHI HVY	S4E2	76.0	57.0	W	N	N	V	I	98	98	2.96	270
MITSUBISHI HVY	S4E2-T	83.0	62.0	W	T	N	V	I	98	98	2.96	275
MITSUBISHI HVY	S4F-T	84.0	63.0	W	T	N	V	D	98	98	2.96	275
MITSUBISHI HVY	S4K	80.0	60.0	W	N	N	V	D	102	130	4.25	340
MITSUI-DEUTZ	BF3L913	80.0	60.0	A	T	N	V	D	102	125	3.06	360
MITSUI-DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
NISSAN DIESEL	ED33	82.0	61.0	W	N	N	V	D	100	105	3.29	300
NISSAN DIESEL	TD23	76.0	57.0	W	N	N	V	I	89	92	2.29	223
NISSAN DIESEL	TD27	90.0	67.0	W	N	N	V	I	96	92	2.66	231
NISSAN MOTOR	CD20	75.0	56.0	W	N	N	V	I	85	88	1.97	154
NISSAN MOTOR	CD20-T	91.0	68.0	W	T	N	V	I	85	88	1.97	162
NISSAN MOTOR	LD20-T	79.0	59.0	W	T	N	C	I	85	86	1.95	195
NISSAN MOTOR	LD23	75.0	56.0	W	N	N	C	I	87	96	2.28	0
TOYOTA	11B	91.0	68.0	W	N	N	V	D	95	105	2.98	279
TOYOTA	2C	75.0	56.0	W	N	N	C	I	86	85	1.97	151
TOYOTA	2C-T	88.0	66.0	W	T	N	C	I	86	85	1.97	166
TOYOTA	2L	85.0	63.0	W	N	N	C	I	92	92	2.45	200
TOYOTA	2L-T	94.0	70.0	W	T	N	C	I	92	92	2.45	208
TOYOTA	3L	91.0	68.0	W	N	N	C	I	96	96	2.78	204

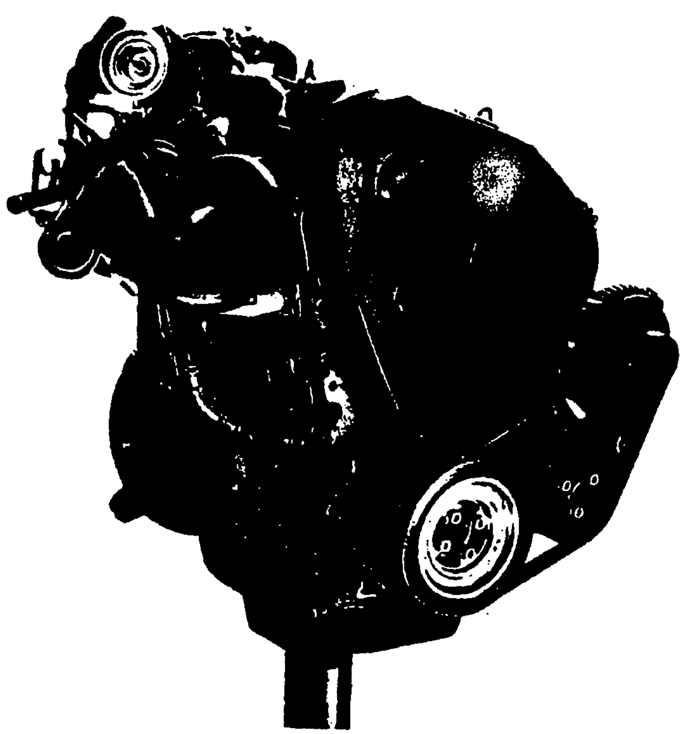
Manufacturer	Mfr Model	Int HP	Kw Rating	Cool	Asp	Inter-cool	Valve Cam	Fuel Distr	Bore	Stroke	Displace	Weight
TOYOTA	B	85.0	63.0	W	N	N	V	I	95	105	2.98	265
YAMAHA	MD201KY	75.0	56.0	W	T	W	V	D	92	100	1.97	260
YANMAR	4JH-DTE	77.0	57.0	W	T	W	V	D	78	86	1.60	225
YANMAR	4JH2-HTE	75.0	56.0	W	T	W	V	D	82	86	1.82	246
YANMAR	4T95TLE	85.0	63.0	W	T	N	V	D	95	110	3.10	296
YANMAR	4TN100E	78.0	58.0	W	N	N	V	D	100	110	3.46	250
HYUNDAI MOTOR	4D31	88.0	66.0	W	N	N	V	D	100	105	3.29	285
KIA MOTORS	HA	90.0	67.0	W	N	N	V	I	95	105	2.98	235
KIA MOTORS	SS	75.0	56.0	W	N	N	V	I	92	89	2.70	0
KIA MOTORS	XA	77.0	57.0	W	N	N	V	I	89	102	2.52	230
SSANGYONG MOTOR	OM601D2.3	78.0	58.0	W	N	N	C	I	89	92	2.30	155
SSANGYONG MOTOR	OM602D2.9	92.0	69.0	W	N	N	C	I	89	92	2.87	186
DEERE	4239D(MX)	80.0	59.6	W	N	N	V	D	106	110	3.92	427
PERKINS	4236(MX)	80.0	59.6	W	N	N	V	D	98	127	3.87	341
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
ANDORIA	4CT90	90.0	67.0	W	T	N	V	I	90	95	2.42	250
URSUS	4236	80.0	60.0	W	N	N	V	D	98	127	3.86	257
URSUS	S316C	82.0	61.0	W	N	N	V	D	94	94	3.91	360
ARO	L-27D	82.0	61.0	W	N	N	V	I	97	90	2.66	0
BELARUS	D-240	81.0	60.0	W	N	N	V	D	110	125	4.74	430
BELARUS	D-240T	92.0	69.0	W	T	N	V	D	110	125	4.74	0
ATLANTIS	236N	75.0	56.0	W	N	N	V	D	98	127	3.86	257
ATLANTIS	617N	75.0	56.0	W	N	N	V	I	91	92	2.99	235
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
MOTOR IBERICA	A4-28II	76.0	57.0	W	N	N	C	D	94	102	2.82	0
MOTOR IBERICA	B4-40	85.0	63.0	W	N	N	V	D	100	127	3.99	253
MWM	D225-6	94.0	70.0	W	N	N	V	D	95	120	5.10	445
MWM	D325-6	94.0	70.0	A	N	N	V	D	95	120	5.10	405
VOLKSWAGEN	028.C	75.0	56.0	W	T	N	C	I	80	96	1.89	0
VOLVO	D45	82.0	61.0	W	N	N	V	D	106	128	4.48	500
TOYOTA	2L	83.0	62.0	W	N	N	C	I	92	92	2.45	200
BMC SANAYI	4.98	75.0	56.0	W	N	N	V	D	98	125	3.77	0
DEUTZ	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
T.Z.D.K.	WD611(B)	85.0	63.0	W	N	N	V	D	100	110	5.18	538
UZEL TRACTOR	4248	81.0	60.0	W	N	N	V	D	101	127	4.07	257
CASE	220T	88.0	66.0	W	T	N	V	D	100	114	3.59	0
FORD	FSE425(B)	80.0	60.0	W	N	N	V	D	94	91	2.50	220
FORD	XLD418T	75.0	56.0	W	T	N	C	I	83	82	1.75	147
FORD	XLD418TI	89.0	66.0	W	T	A	C	I	83	82	1.75	153
KELVIN	4104	84.0	63.0	W	N	N	V	D	104	115	3.90	430
LAND ROVER	2.5LT	86.0	64.0	W	T	N	C	I	90	97	2.49	0
LAND ROVER	3.4L	79.0	59.0	W	N	N	C	I	90	89	3.43	0
LISTER-PETTER	CS4	81.0	60.0	W	N	N	V	D	107	115	4.15	459
NEW HOLLAND	GSD450	90.0	67.0	W	N	N	V	D	112	127	4.99	360
PERKINS	1004-4	79.0	59.0	W	N	N	V	D	100	127	3.98	273
PERKINS	3046T	81.0	60.0	W	T	N	V	D	94	120	5.00	0
PERKINS	4182	76.0	57.0	W	N	N	V	I	95	105	2.98	251
PERKINS	4236	80.0	60.0	W	N	N	V	D	98	127	3.86	257
PERKINS	4248	81.0	60.0	W	N	N	V	D	101	127	4.07	257
PERKINS	PHASER 90	86.0	64.0	W	N	N	V	D	100	127	3.98	273

Manufacturer	Mfr Model	Int HP	Kw Rating	Cool	Asp	Inter-cool	Valve Cam	Fuel Distr	Bore	Stroke	Displace	Weight
ROVER CARS	2.0L4DIT	80.0	60.0	W	T	N	C	D	84	89	1.99	132
ARROW SPEC	VRD330	80.0	59.6	W	N	N	V	D	98	118	5.41	368
CONS DIESEL	4B3.9	78.0	56.7	W	N	N	V	D	102	120	3.92	266
DEERE	4039D	80.0	59.6	W	N	N	V	D	106	110	3.92	422
DEERE	4045D	85.0	63.4	W	N	N	V	D	106	127	4.52	474
HERCULES	D-2300T	80.0	59.6	W	T	N	V	D	102	114	3.70	325
HERCULES	D-3300T	93.0	69.3	W	T	N	V	D	102	114	5.56	477
WIS-CON	TMDT27	80.0	59.6	W	T	N	V	I	91	103	2.70	270
TAM	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320
TORPEDO	F4L912	80.0	60.0	A	N	N	V	D	100	120	3.77	320

APPENDIX B
Volkswagen 1.9L Engine Specifications

Specifications for Volkswagen Industrial Engine.

AFD 1.9 ltr. TDI-Diesel Engine

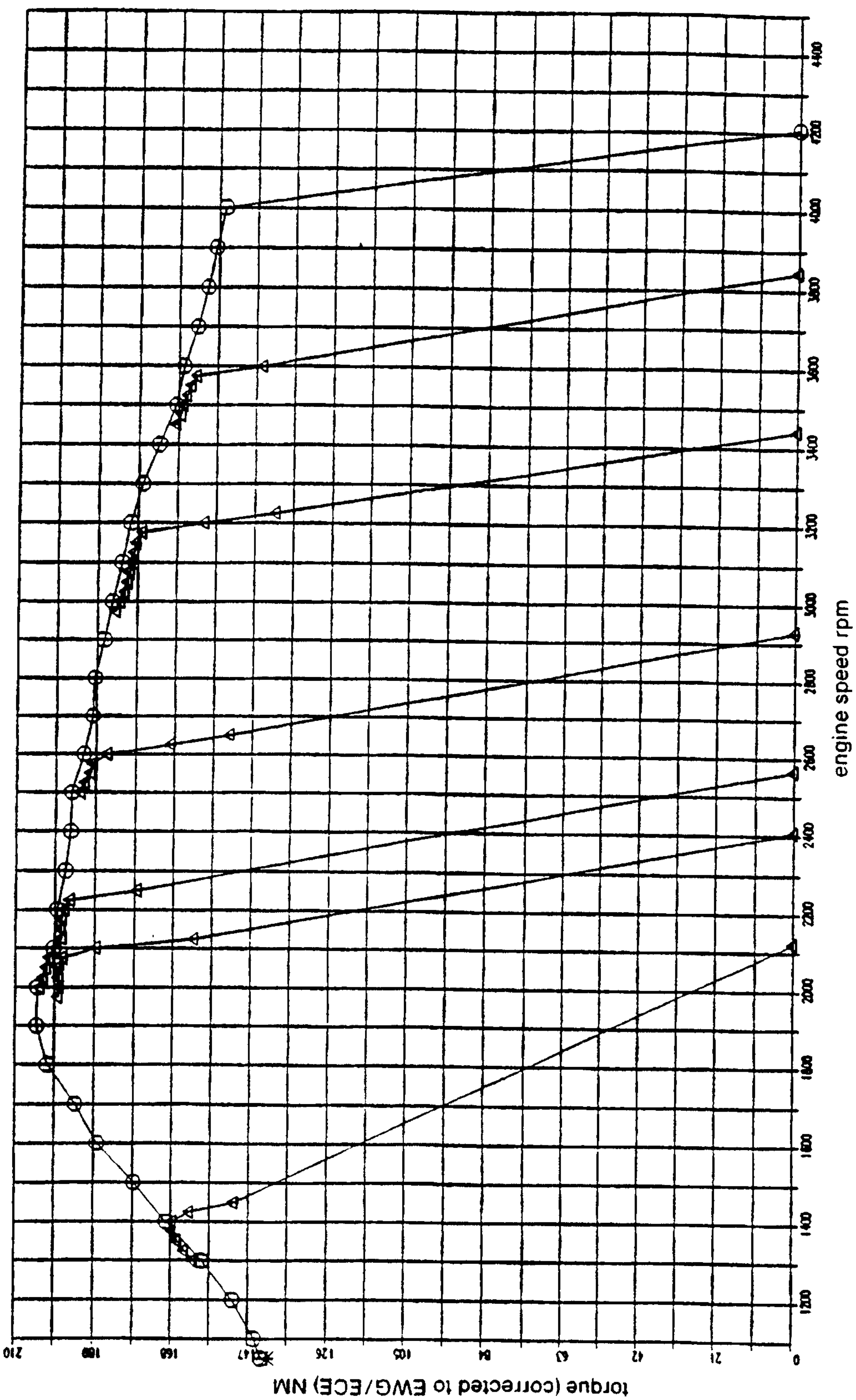


VOLKSWAGEN AG, WOLFSBURG

Volksvagen
Industrial Engines
AFD

GOVERNED CONTROL UNIT
1000 to 4000 rpm

07.94



INTRODUCTION

The Volkswagen Industrial Engine with the engine code **AFD** is a 1,9 ltr. water-cooled, fourcylinder, in-line, Diesel engine with direct injection, turbo-charger, intercooler and oxidation catalyst.
With the multitude of possible applications of this engine it is essential to adhere to the recommendations on the following pages when developing new equipment. This will ensure proper operation and a long service life of the entire assembly under all operating conditions.

Design: Direct valve operation via an overhead camshaft (OHC) driven with a toothed belt. Maintenance-free valve timing gear with hydraulic tappets. Distributor fuel injection pump driven with a toothed belt and electronically regulated by control unit.

Diplacement	cm^3	1896
Bore / stroke	mm	79,5 / 95,5
Compression ratio		19,5
Firing order		1 - 3 - 4 - 2
Output		
with control unit		
(automotive version - Golf A3)		
Nmax at 4000 rpm	kW	66 (89/491/EWG)
upper idling speed	rpm	5000...5200 (not adjustable)
lower idling speed	rpm	860...940 (not adjustable)
Charging pressure	bar (atmos)	0,60 - 0,80
Installation angle	$\angle$°	20
Distributor injection pump	Manufacturer	Bosch
Control unit	Manufacturer	Bosch
Fuel		Diesel
Cetan requirement	CN	> 45
as per	DIN	51601
Fuel consumption	g/kW h	see Page 2
Alternator 12 V	A	90
Starter 12 V	kW	1,8
Battery 12 V	A (Ah)	380 (63) minimum capacity
Glow plugs	V	12

FILLING CAPACITIES

Cooling system	ltr.	approx. 5 - 6 (depending on cooling system)

For first filling, pour in coolant slowly up to Max.-marking while continuosly bleeding cooling system of air. Allow engine to warm up until thermostat is fully open. Switch off engine and allow to cool down before checking and correcting coolant level.

I M P O R T A N T !
Do not open radiator cap while engine is hot, as coolant system is pressurised.
- DANGER OF SCALDING -

Oil circuit		
with filter change	ltr.	4,5
Difference between Min.- und Max.-marking on dipstick	ltr.	approx. 1,0

TEMPERATURES

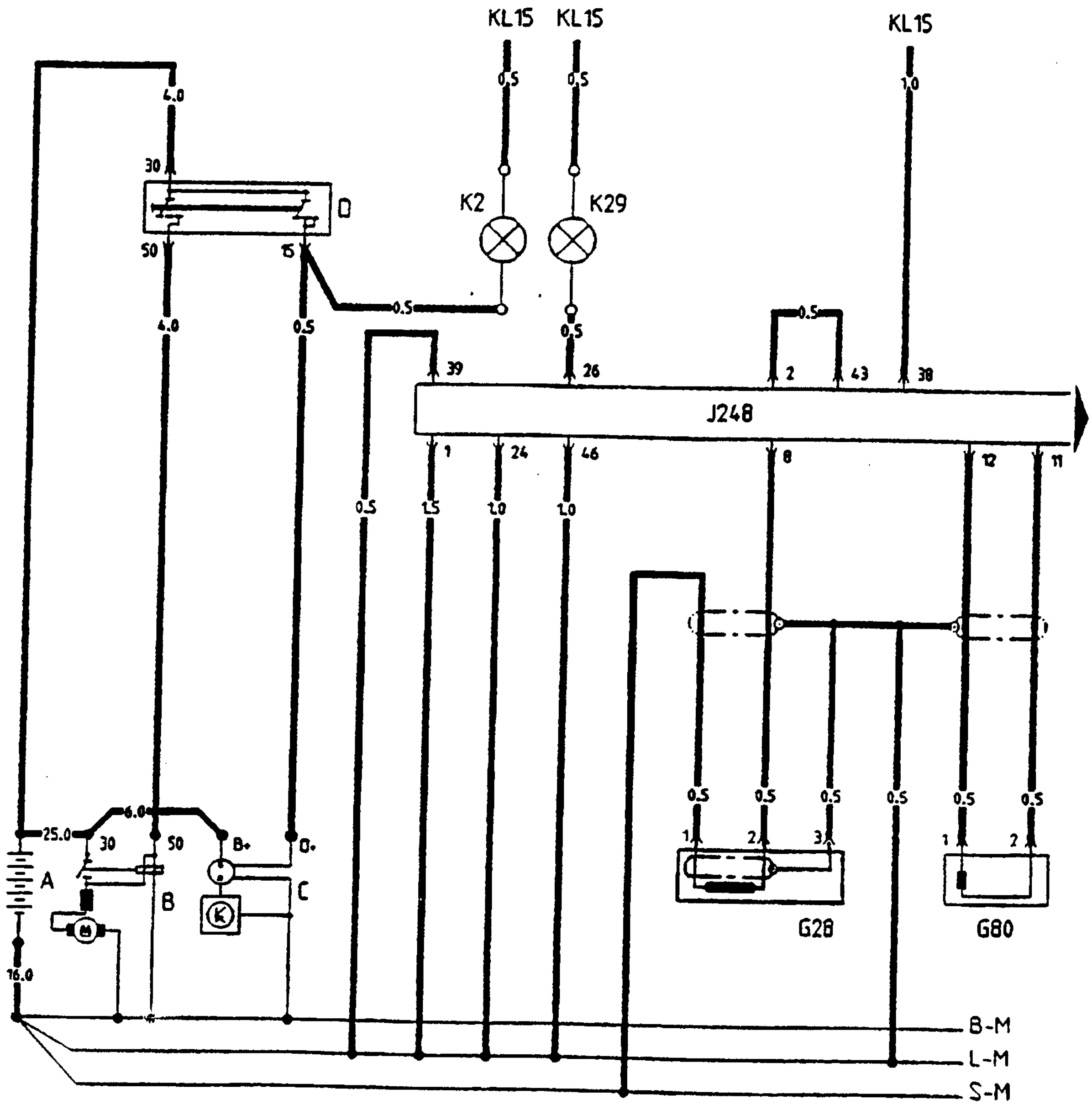
Coolant		
permissible temperature	°C (°F)	105 (221) continuous operation
	°C (°F)	118 (244) absolute limit
Thermostat		
fully open	°C (°F)	102 (216)
starts opening at	°C (°F)	87 (189)
Temperature contact switch		
switches on at	°C (°F)	110 ± 3 (230 ± 5)
Engine oil		
permissible max. temperature	°C (°F)	130 (266) in oil sump

Volkswagen
Industrial Engines
AFD

Wiring diagramm

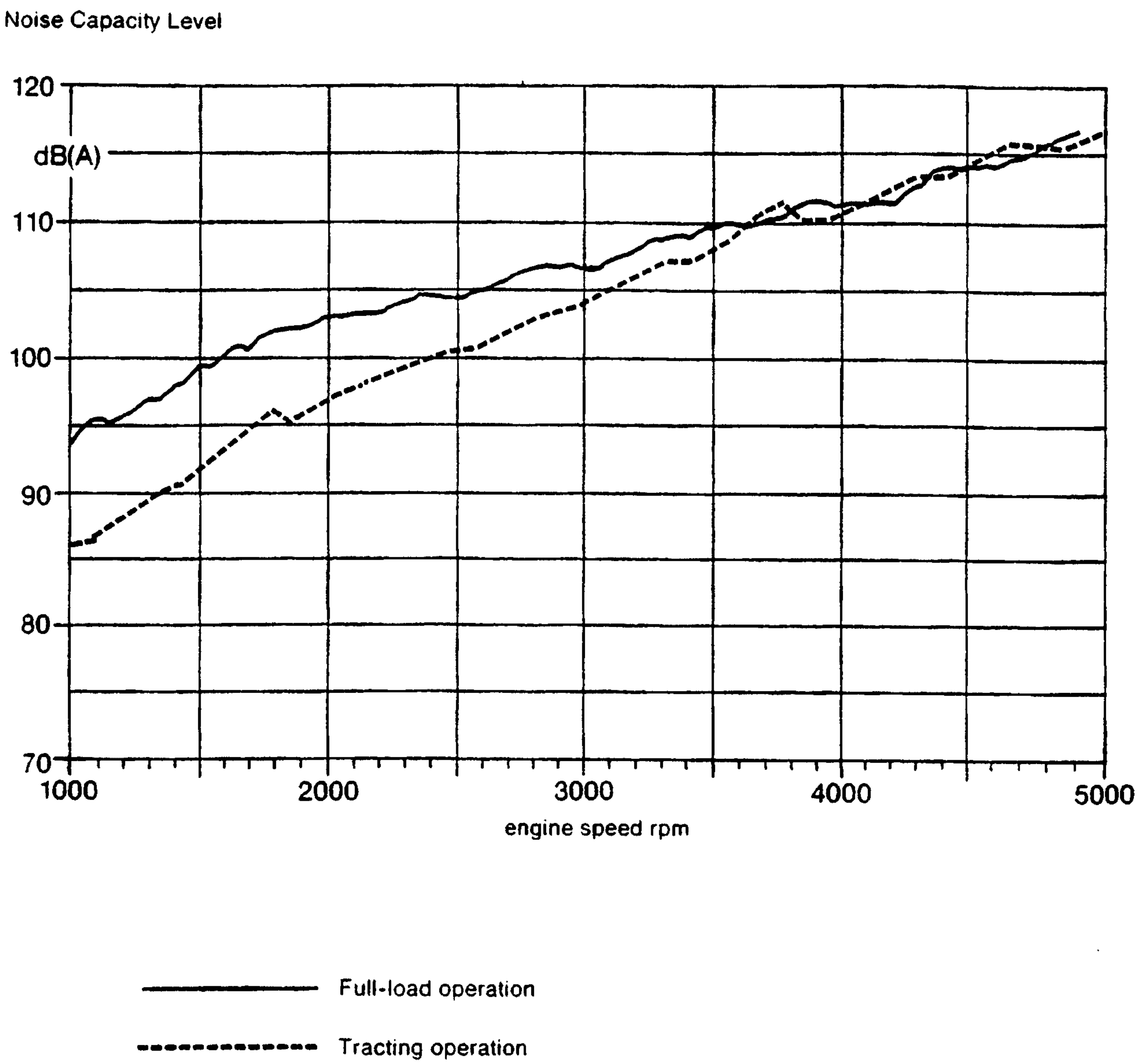
8

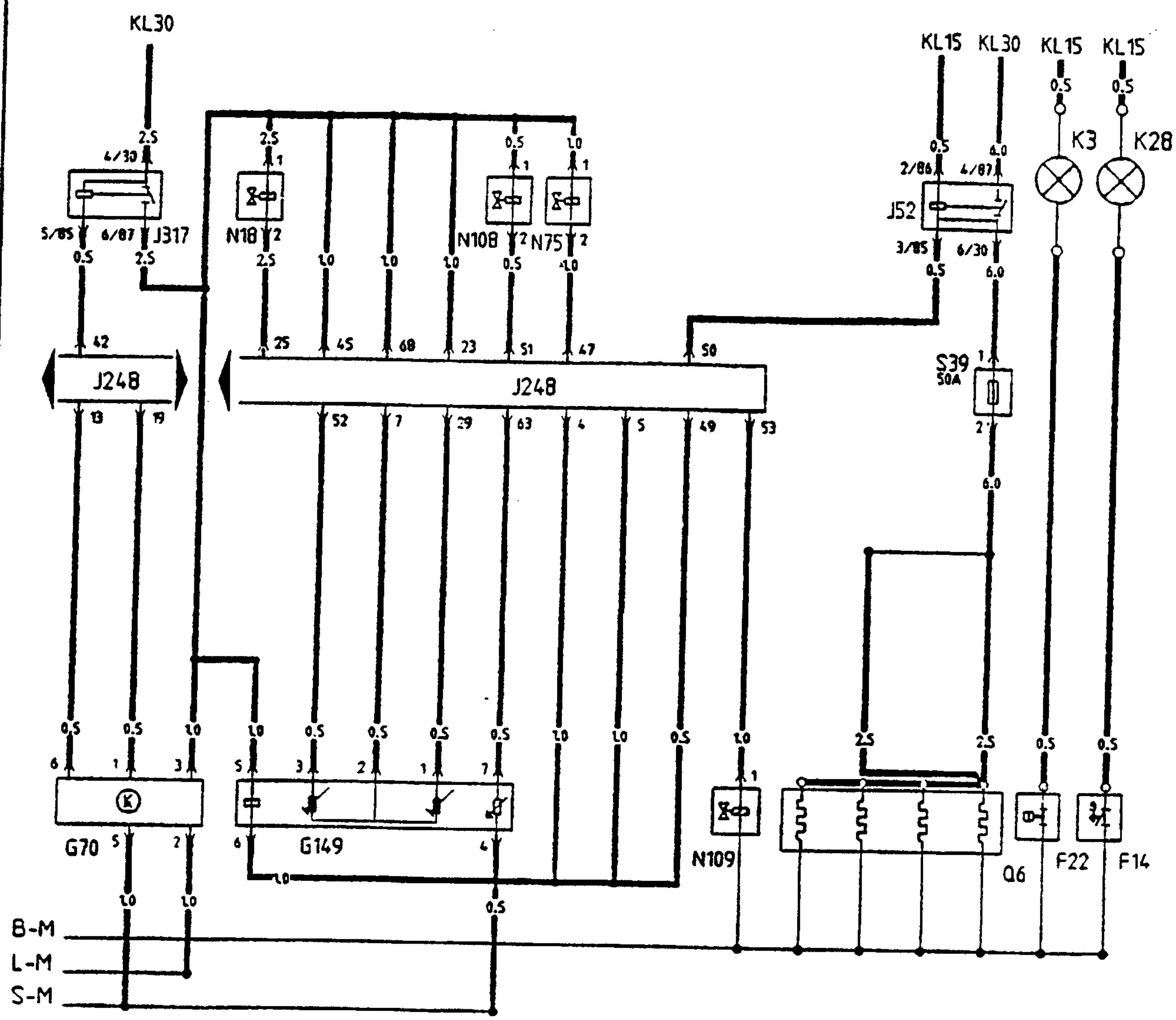
11.94



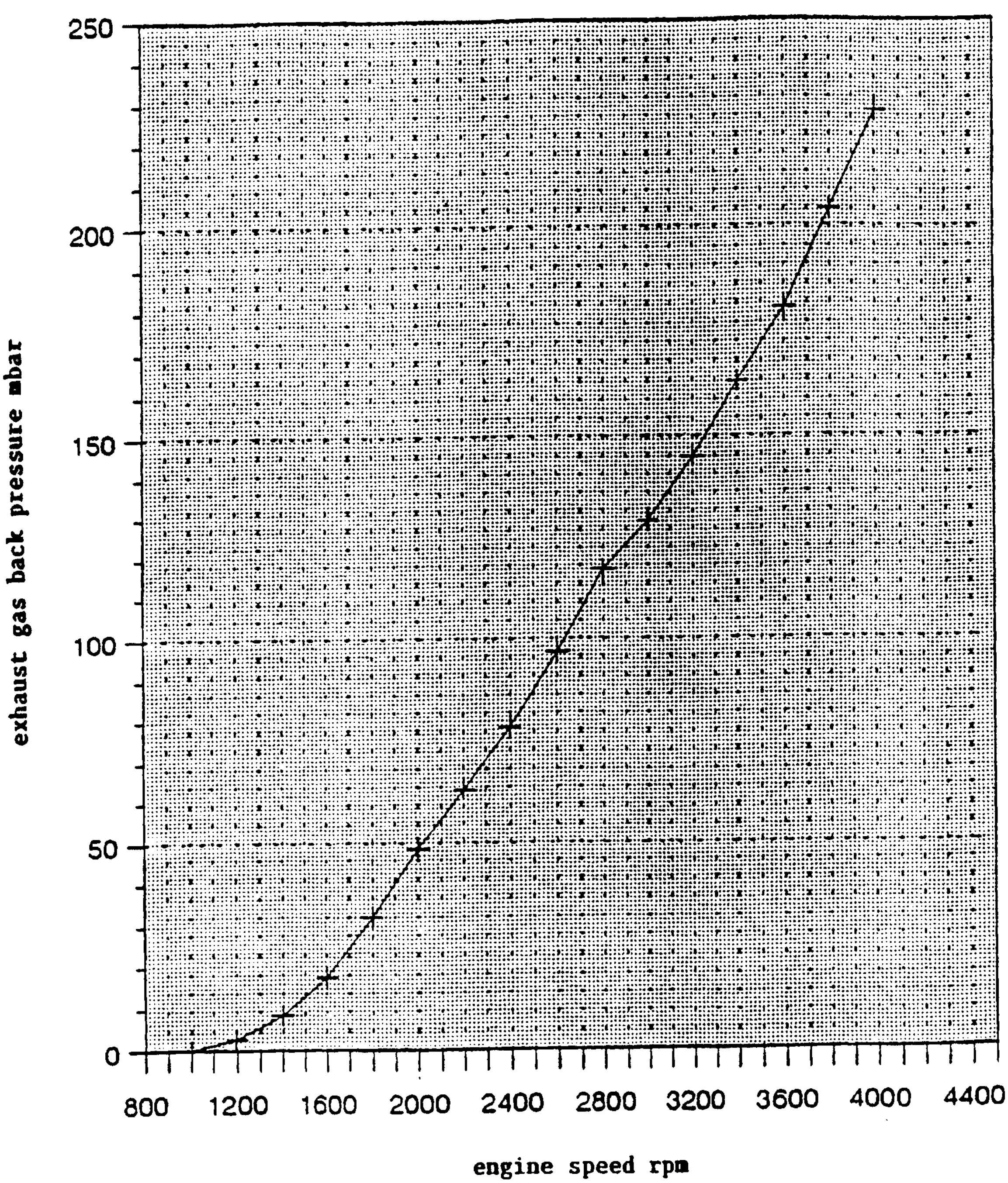
B-M - Battery earth / engine earth
L-M - EDC earth
S-M - Sender earth

A - Battery
B - Starter
C - Alternator
D - Starter switch
G 28 - Engine speed sender
G 80 - Needle lift sender
K 2 - Alternator warning lamp
K 29 - Engine management system and glow period warning lamp
J 248 - EDC control unit


Noise Capacity Level
120
dB(A)
110
100
90
80
70
1000
2000
3000
4000
5000
engine speed rpm
Full-load operation
Tracting operation

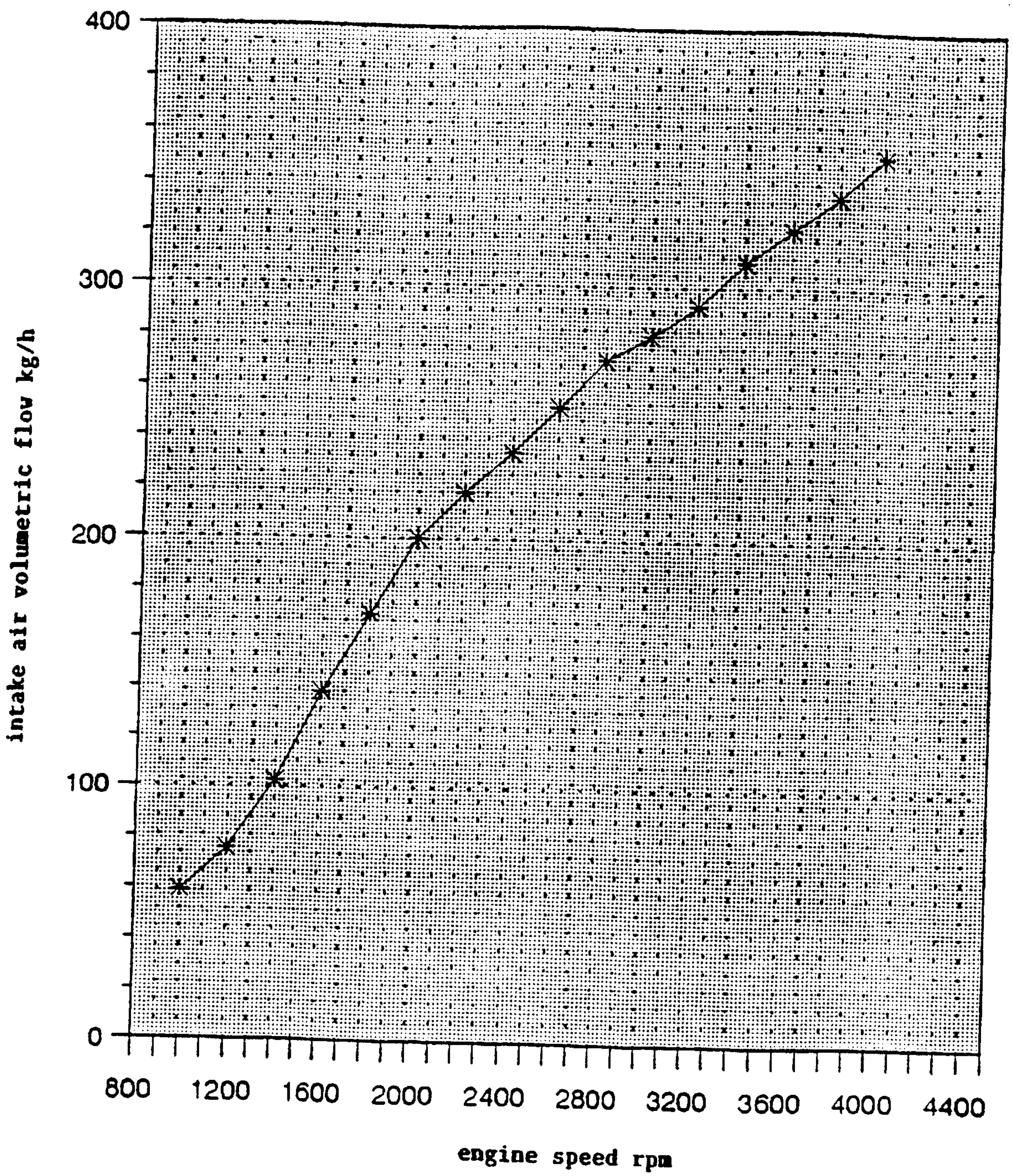


F 14 - Coolant temperature control switch (110 °C)
F 22 - Oil pressure switch (0,25 bar)
G 70 - Air mass meter
G 149 - Control plunger travel sender
N 18 - Exhaust gas recirculation valve
N 75 - Boost pressure control solenoid valve
N 108 - Start of injection valve
N 109 - Fuel cut-off valve
J 52 - Glow plug relay
J 317 - Relay for voltage supply
K 3 - Oil pressure warning lamp
K 28 - Coolant temperature warning lamp
S 39 - Strip fuse (50 A)
Q 6 - Glow plug



engine speed rpm	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000
temperature °C	501	484	483	469	471	479	493	511	535	542	560	575	576	582	608	627

Volkswagen **Industrial Engines** **AFD**	**Air volumetric flow**	16 **10.94**



engine speed rpm	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200	3400	3600	3800	4000
volumetric flow kg/h	58,7	75	102	138	170	200	218	234	252	271	281	293	310	323	336	352

APPENDIX C
Steady-State Test Results

APU testing UDLC 55kw

amb temp	67	Test date	3/4/97	Fuel	AL 24507F
amb baro	28.99			HC btu/#	18,377

Run	elec kw	rpm	bat volts	fuel #	fuel time	fuel #/hr	inlet F	inv in F	gen out F	% eff	% gen eff
1	0	900	294	0.25	875.07	1.02	85	80	81	0	0
2	10	1640	321	0.25	159.1	5.64	88	85	87	32.6	87.5
3	25	2390	301	0.25	64.34	13.98	107	87	91	33.2	90
4	35	2790	322	0.5	90.28	19.92	126	90	95	32.6	91.1
5	45	3210	335	0.5	68.57	26.22	133	92	98	31.9	91.7
6	55	3800	350	0.5	54.11	33.26	135	92	99	30.7	92.1

Run	Heat Exchanger airflow ft/min								
location	1	2	3	4	5	6	avg	cu-ft/min	#/min
1	0	50	50	0	50	0	25	54	3.9
2	150	200	150	300	300	50	192	415	30.3
3	400	400	400	400	500	150	375	810	59.1
4	400	400	400	300	500	500	342	900	65.6
5	400	600	600	400	600	350	492	1063	77.5
6	500	700	700	700	700	400	617	1333	97.2

APPENDIX D
Complete APU Wiring Diagrams for the M113 APU

SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO TEXAS, USA 78228-0510 • (210) 684-5111 • TELEX 244846

ENGINE, FUEL, AND VEHICLE RESEARCH DIVISION
TELECOPIER: (210) 522-5720

March 17, 1997

Mr. Gordon Shafer
United Defense LP
Ground Systems Division
P.O. Box 58123
Santa Clara, CA 95052-8123

Dear Mr. Shafer,

I am enclosing the documentation related to the HMMWV APU that SwRI recently sent you. It should include a number of wiring descriptions and wiring diagrams as described below:

1. *UDC APU Controller External Wiring Description* - These two pages describe the signals and corresponding pin numbers associated to each of the five connectors on the SwRI-supplied APU Interface box.

2. *UDC APU Controller External Wiring Description Diagram* - In addition to the information described above, this diagram also illustrates the SwRI harnesses supplied with the APU. Please note that SwRI is NOT supplying the harnesses for connectors #1 and #2 as agreed earlier in the program. Also note that connector #3 connects to the Engine Harness via connector F2 and C2 described on a separate diagram.

3. *Modified VW 1.9L Engine Harness Diagram* - This diagram illustrates the modifications that were made to the original stock VW engine harness #3A1-971-072 CD. Several connectors not used by the system were eliminated or hard-wired for clarity. Please note that connectors labeled B2 and D2 were shorted out (the connectors were actually removed). Also note that the ECU interface harness and relays connected to connector #3 of the APU Controller box were included in this diagram to illustrate the proper connection in case the relays or weather pack connector became separated during shipping. Connector Q2 should remain disconnected during normal operation. It is intended to be used with a special VW engine diagnostic box during troubleshooting.

4. *VW ECU 68-Pin Connector Diagram* - This is a VW-supplied diagram that illustrates each of the pins being used. It is supplied as a reference only since not all of the sensors shown are connected to this connector. Please note that this diagram does not show the three additional resistors attached to pins #10, #27, #33, #45, and #56 as shown in the "Modified VW 1.9L Engine Harness Diagram."

5. *VW 1.9L TDI Engine Harness Sketch* - This sketch is supplied for future reference. It provides a pictorial view of the physical location of the stock, VW-engine harness connectors before modifications were made to them. Note that the connectors are basically bundled into the sections: Section 1 (labeled from A to J), Section 2 (A to S), and Section 3 (A to E).

6. *VW 1.9L Engine Harness Diagram* - This is a diagram of the original, stock VW engine harness before any modifications were made to it. It provides additional information not included in the sketch of the harness such as number of wires attached to each connector, wire color codes, etc. Note that the numbering system list on the right side of the diagram (and half-way down the diagram) shows the sensors attached to the engine. A separate sheet is provided that shows the same information more clearly. Please note that all the sensors are not being used as it was pointed out earlier.

7. *VW and SwRI Numbering System List* - This page duplicates the information provided in the diagrams described above (items #3 and #6). It more clearly shows the sensors illustrated in the previous diagrams.

If you have any questions regarding these diagrams, please do not hesitate to call me at (210) 522-2629 or e-mail me a message (jsteiber@swri.org). For your convenience, my fax number is (210) 522-5720.

Sincerely,

Joe Steiber

Joe Steiber
Research Engineer
Advanced Vehicle Technology

/krp

Enclosures

UDC APU Controller External Wiring Description

Rev 0 - March 6, 1997

Connector #1 - Bus Power Interface

Pin	Desc.
R	Engine Ground
S	VBus -
U	VBus +

Connector #2 - Vehicle Control Interface

Pin	Desc.
1	APU Power Request +
2	APU Power Request -
3	Coolant Temperature +
4	Coolant Temperature -
5	Engine Speed +
6	Engine Speed -
7	Actual APU Power +
8	Actual APU Power -
9	APU On/Off +
10	APU On/Off -
11	Engine On/Off +
12	Engine On/Off -
13	APU Fault +
14	APU Fault -
17	Unique Mobility Over Temp +
18	Unique Mobility Over Temp -

Connector #3 - Engine Control Interface

Pin	Desc.
A	ECU Continuous Power
C	ECU Switched Power
D	Idle Validation +
F	Pedal Command +
G	Idle Validation -
H	Pedal Command -

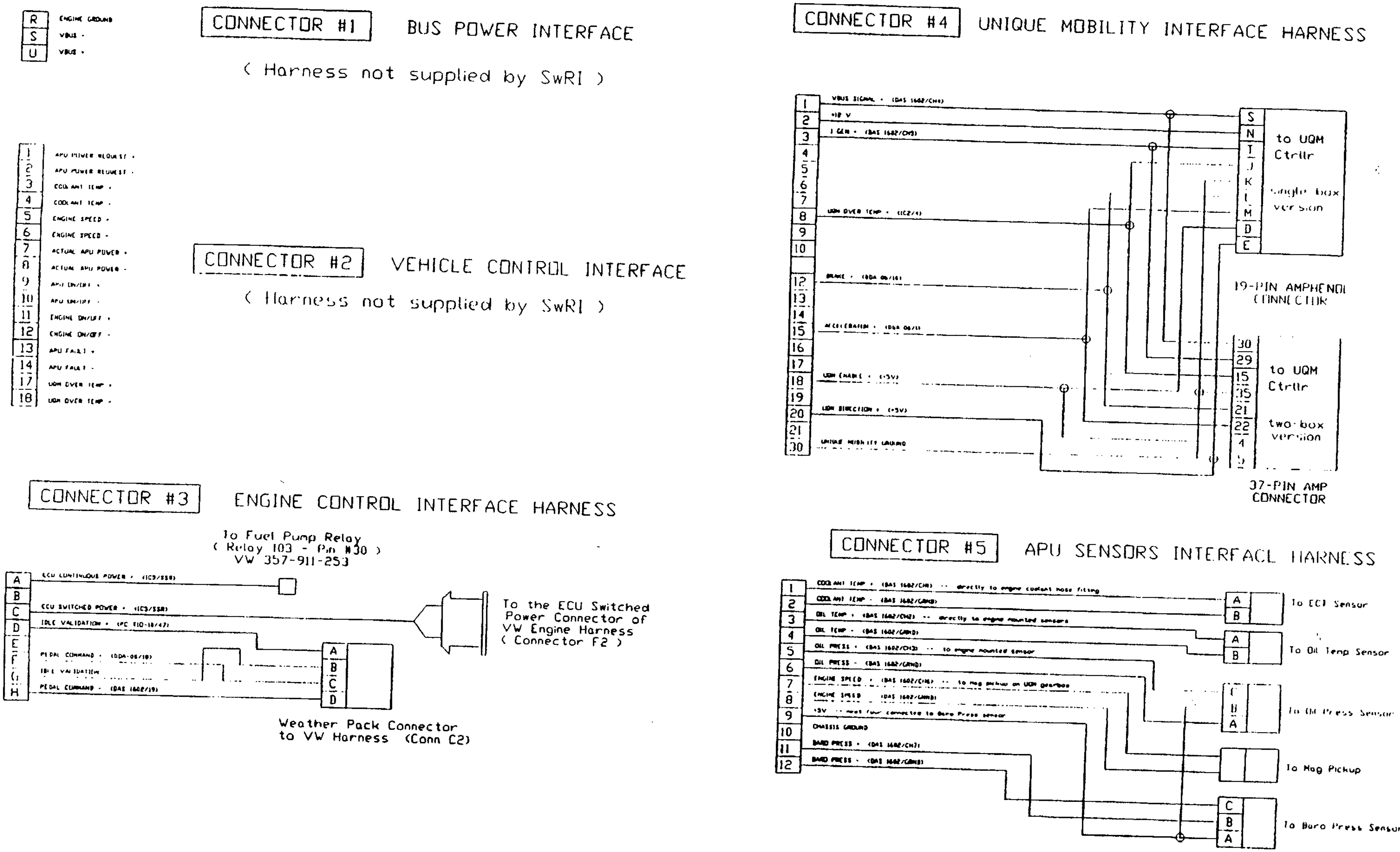
Connector #4 - Unique Mobility Interface

Pin	Desc.
1	VBus Signal
2	+12V
3	IGen Signal
8	U.M. Over Temp +
12	Brake Signal
15	Accelerator Signal
18	U.M. Enable
20	U.M. Direction
30	U.M. Gnd

Connector #5 - APU Sensor Interface

Pin	Desc.
1	Coolant Temperature +
2	Coolant Temperature -
3	Oil Temperature +
4	Oil Temperature -
5	Oil Pressure +
6	Oil Pressure -
7	Engine Speed +
8	Engine Speed -
9	+5V
10	Gnd
11	Barometric Pressure +
12	Barometric Pressure -

UDC APU CONTROLLER EXTERNAL WIRING DESCRIPTION



APPENDIX E
Complete Wiring Diagrams for the HMMWV APU

SOUTHWEST RESEARCH INSTITUTE

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ENGINE, FUEL, AND VEHICLE RESEARCH DIVISION
TELECOPIER: (210) 522-5720

March 17, 1997

Ms. Kathy Bearden
MARCAV Program Manager
Concurrent Technologies Corporation
1450 Scalp Avenue
Johnstown, PA 15902-3450

Dear Ms. Bearden,

I am enclosing the documentation related to the HMMWV APU that SwRI recently sent you. It should include a number of wiring descriptions and wiring diagrams as described below:

1. *CTC APU Controller External Wiring Description* - These two pages describe the signals and corresponding pin numbers associated to each of the five connectors on the SwRI-supplied APU Interface box.

2. *CTC APU Controller External Wiring Description Diagram* - In addition to the information described above, this diagram also illustrates the SwRI harnesses supplied with the APU. Please note that SwRI is NOT supplying the harnesses for connectors #1 and #2 as agreed earlier in the program. Also note that connector #3 connects to the Engine Harness via connector F2 and C2 described on a separate diagram.

3. *Modified VW 1.9L Engine Harness Diagram* - This diagram illustrates the modifications that were made to the original stock VW engine harness #3A1-971-072 CD. Several connectors not used by the system were eliminated or hard-wired for clarity. Please note that connectors labeled B2 and D2 were shorted out (the connectors were actually removed). Also note that the ECU interface harness and relays connected to connector #3 of the APU Controller box were included in this diagram to illustrate the proper connection in case the relays or weather pack connector became separated during shipping. Connector Q2 should remain disconnected during normal operation. It is intended to be used with a special VW engine diagnostic box during troubleshooting.

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6. *VW 1.9L Engine Harness Diagram* - This is a diagram of the original, stock VW engine harness before any modifications were made to it. It provides additional information not included in the sketch of the harness such as number of wires attached to each connector, wire color codes, etc. Note that the numbering system list on the right side of the diagram (and half-way down the diagram) shows the sensors attached to the engine. A separate sheet is provided that shows the same information more clearly. Please note that all the sensors are not being used as it was pointed out earlier.

7. *VW and SwRI Numbering System List* - This page duplicates the information provided in the diagrams described above (items #3 and #6). It more clearly shows the sensors illustrated in the previous diagrams.

If you have any questions regarding these diagrams, please do not hesitate to call me at (210) 522-2629 or e-mail me a message (jsteiber@swri.org). For your convenience, my fax number is (210) 522-5720.

Sincerely,

Joe Steiber

Joe Steiber
Research Engineer
Advanced Vehicle Technology

/krp

Enclosures

CTC APU Controller External Wiring Description

Rev 0 - March 6, 1997

Main APU Control Enclosure Connectors:

Connector #1 - Bus Power Interface

Pin	Desc.
S	Gnd
U	+12V (High Current)
V	+5V
W	+12V (Low Current)
X	-12V
Y	Gnd

Connector #2 - Vehicle Control Interface

Pin	Desc.
1	Silent Run Mode Return
2	Silent Run Mode +
3	Pedal Kick Down Return
4	Pedal Kick Down +
5	Serial Port Tx
6	Serial Port Rx
7	Serial Port Gnd

Connector #3 - Engine Control Interface

Pin	Desc.
A	ECU Continuous Power
C	ECU Switched Power
D	Idle Validation +
F	Pedal Command +
G	Idle Validation -
H	Pedal Command -

Connector #4 - Unique Mobility Interface

Pin	Desc.
1	VBus Signal
2	+12V
3	IGen Signal
8	U.M. Over Temp +
12	Brake Signal
15	Accelerator Signal
18	U.M. Enable
20	U.M. Direction
30	U.M. Gnd

Connector #5 - APU Sensor Interface

Pin	Desc.
1	Coolant Temperature +
2	Coolant Temperature -
3	Oil Temperature +
4	Oil Temperature -
5	Oil Pressure +
6	Oil Pressure -
7	Engine Speed +
8	Engine Speed -
9	+5V
11	Barometric Pressure +
12	Barometric Pressure -

Power Converter Enclosure Connectors

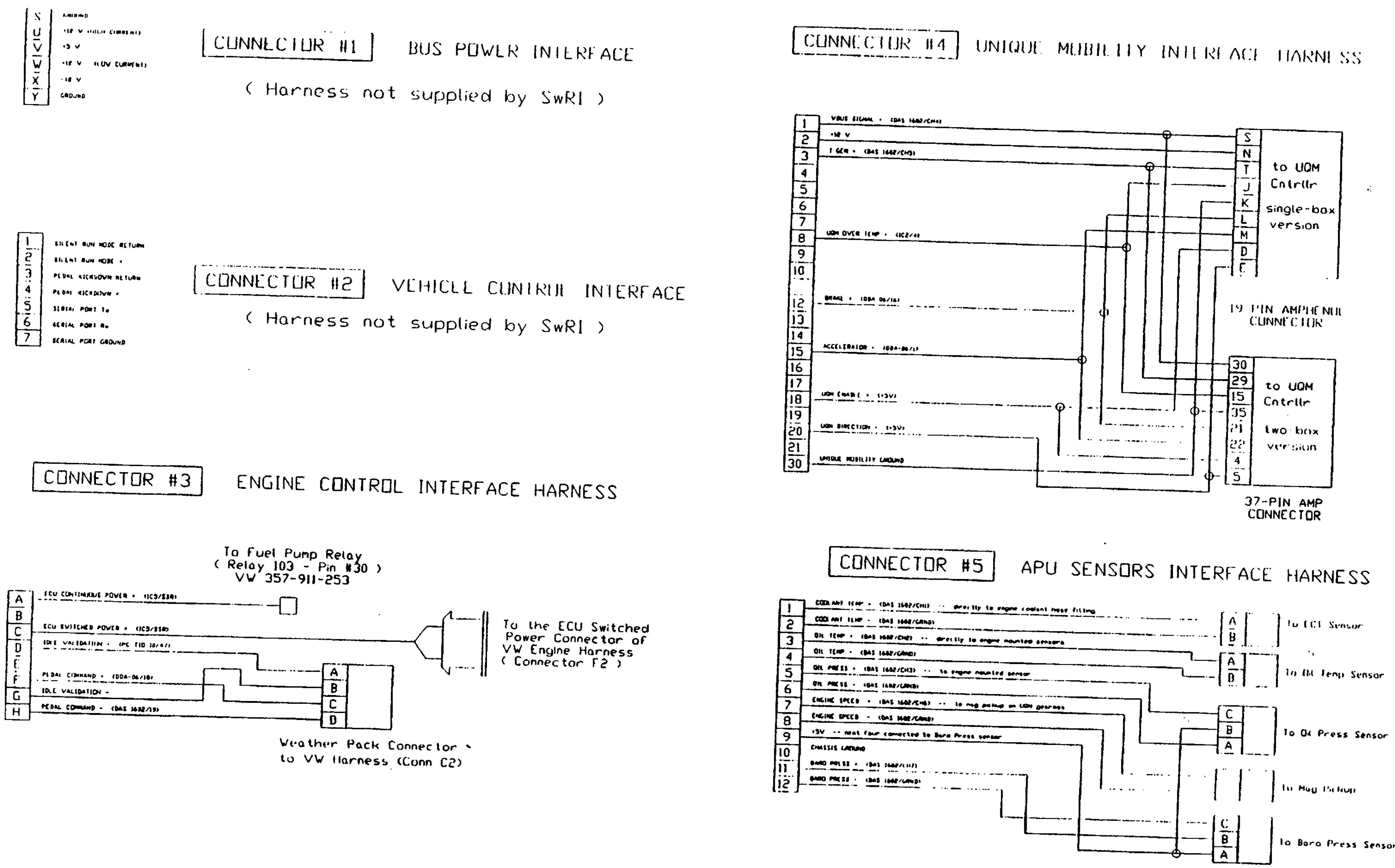
"IN" Connector

Pin	Desc.
3	VBus -
8	VBus +

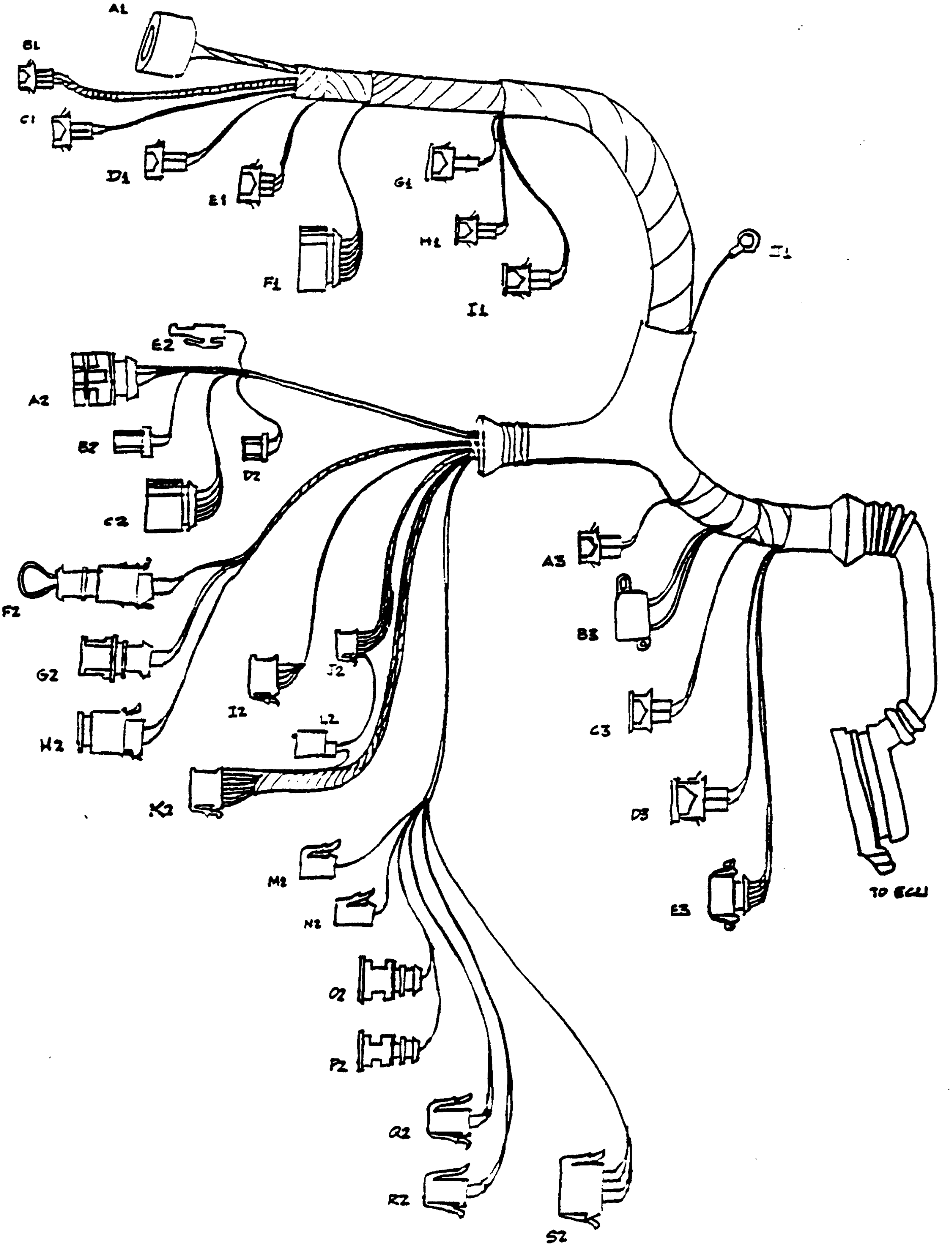
"OUT" Connector

Pin	Desc.
R	Engine Ground (from Engine)
S	Gnd
U	+12V (High Current)
V	+5V
W	+12V (Low Current)
X	-12V
Y	Gnd

CTC APU CONTROLLER EXTERNAL WIRING DESCRIPTION



VW 1.9L TDI ENGINE HARNESS (3A1-971-072 CD)



* VW Numbering System
** SwR Numbering System

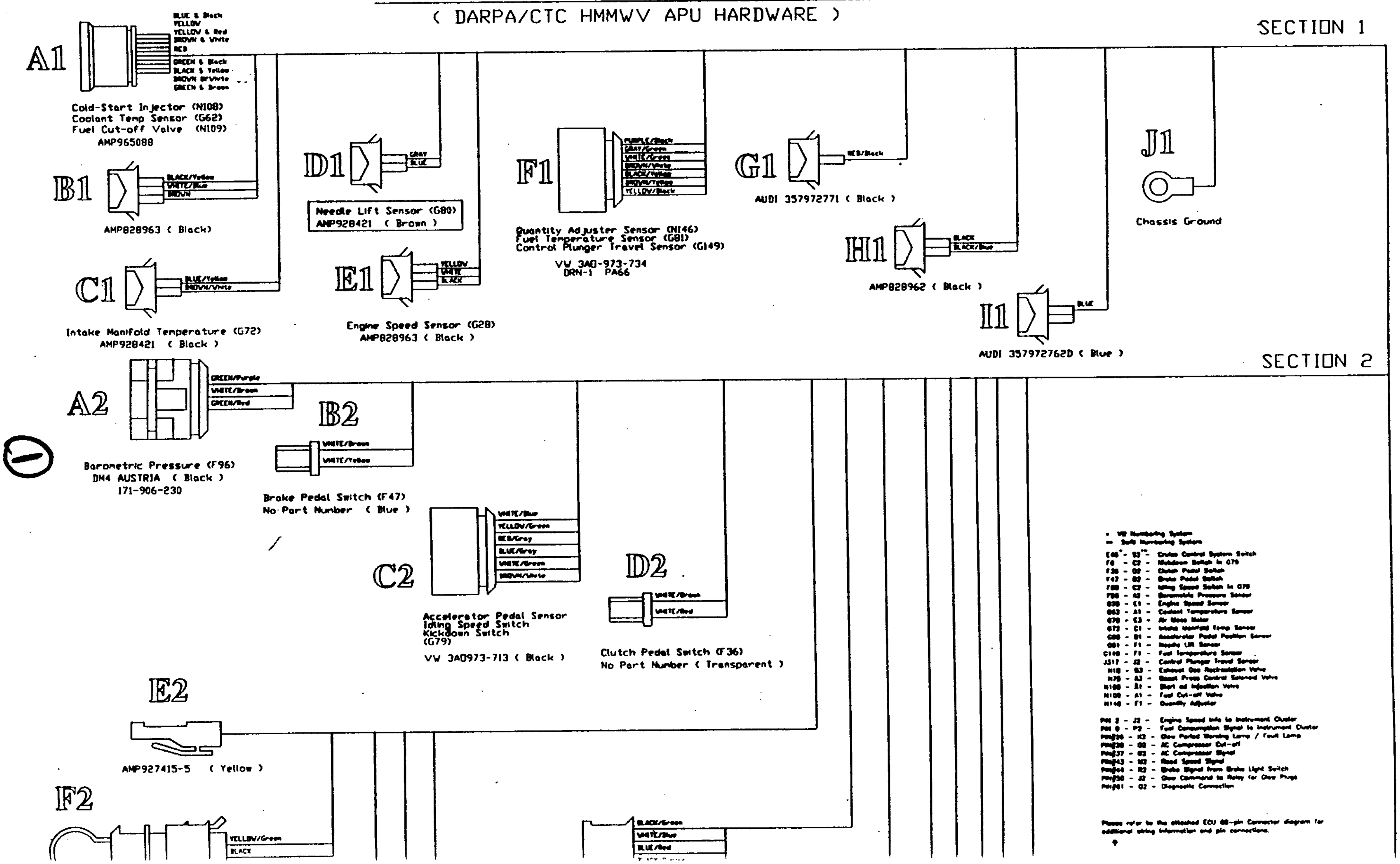
E45* – S2** – Cruise Control System Switch
F8 – C2 – Kickdown Switch in G79
F36 – D2 – Clutch Pedal Switch
F47 – B2 – Brake Pedal Switch
F60 – C2 – Idling Speed Switch in G79
F96 – A2 – Barometric Pressure Sensor
G28 – E1 – Engine Speed Sensor
G62 – A1 – Coolant Temperature Sensor
G70 – E3 – Air Mass Meter
G72 – C1 – Intake Manifold Temp Sensor
G80 – D1 – Accelerator Pedal Position Sensor
G81 – F1 – Needle Lift Sensor
G149 – F1 – Fuel Temperature Sensor
J317 – J2 – Control Plunger Travel Sensor
N18 – D3 – Exhaust Gas Recirculation Valve
N75 – A3 – Boost Press Control Solenoid Valve
N108 – A1 – Start of Injection Valve
N109 – A1 – Fuel Cut-off Valve
N146 – F1 – Quantity Adjuster

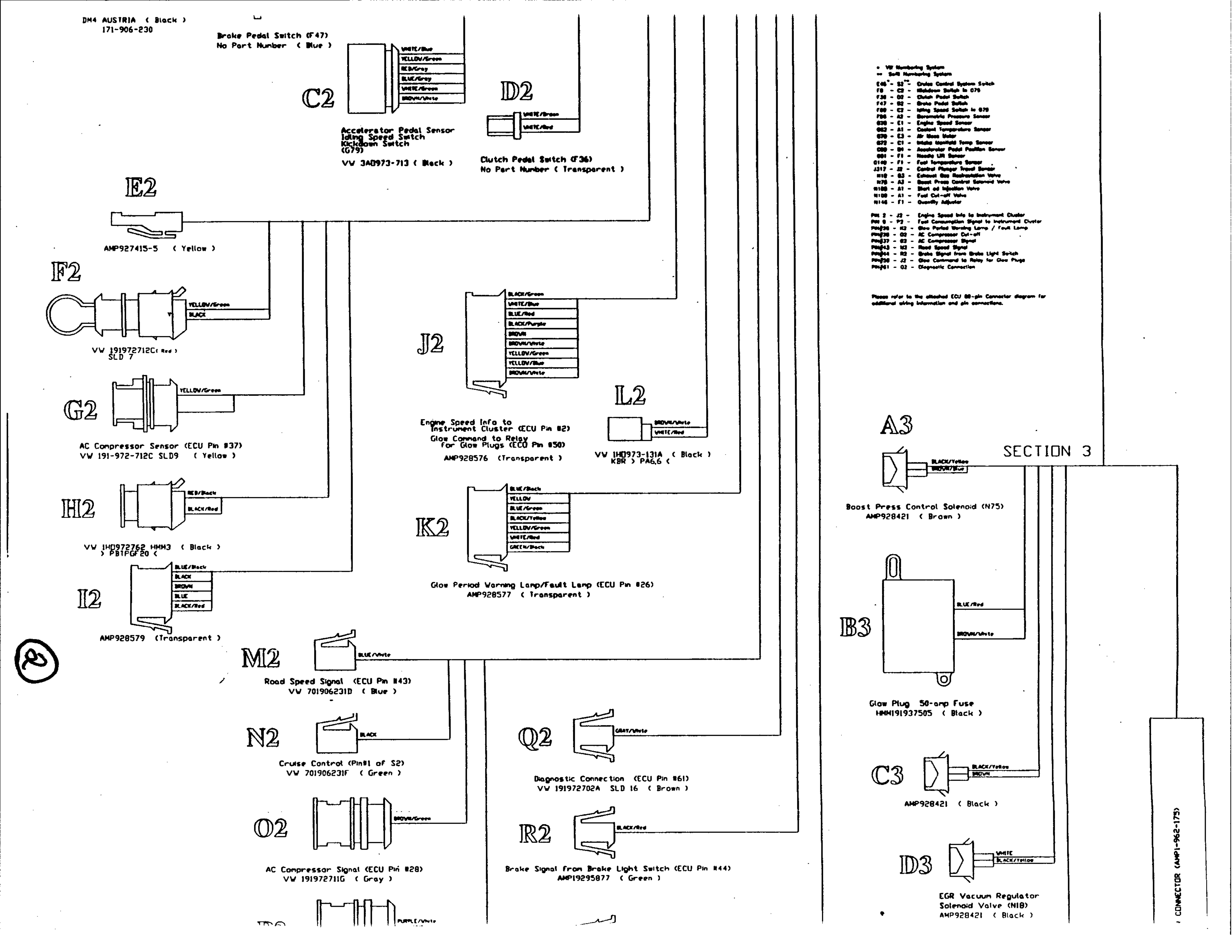
PIN 2 – J2 – Engine Speed Info to Instrument Cluster
PIN 9 – P2 – Fuel Consumption Signal to Instrument Cluster
PIN#26 – K2 – Glow Period Warning Lamp / Fault Lamp
PIN#28 – O2 – AC Compressor Cut-off
PIN#37 – G2 – AC Compressor Signal
PIN#43 – M2 – Road Speed Signal
PIN#44 – R2 – Brake Signal from Brake Light Switch
PIN#50 – J2 – Glow Command to Relay for Glow Plugs
PIN#61 – Q2 – Diagnostic Connection

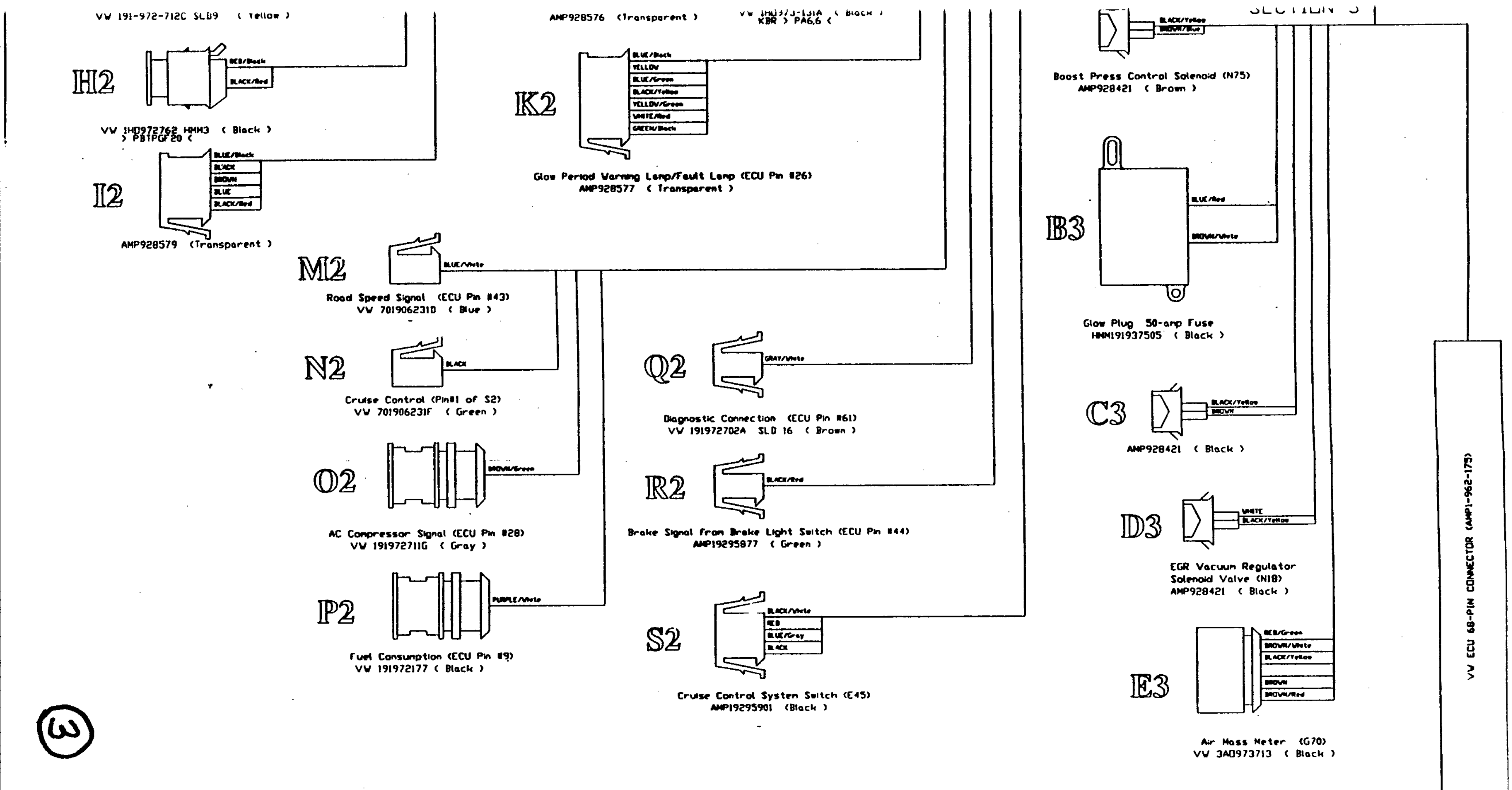
Please refer to the attached ECU 68-pin Connector diagram for additional wiring information and pin connections.

VW 1.9L ENGINE HARNESS 3A1-971-072 CD

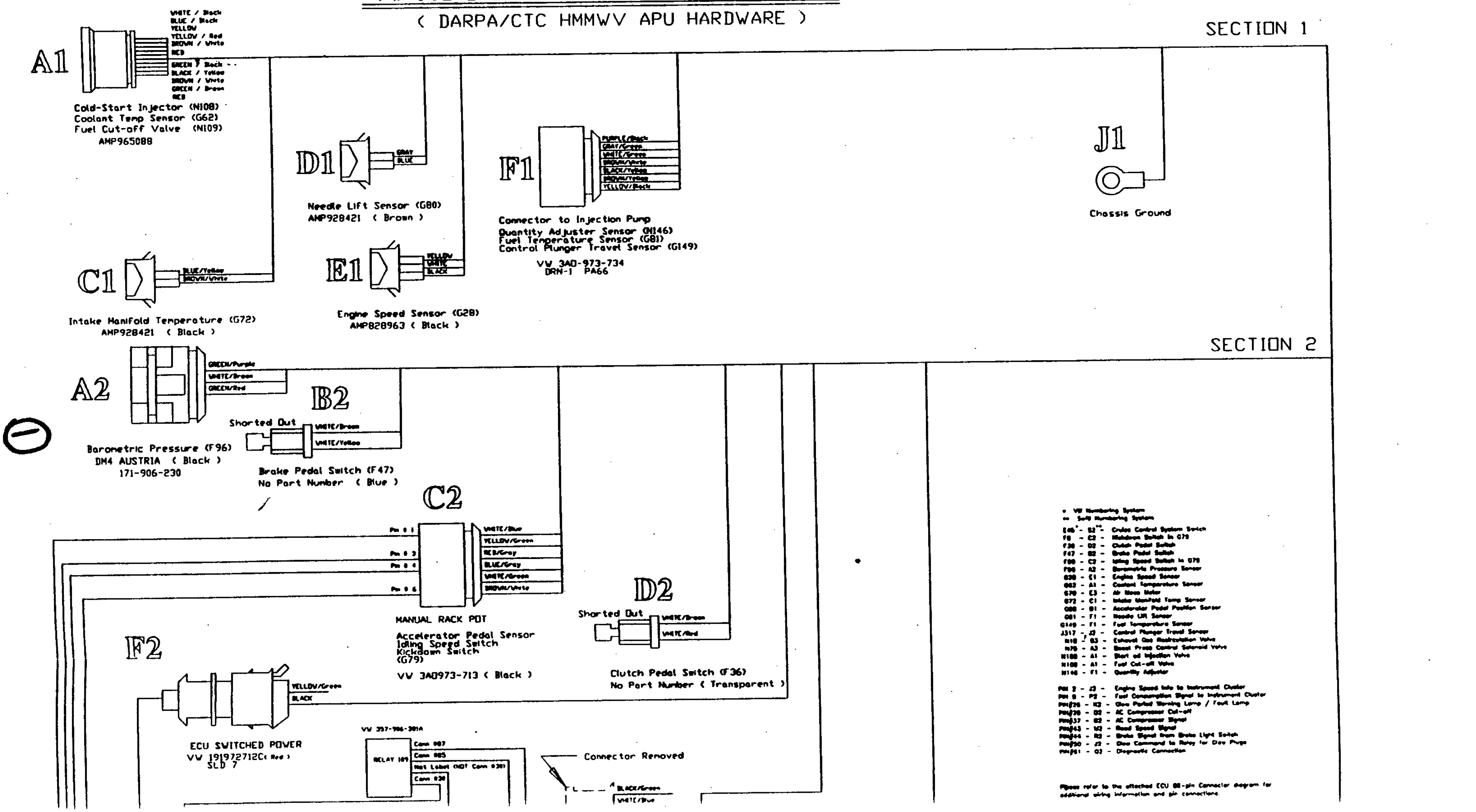
(DARPA/CTC HMMWV APU HARDWARE)

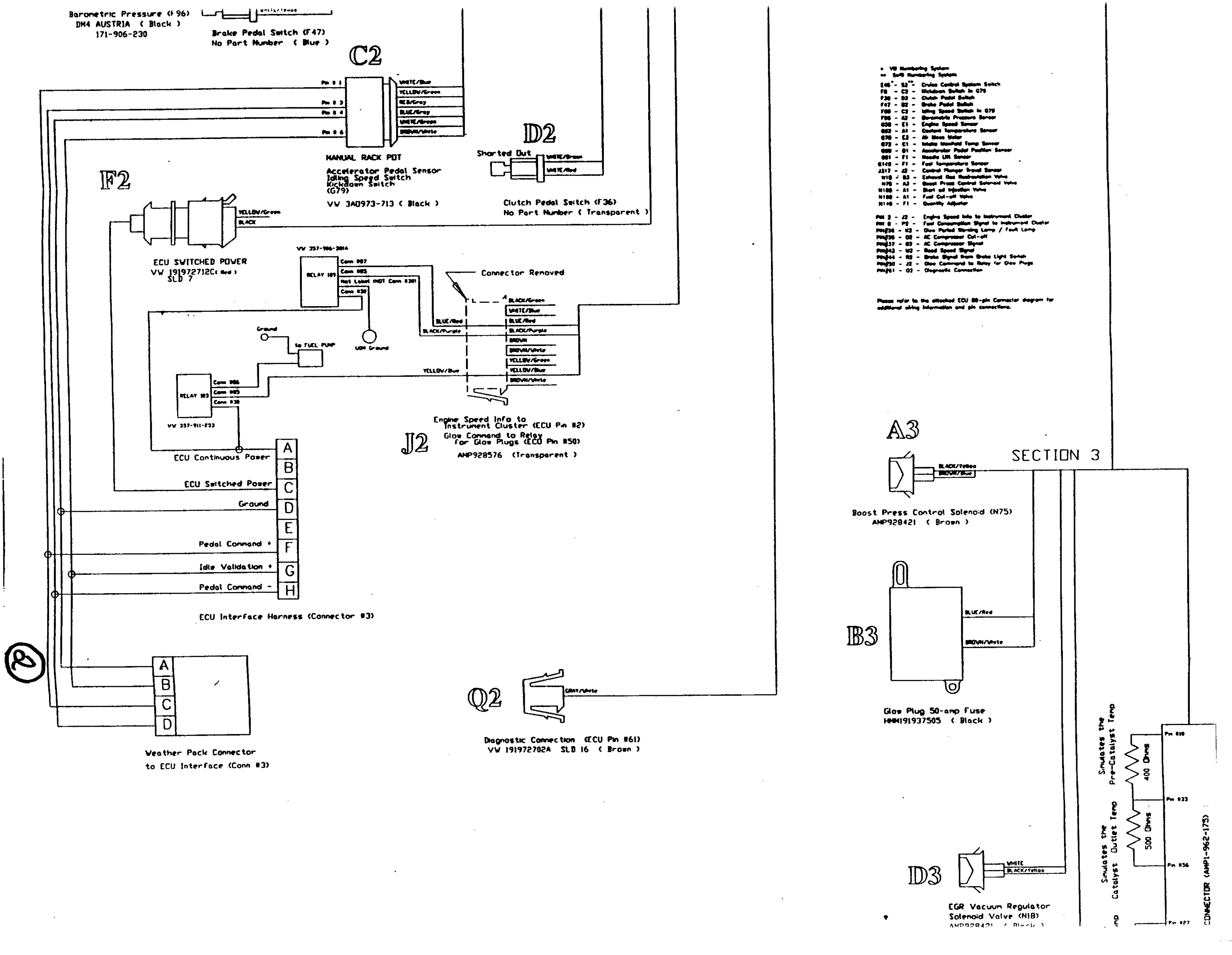



DM4 AUSTRIA (Black)
171-906-230
Brake Pedal Switch (F47)
No Part Number (Blue)
C2
WHITE/Blue
YELLOW/Green
RED/Grey
BLUE/Grey
WHITE/Green
BROWN/White
Accelerator Pedal Sensor
Idling Speed Switch
Kickdown Switch
(G79)
VW 3A0973-713 (Black)
D2
WHITE/Green
WHITE/Red
Clutch Pedal Switch (F36)
No Part Number (Transparent)
E2
AMP927415-5 (Yellow)
F2
YELLOW/Green
BLACK
VW 191972712C (Red)
SLD 7
G2
YELLOW/Green
AC Compressor Sensor (ECU Pin #37)
VW 191-972-712C SLD9 (Yellow)
H2
RED/Black
BLACK/Red
VW 1H0972762 HMM3 (Black)
> PBTPGF20 <
I2
BLUE/Black
BLACK
BROWN
BLUE
BLACK/Red
AMP928579 (Transparent)
J2
BLACK/Green
WHITE/Blue
BLUE/Red
BLACK/Purple
BROWN
BROWN/White
YELLOW/Green
YELLOW/Blue
BROWN/White
Engine Speed Info to Instrument Cluster (ECU Pin #2)
Glow Command to Relay for Glow Plugs (ECU Pin #50)
AMP928576 (Transparent)
L2
BROWN/White
WHITE/Red
VW 1H0973-131A (Black)
KBR > PA6,6 <
K2
BLUE/Black
YELLOW
BLUE/Green
BLACK/Yellow
YELLOW/Green
WHITE/Red
GREEN/Black
Glow Period Warning Lamp/Fault Lamp (ECU Pin #26)
AMP928577 (Transparent)
M2
BLUE/White
Road Speed Signal (ECU Pin #43)
VW 701906231D (Blue)
N2
BLACK
Cruise Control (Pin#1 of S2)
VW 701906231F (Green)
O2
BROWN/Green
AC Compressor Signal (ECU Pin #28)
VW 191972711G (Gray)
PURPLE/White
Q2
GRAY/White
Diagnostic Connection (ECU Pin #61)
VW 191972702A SLD 16 (Brown)
R2
BLACK/Red
Brake Signal From Brake Light Switch (ECU Pin #44)
AMP19295877 (Green)
* VW Numbering System
** Swift Numbering System
Cruise Control System Switch
Kickdown Switch in G79
Clutch Pedal Switch
Brake Pedal Switch
Idling Speed Switch in G79
Barometric Pressure Sensor
Engine Speed Sensor
Coolant Temperature Sensor
Air Mass Meter
Intake Manifold Temp Sensor
Accelerator Pedal Position Sensor
Needle Lift Sensor
Fuel Temperature Sensor
Control Plunger Travel Sensor
Exhaust Gas Recirculation Valve
Boost Press Control Solenoid Valve
Start of Injection Valve
Fuel Cut-off Valve
Quantity Adjuster
Engine Speed Info to Instrument Cluster
Fuel Consumption Signal to Instrument Cluster
Glow Period Warning Lamp / Fault Lamp
AC Compressor Cut-off
AC Compressor Signal
Road Speed Signal
Brake Signal from Brake Light Switch
Glow Command to Relay for Glow Plugs
Diagnostic Connection
Please refer to the attached ECU 80-pin Connector diagram for additional wiring information and pin connections.
SECTION 3
A3
BLACK/Yellow
BROWN/Blue
Boost Press Control Solenoid (N75)
AMP928421 (Brown)
B3
BLUE/Red
BROWN/White
Glow Plug 50-amp Fuse
HHH191937505 (Black)
C3
BLACK/Yellow
BROWN
AMP928421 (Black)
D3
WHITE
BLACK/Yellow
EGR Vacuum Regulator
Solenoid Valve (N18)
AMP928421 (Black)
CONNECTOR (AMP1-962-175)

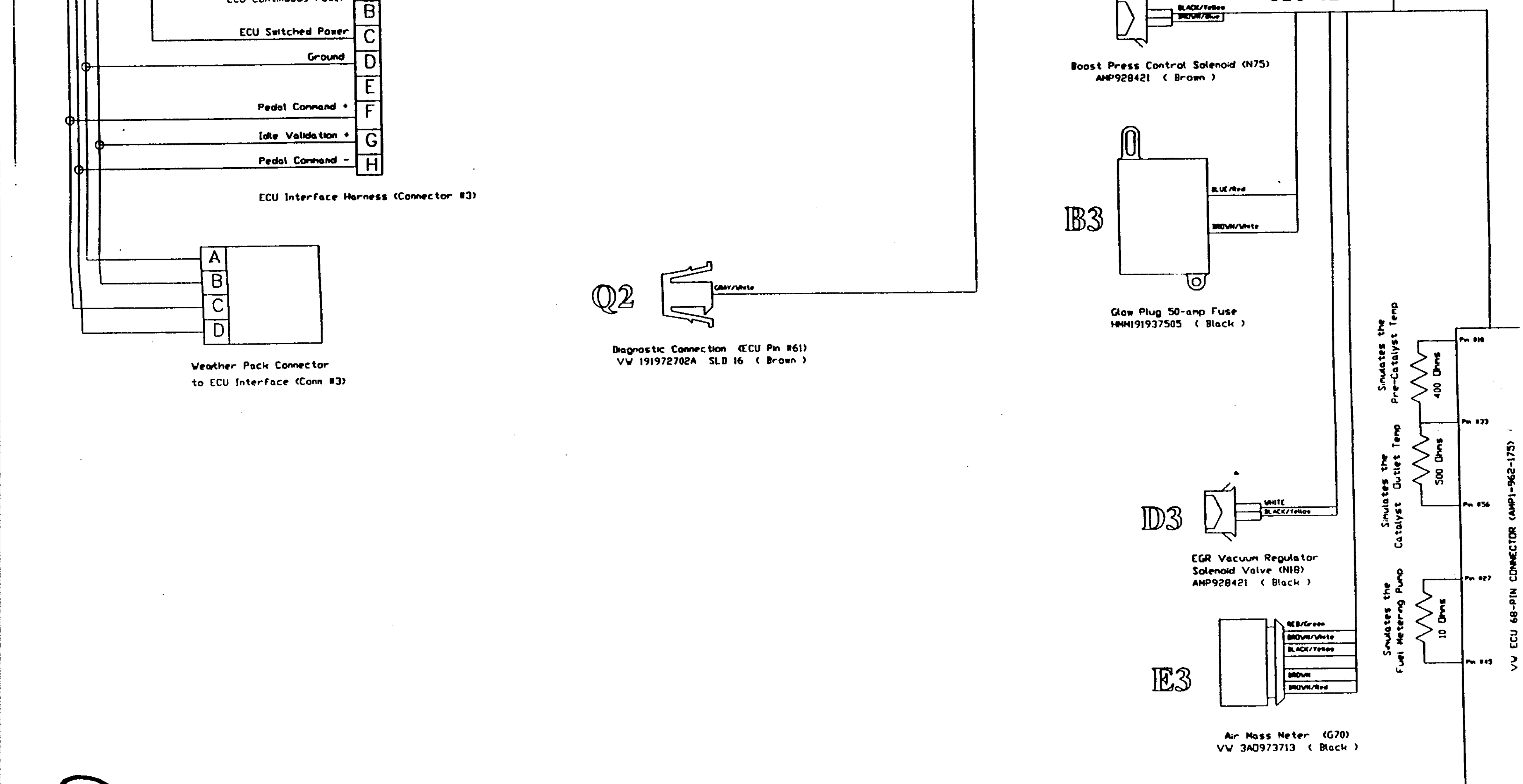

VV ECU 68-PIN CONNECTOR (AMP1-962-175)
SECTION 3
H2
VW 191-972-712C SLD9 (Yellow)
RED/Black
BLACK/Red
VW 1HD972762 HMM3 (Black)
> PB1PGF20 <
I2
BLUE/Black
BLACK
BROWN
BLUE
BLACK/Red
AMP928579 (Transparent)
K2
AMP928576 (Transparent)
BLUE/Black
YELLOW
BLUE/Green
BLACK/Yellow
YELLOW/Green
WHITE/Red
GREEN/Black
Glow Period Warning Lamp/Fault Lamp (ECU Pin #26)
AMP928577 (Transparent)
M2
BLUE/White
Road Speed Signal (ECU Pin #43)
VW 701906231D (Blue)
N2
BLACK
Cruise Control (Pin#1 of S2)
VW 701906231F (Green)
O2
BROWN/Green
AC Compressor Signal (ECU Pin #28)
VW 191972711G (Gray)
P2
PURPLE/White
Fuel Consumption (ECU Pin #9)
VW 191972177 (Black)
Q2
GRAY/White
Diagnostic Connection (ECU Pin #61)
VW 191972702A SLD 16 (Brown)
R2
BLACK/Red
Brake Signal from Brake Light Switch (ECU Pin #44)
AMP19295877 (Green)
S2
BLACK/White
RED
BLUE/Gray
BLACK
Cruise Control System Switch (E45)
AMP19295901 (Black)
BLACK/Yellow
BROWN/Blue
Boost Press Control Solenoid (N75)
AMP928421 (Brown)
B3
BLUE/Red
BROWN/White
Glow Plug 50-amp Fuse
HMM191937505 (Black)
C3
BLACK/Yellow
BROWN
AMP928421 (Black)
D3
WHITE
BLACK/Yellow
EGR Vacuum Regulator
Solenoid Valve (N18)
AMP928421 (Black)
E3
RED/Green
BROWN/White
BLACK/Yellow
BROWN
BROWN/Red
Air Mass Meter (G70)
VW 3A0973713 (Black)
3

M O D I F I E D
VW 1.9L ENGINE HARNESS 3A1-971-072 CD
(DARPA/CTC HMMWV APU HARDWARE)

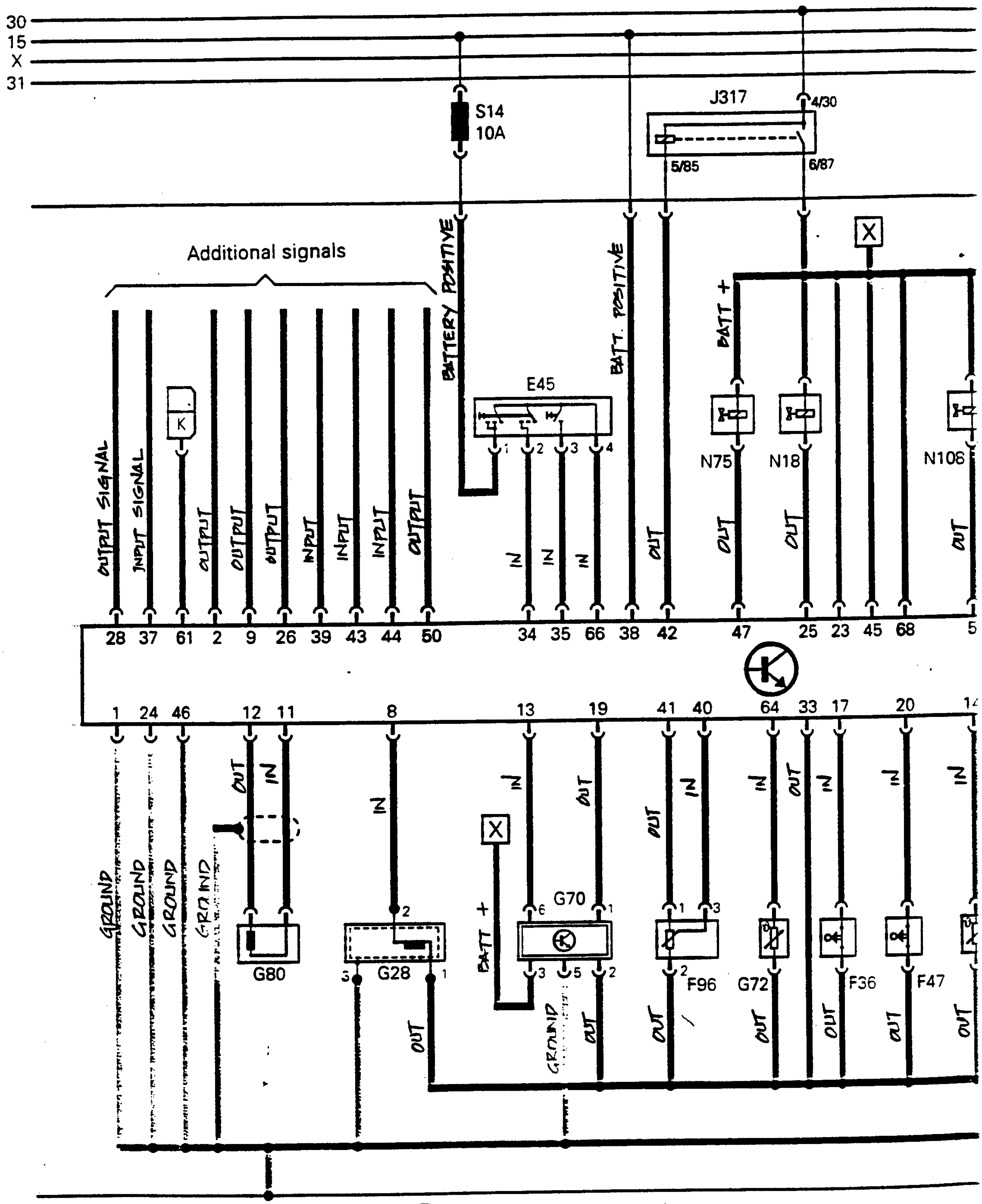




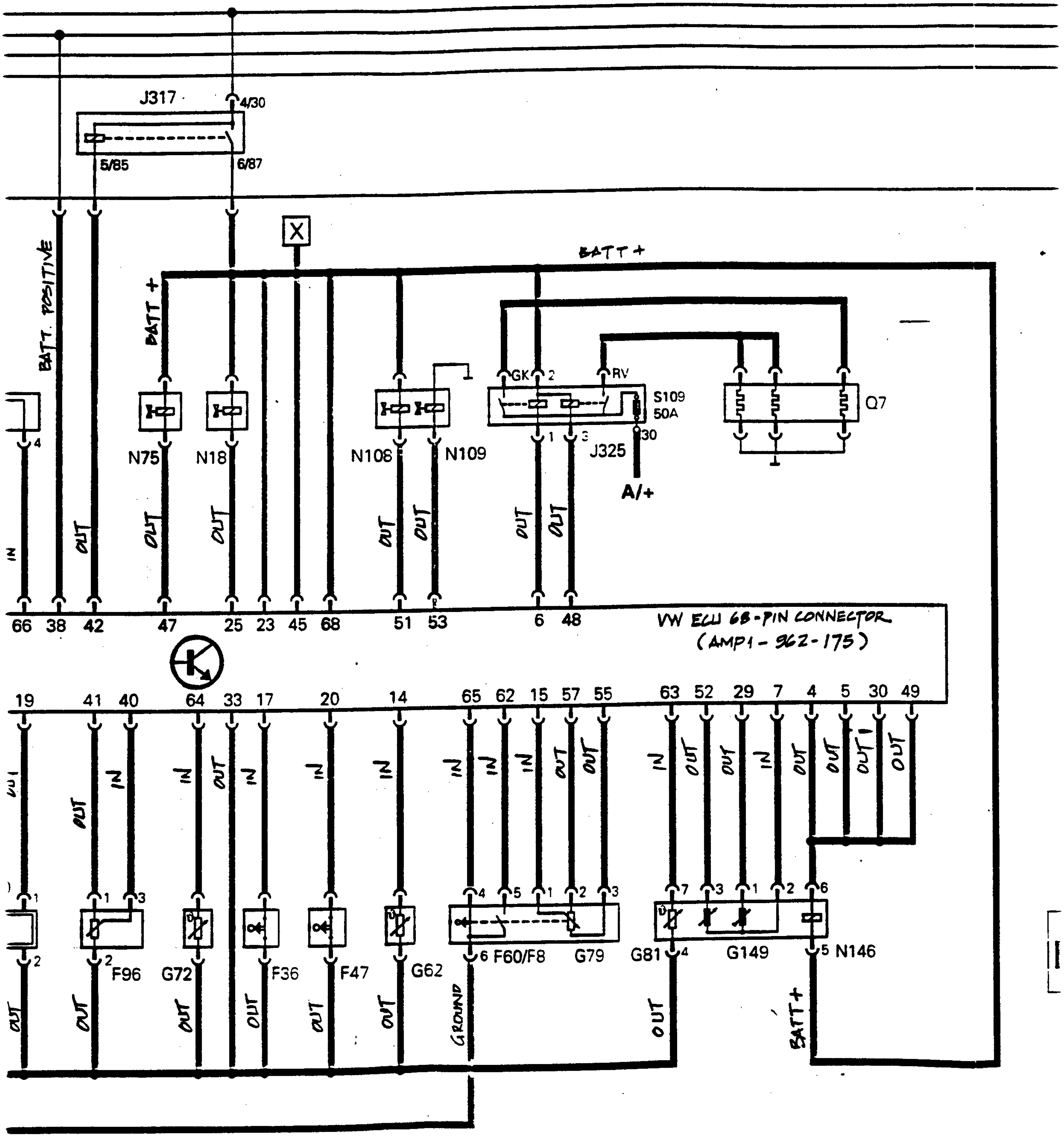
Barometric Pressure (F96)
DM4 AUSTRIA (Black)
171-906-230
Brake Pedal Switch (F47)
No Part Number (Blue)
C2
MANUAL RACK POT
Accelerator Pedal Sensor
Idling Speed Switch
Kickdown Switch
(G79)
VV 3A0973-713 (Black)
D2
Shorted Out
Clutch Pedal Switch (F36)
No Part Number (Transparent)
F2
ECU SWITCHED POWER
VV 191972712C
SLD 7
Connector Removed
J2
Engine Speed Info to Instrument Cluster (ECU Pin #2)
Glow Command to Relay for Glow Plugs (ECU Pin #50)
AMP928576 (Transparent)
ECU Continuous Power
ECU Switched Power
Ground
Pedal Command +
Idle Validation +
Pedal Command -
ECU Interface Harness (Connector #3)
Weather Pack Connector
to ECU Interface (Conn #3)
Q2
Diagnostic Connection (ECU Pin #61)
VV 191972702A SLD 16 (Brown)
SECTION 3
A3
Boost Press Control Solenoid (N75)
AMP928421 (Brown)
B3
Glow Plug 50-amp Fuse
HNM191937505 (Black)
D3
EGR Vacuum Regulator
Solenoid Valve (N18)
Simulates the Pre-Catalyst Temp
400 Ohms
Simulates the Catalyst Outlet Temp
500 Ohms
CONNECTOR (AMP1-962-175)



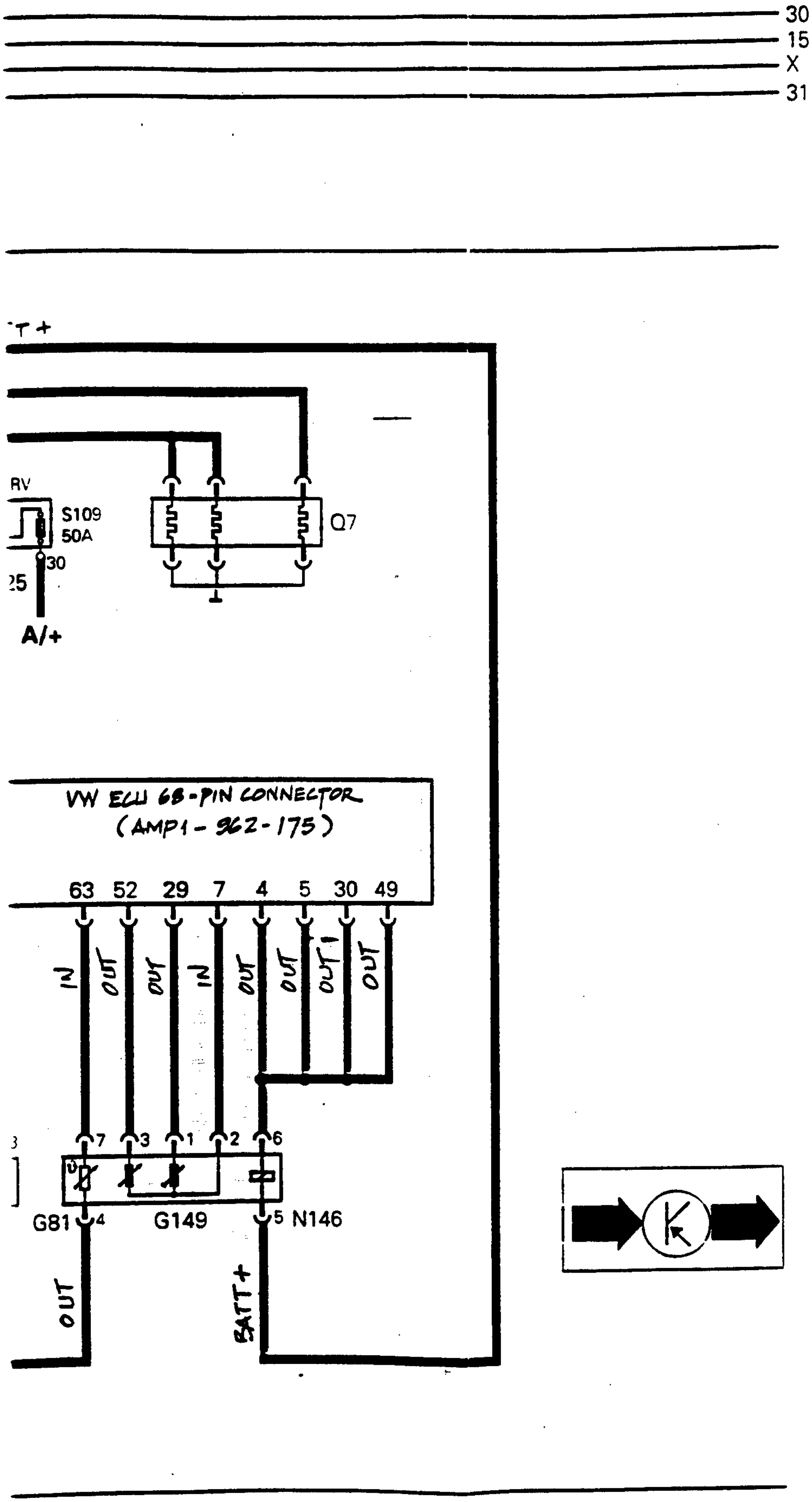
ECU Continuous Power
ECU Switched Power
Ground
Pedal Command +
Idle Validation +
Pedal Command -
B
C
D
E
F
G
H
ECU Interface Harness (Connector #3)
AMP928576 (Transparent)
A
B
C
D
Weather Pack Connector
to ECU Interface (Conn #3)
Q2
GRAY/White
Diagnostic Connection (ECU Pin #61)
VW 191972702A SLD 16 (Brown)
BLACK/Yellow
BROWN/Blue
Boost Press Control Solenoid (N75)
AMP928421 (Brown)
B3
BLUE/Red
BROWN/White
Glow Plug 50-amp Fuse
HHM191937505 (Black)
D3
WHITE
BLACK/Yellow
EGR Vacuum Regulator
Solenoid Valve (N18)
AMP928421 (Black)
E3
RED/Green
BROWN/White
BLACK/Yellow
BROWN
BROWN/Red
Air Mass Meter (G70)
VW 3A0973713 (Black)
Simulates the
Pre-Catalyst Temp
400 Ohms
Simulates the
Catalyst Outlet Temp
500 Ohms
Simulates the
Fuel Metering Pump
10 Ohms
VW ECU 68-PIN CONNECTOR (AMP1-962-175)



30
15
X
31
S14
10A
J317
4/30
5/85
6/87
Additional signals
BATTERY POSITIVE
BATT. POSITIVE
BATT +
X
E45
K
OUTPUT SIGNAL
INPUT SIGNAL
OUTPUT
INPUT
OUT
IN
N75
N18
N108
28 37 61 2 9 26 39 43 44 50
34 35 66 38 42
47 25 23 45 68 5
1 24 46 12 11 8 13 19 41 40 64 33 17 20
GROUND
G80
G28
G70
F96
G72
F36
F47



J317
4/30
5/85
6/87
BATT. POSITIVE
BATT +
X
N75
N18
N108
N109
GK
2
RV
S109
50A
30
J325
A/+
Q7
IN
OUT
66 38 42 47 25 23 45 68 51 53 6 48
VW ECU 68-PIN CONNECTOR
(AMP1-962-175)
19 41 40 64 33 17 20 14 65 62 15 57 55 63 52 29 7 4 5 30 49
F96
G72
F36
F47
G62
F60/F8
G79
G81
G149
N146
GROUND



30
15
X
31
T +
RV
S109
50A
30
25
A/+
Q7
VW ECU 68-PIN CONNECTOR
(AMP1-962-175)
63 52 29 7 4 5 30 49
IN
OUT
OUT
IN
OUT
OUT
OUT 1
OUT
7
3
1
2
6
G81
4
G149
5 N146
OUT
BATT +

SSP 153/42

CTC APU CONTROLLER EXTERNAL \

S	GROUND
U	+12 V (HIGH CURRENT)
V	+5 V
W	+12 V (LOW CURRENT)
X	-12 V
Y	GROUND

CONNECTOR #1 BUS POWER INTERFACE

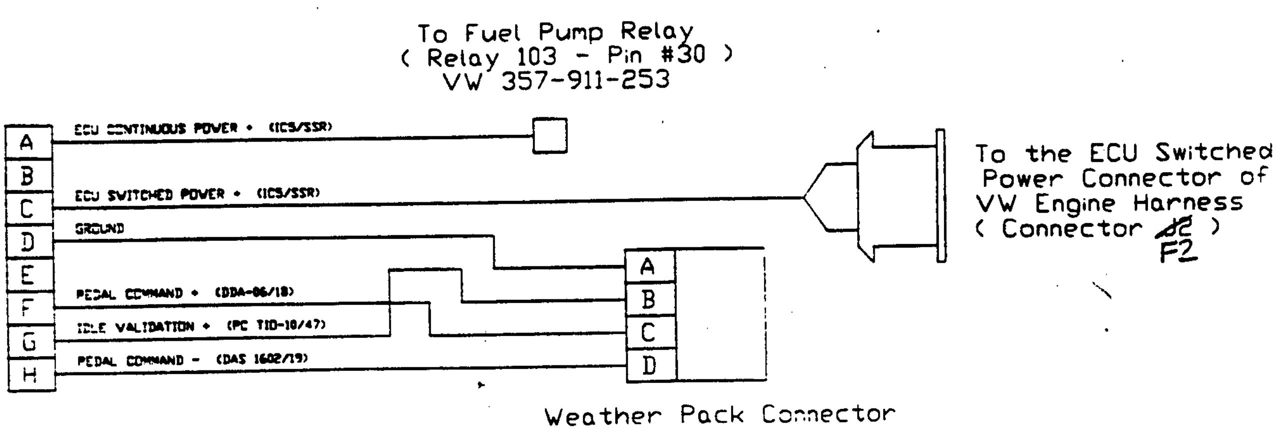
(Harness not supplied by SwRI)

1	SILENT RUN MODE RETURN
2	SILENT RUN MODE +
3	PEDDAL KICKDOWN RETURN
4	PEDAL KICKDOWN +
5	SERIAL PORT Tx
6	SERIAL PORT Rx
7	SERIAL PORT GND

CONNECTOR #2 VEHICLE CONTROL INTERFACE

(Harness not supplied by SwRI)

CONNECTOR #3 ENGINE CONTROL INTERFACE HARNESS

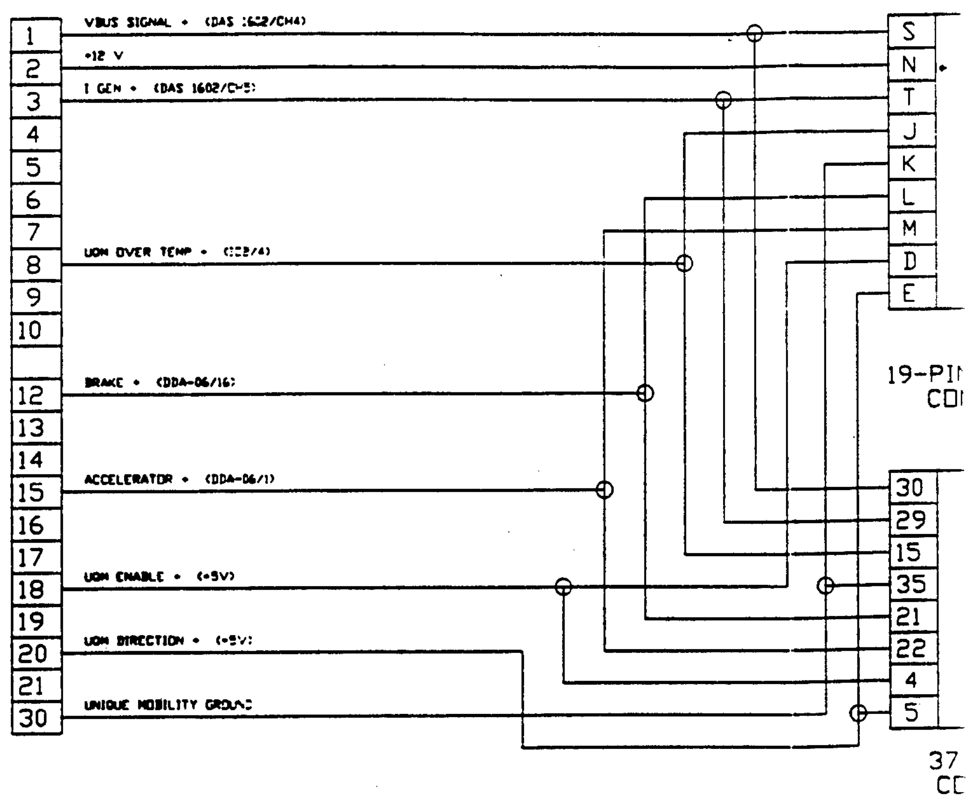


LLER EXTERNAL WIRING DESCRIPTION

CONNECTOR #4 UNIQUE MOBILITY INTERFACE

ER INTERFACE

by SwRI)



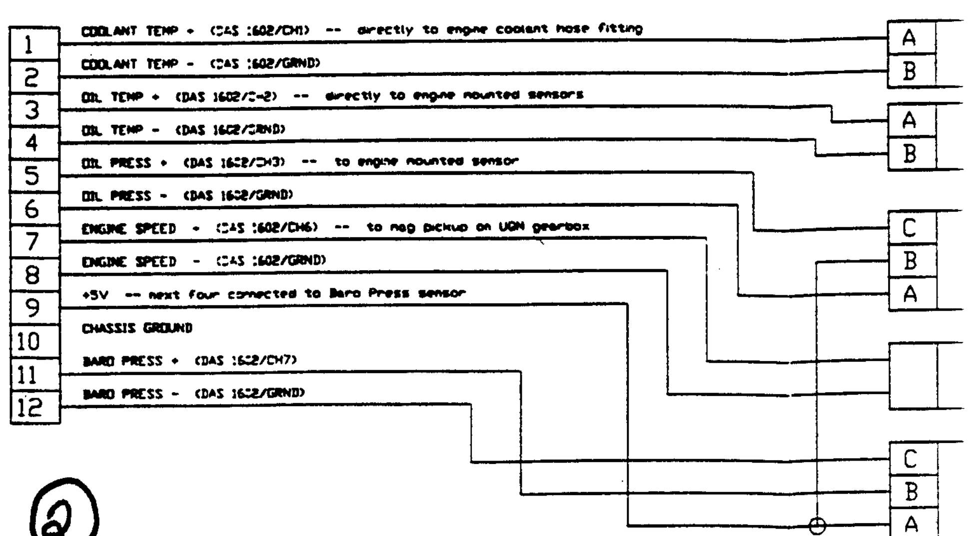
CONTROL INTERFACE

d by SwRI)

ACE HARNESS

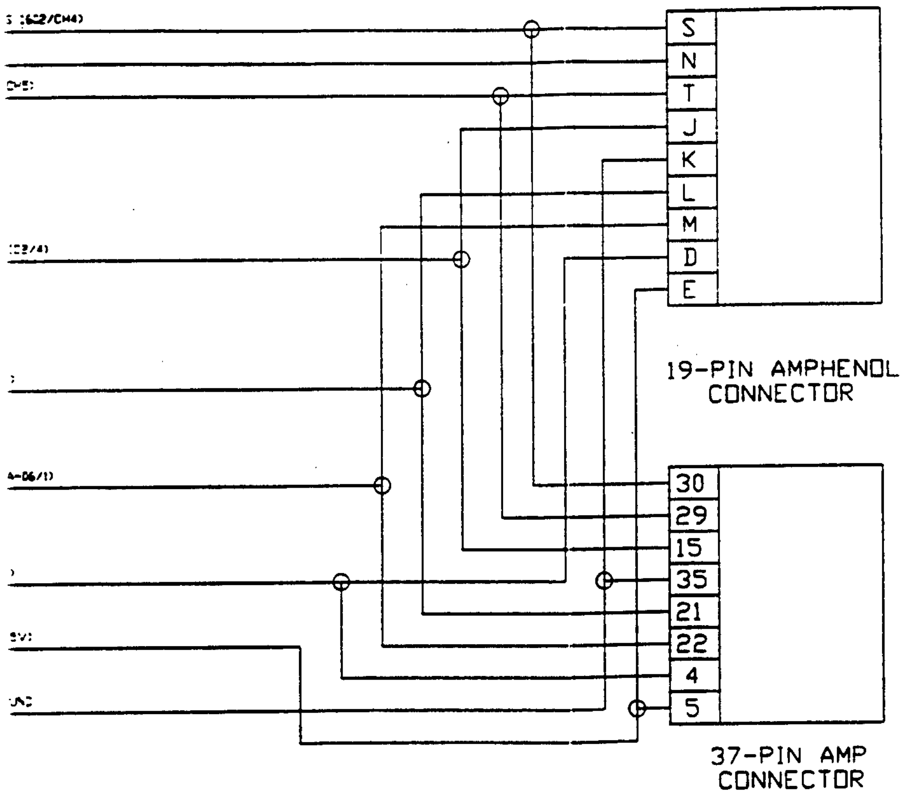
CONNECTOR #5 APU SENSORS INTERFAC

To the ECU Switched Power Connector of VW Engine Harness (Connector ~~#2~~ F2)

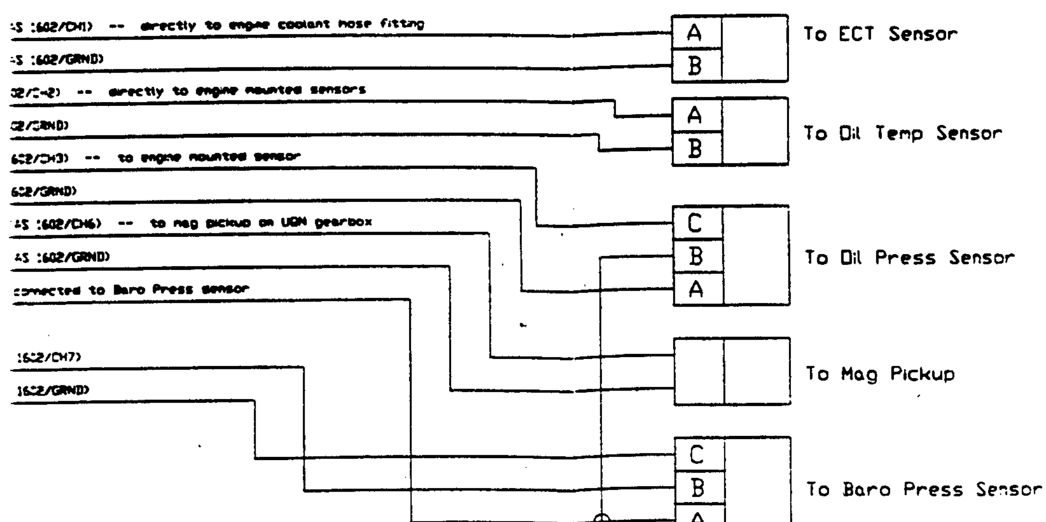


DESCRIPTION

꞉ #4 UNIQUE MOBILITY INTERFACE HARNESS



ECTOR #5 APU SENSORS INTERFACE HARNESS



FUELS DISTRIBUTION LIST

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DFSC IQ (L OPPENHEIM) 1
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Department of the Army

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DALO SM 1
500 PENTAGON
WASHINGTON DC 20310-0500

SARDA
ATTN: SARD TT 1
PENTAGON
WASHINGTON DC 20310-0103

CDR AMC
ATTN: AMCRD S 1
AMCRD E 1
AMCRD IT 1
AMCEN A 1
AMCLG M 1
AMXLS H 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

U.S. ARMY TACOM
TARDEC PETR. & WTR. BUS. AREA
ATTN AMSTA TR-R/210 (L. VILLHAHERMOSA) 10
AMSTA TR-R/210 (T. BAGWELL) 1
WARREN, MI 48397-5000

CDR ARMY TACOM
ATTN: AMSTA IM LMM 1
AMSTA IM LMB 1
AMSTA IM LMT 1
AMSTA TR NAC MS 002 1
AMSTA TR R MS 202 1
AMSTA TR D MS 201A 1
AMSTA TR M 1
AMSTA TR R MS 121 (C RAFFA) 1
AMSTA TR R MS 158 (D HERRERA) 1
AMSTA TR R MS 121 (R MUNT) 1
AMCPM ATP MS 271 1
AMSTA TR E MS 203 1
AMSTA TR K 1
AMSTA IM KP 1
AMSTA IM MM 1
AMSTA IM MT 1
AMSTA IM MC 1
AMSTA IM GTL 1
AMSTA CL NG 1
USMC LNO 1
AMCPM LAV 1
AMCPM M113 1
AMCPM CCE 1
WARREN MI 48397-5000

PROG EXEC OFFICER
ARMORED SYS MODERNIZATION
ATTN: SFAE ASM S 1
SFAE ASM H 1
SFAE ASM AB 1
SFAE ASM BV 1
SFAE ASM CV 1
SFAE ASM AG 1
CDR TACOM
WARREN MI 48397-5000

PROG EXEC OFFICER
ARMORED SYS MODERNIZATION
ATTN: SFAE FAS AL 1
SFAE FAS PAL 1
PICATINNY ARSENAL
NJ 07806-5000

PROG EXEC OFFICER
TACTICAL WHEELED VEHICLES
ATTN: SFAE TWV TVSP 1
SFAE TWV FMTV 1
SFAE TWV PLS 1
CDR TACOM
WARREN MI 48397-5000

PROG EXEC OFFICER
ARMAMENTS
ATTN: SFAE AR HIP 1
SFAE AR TMA 1
PICATINNY ARSENAL
NJ 07806-5000

PROG MGR
UNMANNED GROUND VEH
ATTN: AMCPM UG 1
REDSTONE ARSENAL
AL 35898-8060

DIR
ARMY RSCH LAB
ATTN: AMSRL PB P 1
2800 POWDER MILL RD
ADELPHIA MD 20783-1145

VEHICLE PROPULSION DIR
ATTN: AMSRL VP (MS 77 12) 1
NASA LEWIS RSCH CTR
21000 BROOKPARK RD
CLEVELAND OH 44135

CDR AMSAA
ATTN: AMXSY CM 1
AMXSY L 1
APG MD 21005-5071

CDR ARO
ATTN: AMXRO EN (D MANN) 1
RSCH TRIANGLE PK
NC 27709-2211

CDR AEC
ATTN: SFIM AEC ECC (T ECCLES) 1
APG MD 21010-5401

CDR ARMY ATCOM
ATTN: AMSAT I WM 1
AMSAT I ME (L HEPLER) 1
AMSAT I LA (V SALISBURY) 1
AMSAT R EP (V EDWARD) 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR ARMY SOLDIER SPT CMD
ATTN: SATNC US (J SIEGEL) 1
SATNC UE 1
NATICK MA 01760-5018

CDR ARMY ARDEC
ATTN: AMSTA AR EDE S 1
PICATINNY ARSENAL
NJ 07808-5000

CDR ARMY WATERVLIET ARSN
ATTN: SARWY RDD 1
WATERVLIET NY 12189

CDR APC
ATTN: SATPC L 1
SATPC Q 1
NEW CUMBERLAND PA 17070-5005

CDR ARMY LEA
ATTN: LOEA PL 1
NEW CUMBERLAND PA 17070-5007

CDR ARMY TECOM
ATTN: AMSTE TA R 1
AMSTE TC D 1
AMSTE EQ 1
APG MD 21005-5006

PROJ MGR MOBILE ELEC PWR
ATTN: AMCPM MEP T 1
AMCPM MEP L 1
7798 CISSNA RD STE 200
SPRINGFIELD VA 22150-3199

CDR
ARMY COLD REGION TEST CTR
ATTN: STECR TM 1
STECR LG 1
APO AP 96508-7850

CDR
ARMY BIOMED RSCH DEV LAB
ATTN: SGRD UBZ A 1
FT DETRICK MD 21702-5010

CDR FORSCOM
ATTN: AFLG TRS 1
FT MCPHERSON GA 30330-6000

CDR TRADOC
ATTN: ATCD SL 5 1
INGALLS RD BLDG 163
FT MONROE VA 23651-5194

CDR ARMY ARMOR CTR
ATTN: ATSB CD ML 1
ATSB TSM T 1
FT KNOX KY 40121-5000

CDR ARMY QM SCHOOL
ATTN: ATSM PWD 1
FT LEE VA 23001-5000

ARMY COMBINED ARMS SPT CMD
ATTN: ATCL MS 1
FT LEE VA 23801-6000

CDR ARMY FIELD ARTY SCH
ATTN: ATSF CD 1
FT SILL OK 73503

CDR ARMY TRANS SCHOOL
ATTN: ATSP CD MS 1
FT EUSTIS VA 23604-5000

CDR ARMY INF SCHOOL
ATTN: ATSH CD 1
ATSH AT 1
FT BENNING GA 31905-5000

CDR ARMY AVIA CTR
ATTN: ATZQ DOL M 1
ATZQ DI 1
FT RUCKER AL 36362-5115

CDR ARMY ENGR SCHOOL
ATTN: ATSE CD 1
FT LEONARD WOOD
MO 65473-5000

CDR 49TH QM GROUP
ATTN: AFFL GC 1
FT LEE VA 23801-5119

CDR ARMY ORDN CTR
ATTN: ATSL CD CS 1
APG MD 21005

CDR ARMY SAFETY CTR
ATTN: CSSC PMG 1
CSSC SPS 1
FT RUCKER AL 36362-5363

CDR ARMY ABERDEEN TEST CTR
ATTN: STEAC EN 1
STEAC LI 1
STEAC AE 1
STEAC AA 1
APG MD 21005-5059

CDR ARMY YPG
ATTN: STEYP MT TL M 1
YUMA AZ 85365-9130

CDR ARMY CERL
ATTN: CECER EN 1
P O BOX 9005
CHAMPAIGN IL 61826-9005

DIR 1
AMC FAST PROGRAM
10101 GRIDLEY RD STE 104
FT BELVOIR VA 22060-5818

CDR I CORPS AND FT LEWIS
ATTN: AFZH CSS 1
FT LEWIS WA 98433-5000

CDR
RED RIVER ARMY DEPOT
ATTN: SDSRR M 1
SDSRR Q 1
TEXARKANA TX 75501-5000

PS MAGAZINE DIV
ATTN: AMXLS PS 1
DIR LOGSA
REDSTONE ARSENAL AL 35898-7466

CDR 6TH ID (L)
ATTN: APUR LG M 1
1060 GAFFNEY RD
FT WAINWRIGHT AK 99703

Department of the Navy

OFC CHIEF NAVAL OPER
ATTN: DR A ROBERTS (N420) 1
2000 NAVY PENTAGON
WASHINGTON DC 20350-2000

CDR
NAVAL SEA SYSTEMS CMD
ATTN: SEA 03M3 1
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

CDR
NAVAL SURFACE WARFARE CTR
ATTN: CODE 63 1
CODE 632 1
CODE 859 1
3A LEGGETT CIRCLE
ANNAPOLIS MD 21402-5067

CDR
NAVAL RSCH LABORATORY
ATTN: CODE 6181 1
WASHINGTON DC 20375-5342

CDR
NAVAL AIR WARFARE CTR
ATTN: CODE PE33 AJD 1
P O BOX 7176
TRENTON NJ 08628-0176

CDR 1
NAVAL PETROLEUM OFFICE
8725 JOHN J KINGMAN RD
STE 3719
FT BELVOIR VA 22060-6224

CDR
NAVAL AIR SYSTEMS CMD
ATTN: AIR 4.4.5 (D MEARNS) 1
1421 JEFFERSON DAVIS HWY
ARLINGTON VA 22243-5360

Department of the Navy/U.S. Marine Corps

HQ USMC
ATTN: LPP 1
WASHINGTON DC 20380-0001

PROG MGR COMBAT SER SPT 1
MARINE CORPS SYS CMD
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

PROG MGR GROUND WEAPONS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080
PROG MGR ENGR SYS 1
MARINE CORPS SYS CMD
2033 BARNETT AVE
QUANTICO VA 22134-5080

CDR
BLOUNT ISLAND CMD
ATTN: CODE 922/1 1
5880 CHANNEL VIEW BLVD
JACKSONVILLE FL 32226-3404

CDR
ATTN: CODE 837 1
814 RADFORD BLVD
ALBANY GA 31704-1128

CDR 1
2ND MARINE DIV
PSC BOX 20090
CAMP LEJEUNNE
NC 28542-0090

CDR
MARINE CORPS SYS CMD
ATTN: SSE 1
2030 BARNETT AVE STE 315
QUANTICO VA 22134-5010

CDR 1
1ST MARINE DIV
CAMP PENDLETON
CA 92055-5702

CDR 1
FMFPAC G4
BOX 64118
CAMP H M SMITH
HI 96861-4118

Department of the Air Force

HQ USAF/LGSF
ATTN: FUELS POLICY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

HQ USAF/LGTV
ATTN: VEH EQUIP/FACILITY 1
1030 AIR FORCE PENTAGON
WASHINGTON DC 20330-1030

AIR FORCE WRIGHT LAB
ATTN: WL/POS 1
WL/POSF 1
1790 LOOP RD N
WRIGHT PATTERSON AFB
OH 45433-7103

AIR FORCE MEEP MGMT OFC 1
OL ZC AFMC LSO/LOT PM
201 BISCAYNE DR
BLDG 613 STE 2
ENGLIN AFB FL 32542-5303

SA ALC/SFT 1
1014 BILLY MITCHELL BLVD STE 1
KELLY AFB TX 78241-5603

SA ALC/LDPG
ATTN: D ELLIOTT 1
580 PERRIN BLDG 329
KELLY AFB TX 78241-6439

WR ALC/LVRS 1
225 OCMULGEE CT
ROBINS AFB
GA 31098-1647

Other Federal Agencies

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DOT
FAA
AWS 110 1
800 INDEPENDENCE AVE SW
WASHINGTON DC 20590

DOE
CE 151 (MR RUSSELL) 1
1000 INDEPENDENCE AVE SW
WASHINGTON DC 20585

EPA
AIR POLLUTION CONTROL 1
2565 PLYMOUTH RD
ANN ARBOR MI 48105