Subcontractor Report

January 2000 • NREL/SR-540-26935

Mack LNG Vehicle Development

Southwest Research Institute
San Antonio, Texas

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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NREL Technical Monitor: Mike Frailey

Prepared under Subcontract No. AAC-5-15249-01

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Mack LNG Vehicle Development

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Note: This document is an abbreviated version of a larger report that contains the following appendices:

A. Recorded Data for Lean Limit Tests

B. Recorded Data for Steady-State Tests

C. Final Calibration, 325 bhp

D. Final Report for Task 2 – 1000-Hour Super Thermal Cycle Test, SwRI Project No. 03-7501-002

E. Final Report for 1000-Hour Super Thermal Cycle Test on a Mack E-7 Natural Gas Fueled Engine, SwRI Project No. 03-1248

F. Histograms from the Data Logger

G. Final Report for Transient Emissions Testing on a Mack E&G Engine, SwRi Project No. 03-2377

H. Final Calibration, 350 bhp

If you would like a copy of the appendices, please contact Mike Frailey at the National Renewable Energy Laboratory at 303-275-3607 or mike_frailey@nrel.gov.

Executive Summary

The goal of this project was to install a production-ready, state-of-the-art engine control system on the Mack E7G natural gas engine to improve efficiency and lower exhaust emissions. In addition, the power rating was increased from 300 brake horsepower (bhp) to 325 bhp. The emissions targets were oxides of nitrogen plus nonmethane hydrocarbons (NO_x+NMHC) of less than 2.5 g/bhp-hr (with a mandatory NO_x of less than 2.5 g/bhp-hr) and particulate matter of less than 0.05 g/bhp-hr on 99% methane. Vehicle durability and field tests were also conducted.

A Woodward OH-1 state-of-the-art engine controller was successfully installed on the Mack E7G engine and a calibration for the Mack engine was developed. Knock tolerance testing and misfire limit testing were conducted to aid in the development of the calibration. The first 1000-hour durability test was conducted with partial funding from this project, and a second 1000-hour durability test to address the concerns from the first test was successfully completed. A data logger was installed on an in-service refuse hauler and engine and vehicle operation was successfully recorded.

The brake-specific fuel consumption over the transient emissions test cycle was decreased from 0.474 lb/bhp-hr on the previous version of this engine, to 0.400 lb/bhp-hr on the current version. The NO_x emissions over the transient emissions test cycle were decreased from 2.95 g/bhp-hr to 2.20 g/bhp-hr. The NO_x+NMHC emissions were 2.53 g/bhp-hr and particulate matter was 0.03 g/bhp-hr on the current version of this engine. Emissions for the current version of this engine include the deterioration factor, whereas emissions from the previous version do not include the deterioration factor. California Air Resources Board (CARB) certification gas was used for the transient emissions testing on the current version of this engine. NO_x+NMHC emissions are expected to decrease on a 99% methane fuel. Actual driving cycle fuel economy comparisons are not readily available because the previous version of this engine was installed in a refuse hauler, which was at a different location. Further development of this engine should include efficiency improvements and NO_x reductions.

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Acronyms

AER	average equivalence ratios
bhp	brake horsepower
BSCO	brake specific carbon monoxide
$BSNO_x$	brake specific nitrogen oxides
BSTHC	brake specific total hydrocarbon
BTDC	before top dead center
BTE	brake thermal efficiency
CARB	California Air Resources Board
CBD	central business district
CNG	compressed natural gas
COV_{imep}	coefficient of variation of the indicated mean effective pressure
deg	degree
ºF	degree Fahrenheit
EPA	Environmental Protection Agency
ft-lb	foot-pound
FTP	Federal Test Procedure
g/bhp-hr	grams/brake horsepower per hour
GEM	Gas Engine Management
HC	hydrocarbons
HC/OMHCE	hydrocarbon/organic material hydrocarbon equivalent
imep	indicated mean effective pressure
LNG	liquefied natural gas
MAP	manifold absolute pressure
MBT	minimum for best torque
mpg	miles per gallon
mph	miles per hour
ms	millisecond
MS	mass spectrometer **
NMHC	nonmethane hydrocarbon
OMNMHC	organic material non-methane hydrocarbon
NO_x	oxides of nitrogen
OACT	original and advanced cam timing
OH-1	on highway-1
PM	particulate matter
ppm	parts per million
psia	pounds per square inch absolute
psig	pounds per square inch gauge
PWM	pulse-width modulated
rpm	revolutions per minute
SE	standard error
SwRI	Southwest Research Institute
THC	total hydrocarbons
UEGO	universal exhaust gas oxygen
VE	volumetric efficiency
WOT	wide open throttle

1.0 Background

This project was a continuation of the development of a natural-gas refuse hauler. A compressed natural gas (CNG) Mack MR demonstration vehicle was operated for nearly a year in revenue service on a previous project. Engine performance, emissions, driveability, and durability were acceptable for a demonstration vehicle; however, several areas were identified for improvement. These included vehicle range, refueling time, driving cycle fuel economy, and installation of improved and production-ready natural gas specific engine control hardware.

Vehicle range and refueling time can be improved by operating the vehicle on liquefied natural gas (LNG). Project efforts focused on minimizing throttling losses and increasing the NO_x efficiency tradeoff by using a state-of-the-art engine controller.

The original objectives of this project were to:

1. Improve the driving cycle thermal efficiency of the engine
2. Install and aid in the development of a state-of-the-art engine control system
3. Assess control system and engine integrity through a 480-hour durability test
4. Calibrate the engine to exactly meet the diesel torque curve of the 300 bhp engine
5. Conduct transient emissions testing to verify that exhaust emissions are lower than the 1998 Environmental Protection Agency (EPA) emissions targets with NO_x emissions being less than 2.0 g/bhp-hr
6. Monitor the vehicle through a 3-month field test using an on-board data logger equipped with a cellular telephone
7. Provide detailed drawings, manuals, and training to Mack personnel so that Mack can develop a full understanding of the engine control system and be capable of producing six identical vehicles.

Several project components were revised as follows:

- A 1000-hour durability test was performed. This project funded up to the amount provided in the contract, and Mack Trucks funded the remainder.
- The engine was calibrated to a 325 bhp at 1950 revolutions per minute (rpm) and 1180 ft-lb at 1250 rpm torque curve.
- The PM target had been revised to 0.05 g/bhp-hr, and there was an additional target for NO_x+NMHC of less than 2.5 g/bhp-hr.

2.0 Conclusions

The successful completion of the project resulted in several conclusions regarding the technical content of the program, described below.

In comparing the previous demonstration engine to the current engine developed in this project:

- Peak power was increased from 300 bhp to 325 bhp to match the 325-bhp diesel torque curve.
- Peak torque was increased from 1100 ft-lb to 1180 ft-lb to match the 325 bhp diesel torque curve.
- The NO_x emissions over the transient emissions test cycle decreased from 2.95 g/bhp-hr to 2.20 g/bhp-hr.
- The brake specific fuel consumption over the transient emissions test cycle decreased from 0.474 lb/bhp-hr to 0.400 lb/bhp-hr, increasing efficiency.
- A comparison of in-use fuel economy was not possible due to the different driving cycles of the previous demonstration engine and the current engine.

A state-of-the-art engine control system was successfully integrated onto the engine. Control system and engine integrity were assessed through a 1000-hour durability test, which indicated a problem with the piston. A subsequent 1000-hour durability test was conducted on a separate project at the Southwest Research Institute (SwRI) with revised pistons. This test confirmed that the problem was solved.

The NO_x+NMHC emissions were 2.53 g/bhp-hr with the deterioration factor and 2.40 g/bhp-hr without the deterioration factor on CARB gas. Emissions on 99% methane were not conducted with the final calibration, but were expected to be below the 2.5 g/bhp-hr target, even with the deterioration factor.

A vehicle was successfully monitored using an on-board data logger.

Mack has produced six identical engines with this state-of-the-art control system and all associated engine and vehicle modifications.

Durability of the cylinder heads, including valve recession, was greatly improved from the previous engine (one of the problem areas from the final report for the previous engine). Funding to test head durability was provided by Mack Trucks.

3.0 Recommendations

Following are recommendations for further development of the engine.

1. Lower NO_x emissions are possible on this engine with:

   - Humidity compensation to allow for a calibration with lower NO_x emissions on the transient test cycle (which has been demonstrated on this engine) without producing driveability problems in the field.
   - Decreased equivalence ratio at the lower engine speeds and full load to reduce NO_x emissions during transients from idle along with alternative turbo lag compensation methods to retain driveability.

2. Higher thermal efficiency for this engine is possible with:

   - Humidity compensation to allow for equivalence ratios closer to the lean-limit.
   - Turbo lag compensation methods to reduce transient NO_x, which can allow for higher NO_x, and therefore higher efficiency over the driving cycle of the engine.

3. Investigation of other methods to improve the NO_x efficiency trade-off of this engine.

Higher thermal efficiency and improved NO_x efficiency trade-offs are being investigated and developed under the current *Efficiency Enhancements for the Mack E7G Natural Gas-Fueled Engine* program.

4.0 Technical Discussion

This section describes the results of the project.

4.1 Engine Specifications

The Mack E7 engine (S/N 1P0144) was used for calibration development on this project. This engine was used on the previous Mack natural gas engine project, but was rebuilt with new cylinder liners, new pistons with an 11.5:1 compression ratio (replaces pistons with a 10.5:1 compression ratio), new piston rings, new cylinder heads with higher swirl, and a new camshaft. Engine specifications are shown in Table 1.

Table 1. Engine Specifications

Engine Model	E7G-325
Engine Serial Number	1P1044
Engine Displacement (in^3/liter)	728/12
Bore and Stroke (in/mm)	4.875/123.8 x 6.5/165.1
Ignition System Controller Supplier	MESA/Woodward Governor Company
Ignition System Coil Supplier	Nippondenso
Ignition System Type	Inductive, Coil on Plug (non-waste spark)
Ignition System Timing Sensor	Electro, K Coil (originally), Bosch (currently)
Spark Plug Supplier	Champion
Spark Plug Model	RX501PYP/2H6
Fuel Metering System Supplier	MESA/Woodward Governor Company
Fuel Injector Type	Servojet SP021
Number of Injectors	8
Throttle Supplier	Woodward Governor Company
Throttle Model	FloTech, 68mm
Throttle Type	Electronic, Analog
Universal exhaust gas oxygen (UEGO) sensor	Honda version of the NGK
Turbocharger	Mack 631GCX5146M, Garrett GT40-88 Compressor Trim, A/R = 52/88mm, 0.58 Turbine Trim, A/R = 78/77mm, 1.05

A Mesa gas engine management (GEM) controller was selected for this project. The Mesa heavy-duty natural gas business was bought by Woodward Governor Company, and the controller is now called the On Highway-1 (OH-1). The OH-1 uses a state-of-the-art speed-density control strategy that provides excellent driveability and response without the aid of a mass air flow sensor. Table 2 shows the capabilities of the OH-1. It is a closed-loop lean-burn strategy with adaptive learn controller. It includes advanced turbo lag compensation, electronic wastegate control, an electronic throttle, high-energy inductive ignition system, full diagnostics, and reduced power engine protection. Fuel is inducted upstream of the throttle. Pseudo-continuous fuel metering is accomplished through single point injection using eight pulse-width modulated (PWM) fuel injectors that supply a common manifold. The injectors are fired sequentially in pairs and fuel flow is governed by modulating the pulse width of the fuel injector drive signals. A drive-by-wire throttle is utilized for speed governing, overboost protection, and driveability enhancements.

Table 2. Woodward OH-1 Capabilities

Capability	**Description**
Diagnostics	Advanced diagnostics for easy debugging with limp home mode for component failure
Drive-By-Wire	Idle speed control, packing speed control, speed governing, load limiting during component failure, throttle opening during deceleration for reduced oil consumption
Cold Start	Fuel enrichment and ignition timing advance to avoid lean misfire during cold engine operation with boost limits
Equivalence Ratio Control	A volumetric efficiency table with adaptive learn to determine fueling rate with an UEGO sensor for closed-loop control
Manifold Filling Calibration	Predictions for air flow during transients for more accurate equivalence ratio control
Turbo Lag Compensation	Fuel enrichment and ignition timing retard to reduce turbo lag without increasing NO_x emissions
Boost Control Calibration	Controls turbocharger wastegate to determine power for a given throttle position, also used to reduce throttling losses by using the wastegate for load control with an open throttle
Ignition Timing Calibration	Table to determine ignition timing for various speeds and loads
Equivalence Ratio Calibration	Table to determine equivalence ratio for various speeds and loads

Part-load fuel economy was increased by the use of a “delta-P” load control strategy. With this strategy, the throttle on the engine is kept as wide open as possible, and load is modulated by wastegate control. Foot pedal position is used to determine load. The pressure differential (delta-P) across the throttle is minimized at part loads, thereby reducing pumping losses and increasing efficiency. The fuel is shut off during deceleration and braking conditions to provide additional improvements in fuel economy. Under these conditions, the throttle is opened, thereby increasing manifold air pressure and reducing oil consumption.

4.2 Air/Fuel Mixing

A study was conducted to look at the effects of the mixing ring and elbow (mixing elbow) on lean-limit and cylinder-to-cylinder equivalence ratios. The mixing ring is an annular manifold around the inlet pipe to the engine. It is located after the intercooler and before the throttle. To aid in the air/fuel mixing, a 90° elbow is connected between the mixing ring and the throttle and eight configurations were tested as shown in Table 3. The seven engine operating conditions were 100%, 50%, and 25% load at both 1250 rpm and 1950 rpm, and an idle condition. Equivalence ratio was measured for each individual cylinder with an UEGO sensor. The equivalence ratios for all six cylinders were averaged and a standard error was calculated.The results are shown in Table 3 for the leanest equivalence ratio without audible misfire at 1950 rpm and 100% load, and the average of the seven standard errors for the seven engine operating conditions. Results for each load condition are shown in Figures 1 through 8. Elbow number 3 was selected for this engine because of its lowest lean-limit and low average standard error.

Table 3. Description and Results of the Mixing Elbow Configurations

ELBOW NUMBER	1	2	3	4	5	6	7	8
64 mm spacer between elbow and throttle	No	No	Yes	Yes	Yes	Yes	No	No
152 mm spacer between elbow and mixing ring	No	No	No	No	Yes	Yes	Yes	Yes
Number of holes in mixing ring	18	9	9	18	18	9	9	18
Equivalence ratio limit w/o audible misfire at 1950 rpm, 100% load	0.62	0.62	0.59	0.62	0.62	0.61	0.60	0.63
Average of the standard error of the seven load conditions	0.0127	0.0041	0.0037	0.0066	0.0129	0.0044	0.0032	0.0053

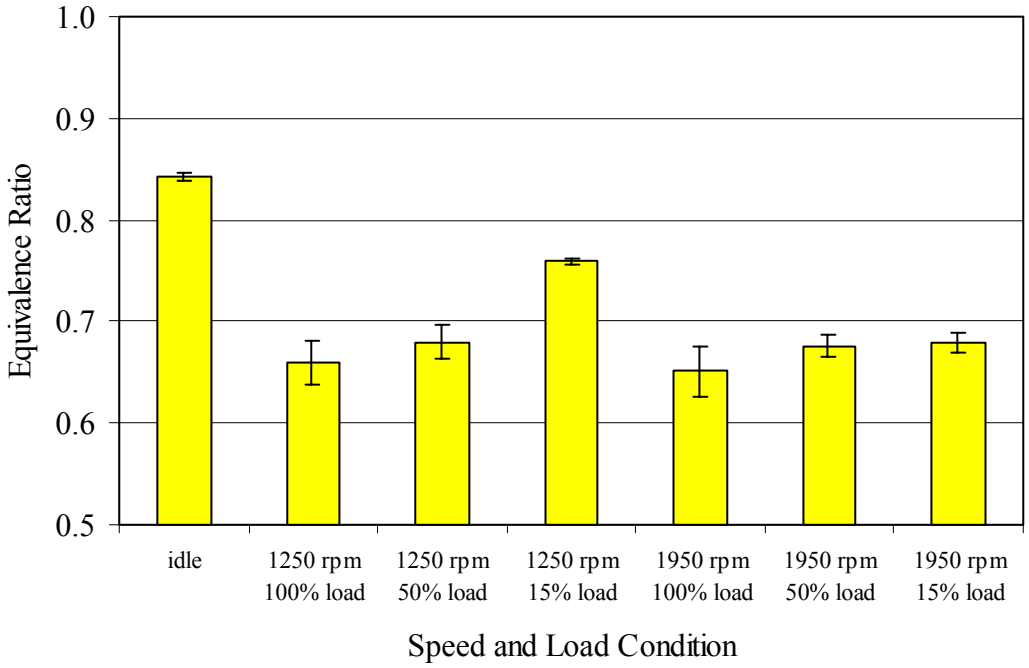

Figure 1. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 1

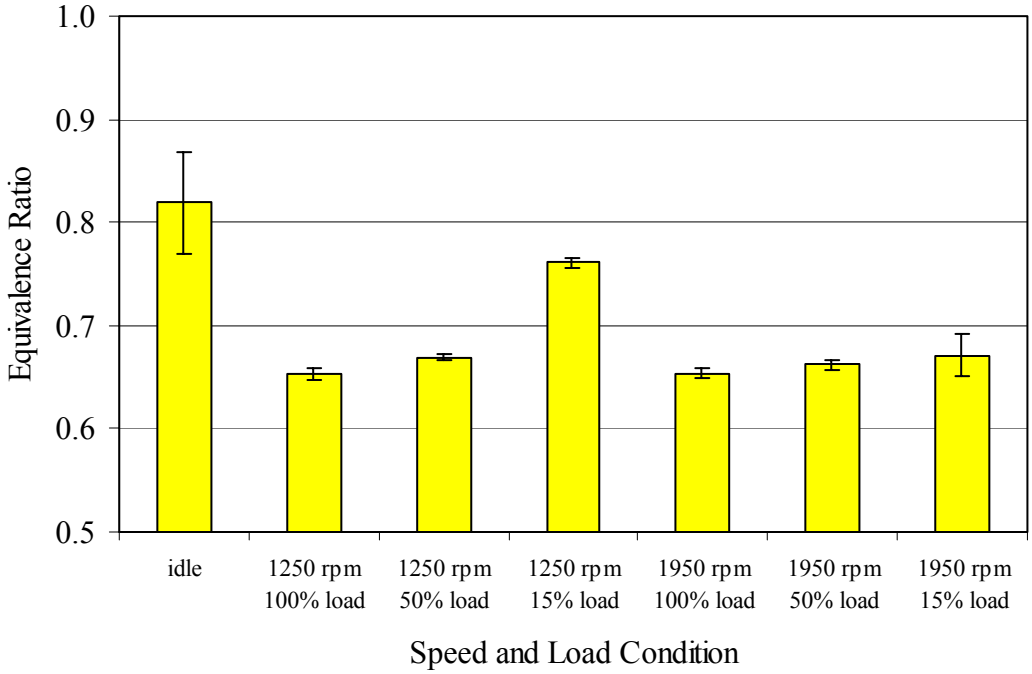

Figure 2. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 2

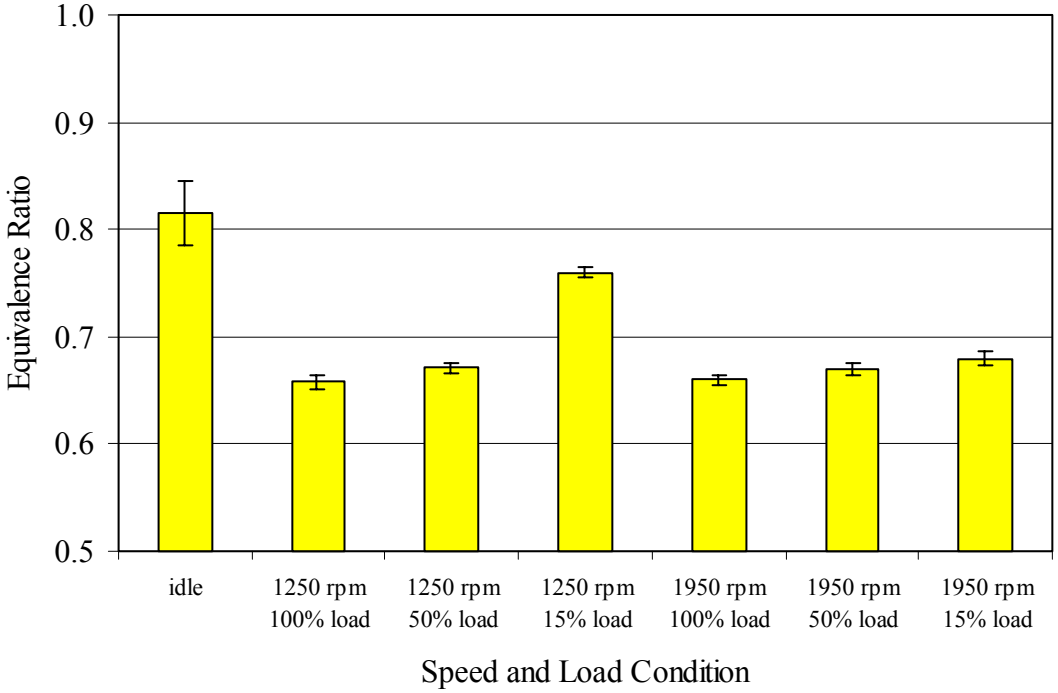

Figure 3. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 3

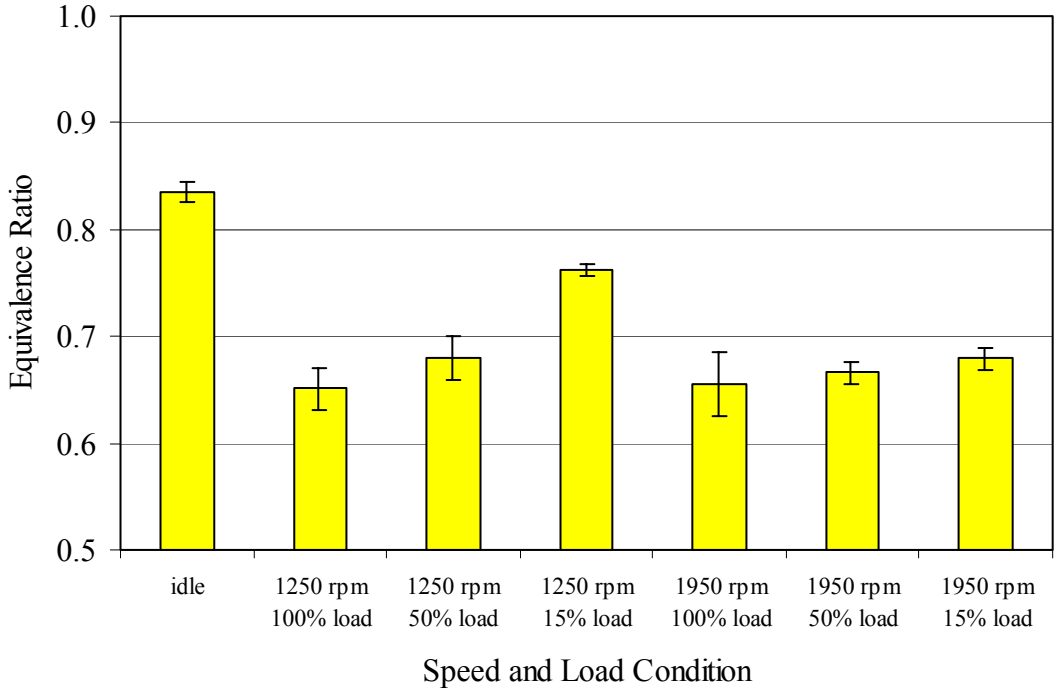

Figure 4. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 4

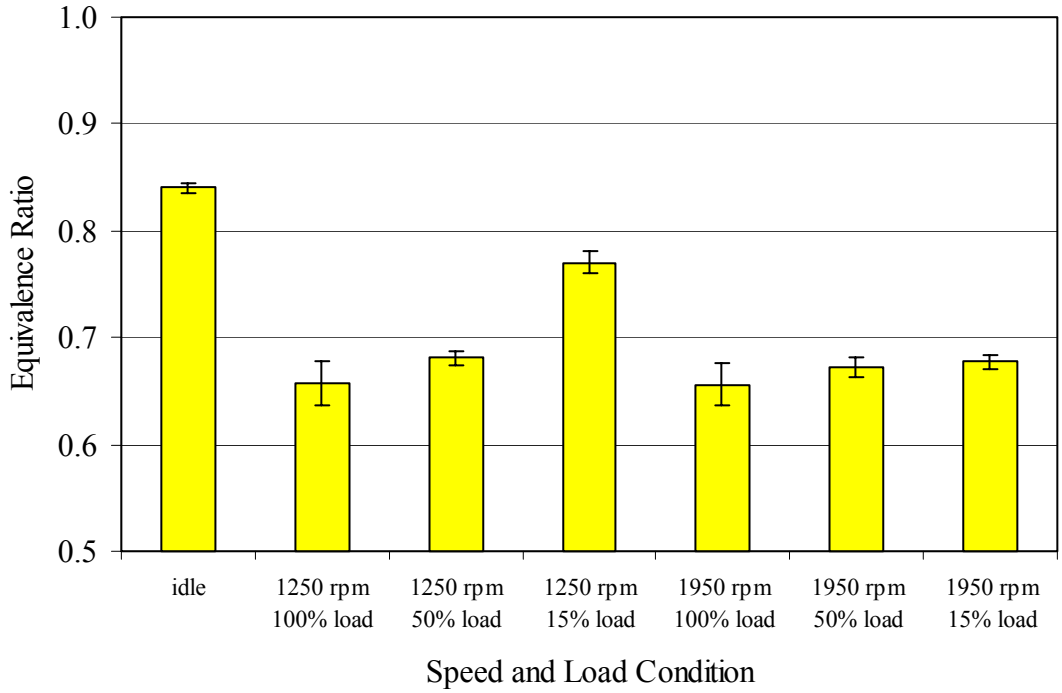

Figure 5. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 5

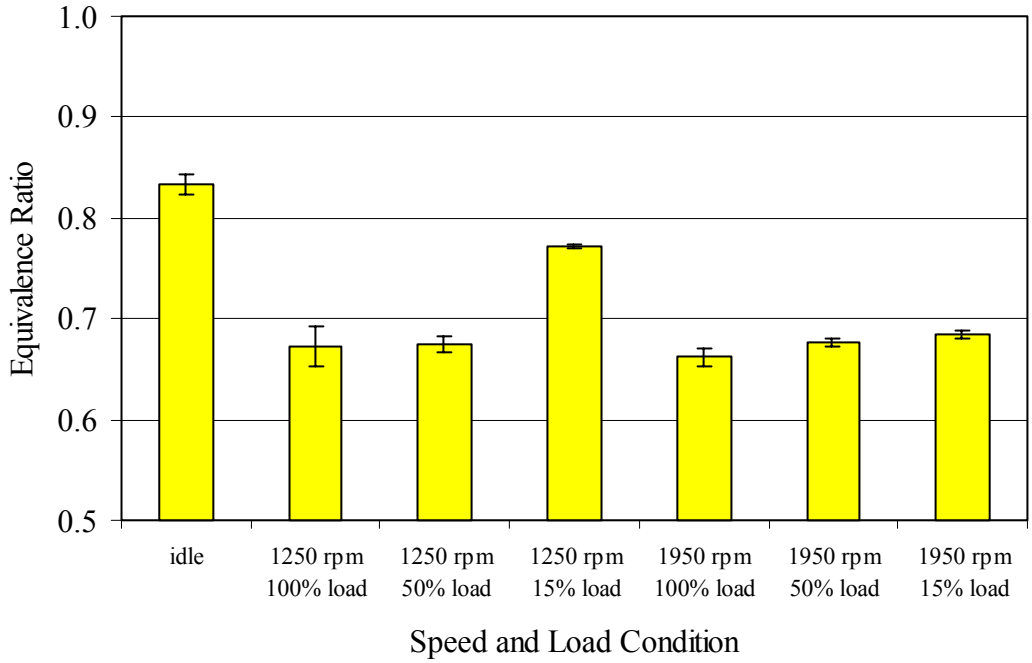

Figure 6. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 6

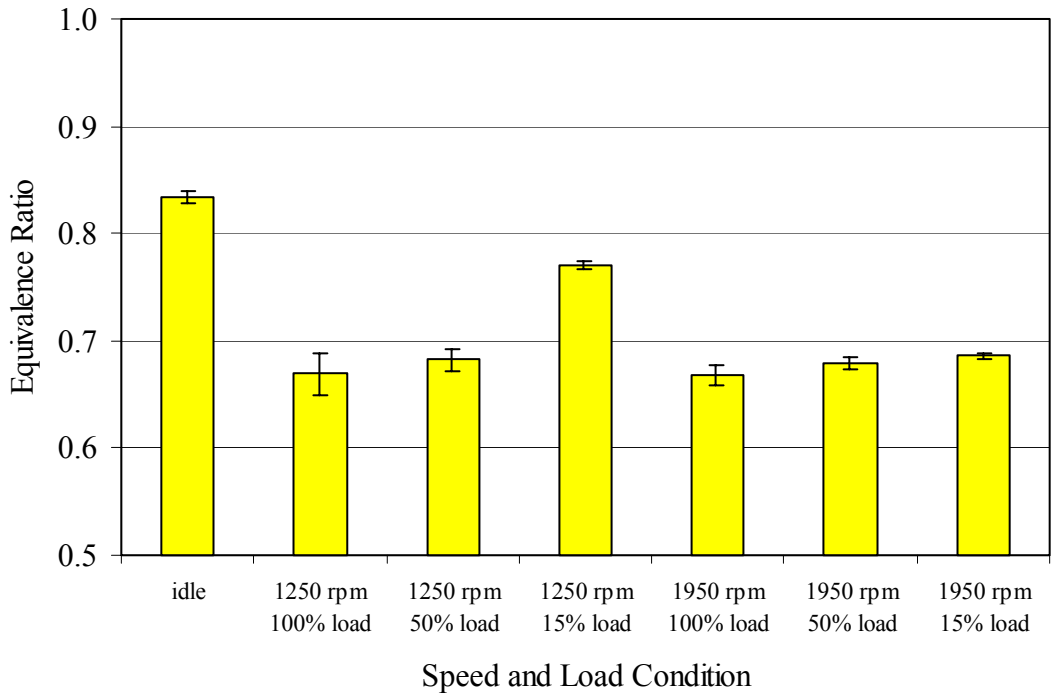

Figure 7. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 7

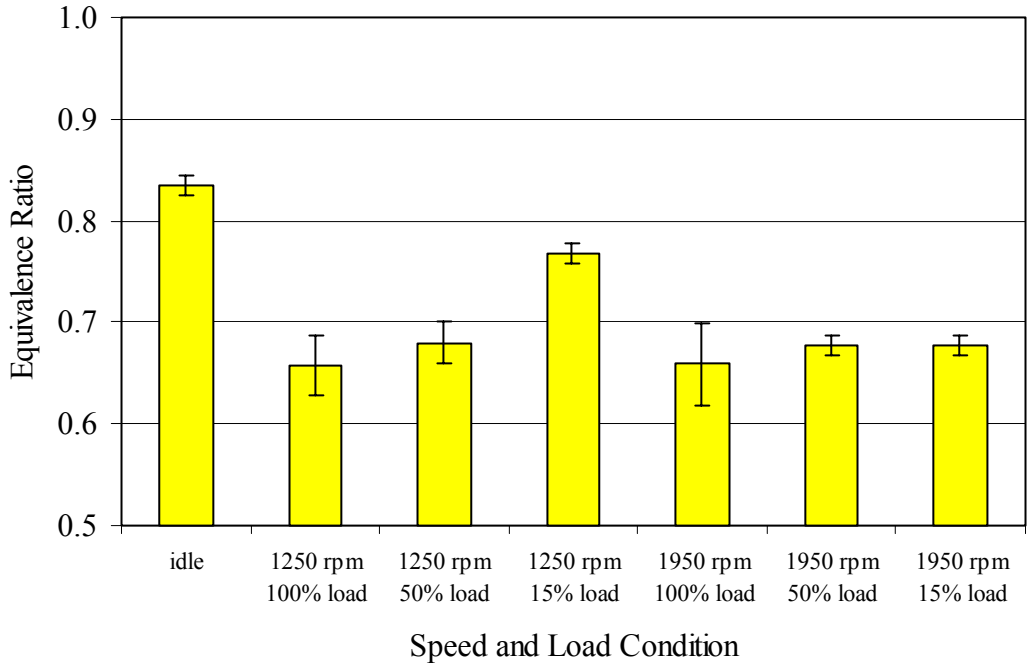

Figure 8. Average Equivalence Ratios and the Standard Error For the Six Cylinders using Mixing Elbow Number 8

4.3 Cam Timing

Another project, funded by Mack Trucks, was conducted concurrently with the Mack E7G project. A separate engine was used for each project, and one engine showed higher torque at low engine speeds than the other engine. Mack Trucks had mis-machined a cam gear such that it advanced the cam by one tooth. Therefore, a study was conducted to determine the optimal cam timing for this engine; the cam profile was the same as the diesel engine it was derived from. The cam timing was tested at the original diesel cam timing and advanced one tooth on the cam gear. One tooth advanced is 8.57 crank angle degrees in an 84-tooth cam gear. Figures 9 through 17 show the results for 1950, 1500, and 1250 rpm at 100%, 75%, and 50% load. For either cam timing, the efficiencies are about the same for a given NO_x level, whereas the HC emissions are lower with the original cam timing. With the advanced cam timing, higher torque at 1100 rpm at WOT were noted. The advanced cam timing was selected for this engine at the higher low-speed torque capability.

4.4 Steady-State Engine Mapping

Engine mapping included knock tolerance testing, lean-limit testing, and calibration of the engine controller tables.

4.4.1 Knock Tolerance Testing

Knock tolerance testing for the Mack E7G engine was presented in the final report for the Mack LNG Engine Development for Long-Haul Truck, SwRI Project No. 03-7816, and is presented again here. Results are based on an engine rated at 350 bhp at 1900 rpm.

Knock testing was performed to determine the highest intake manifold air temperature, highest equivalence ratio, and the most advance ignition timing possible without the engine knocking. The testing was conducted at various equivalence ratios, 105 and 150 deg F air temperature after the intercooler, and 200 deg F coolant out temperature. Ignition timing was advanced until the pressure signal from the number two cylinder showed presence of knock. The composition of the natural gas fuel used for knock testing is shown in Table 4.

Table 4. Gas Composition for Knock Testing

Gas	Volume (%)
Methane	85.1
Ethane	9.0
Propane	2.4
Nitrogen	3.5

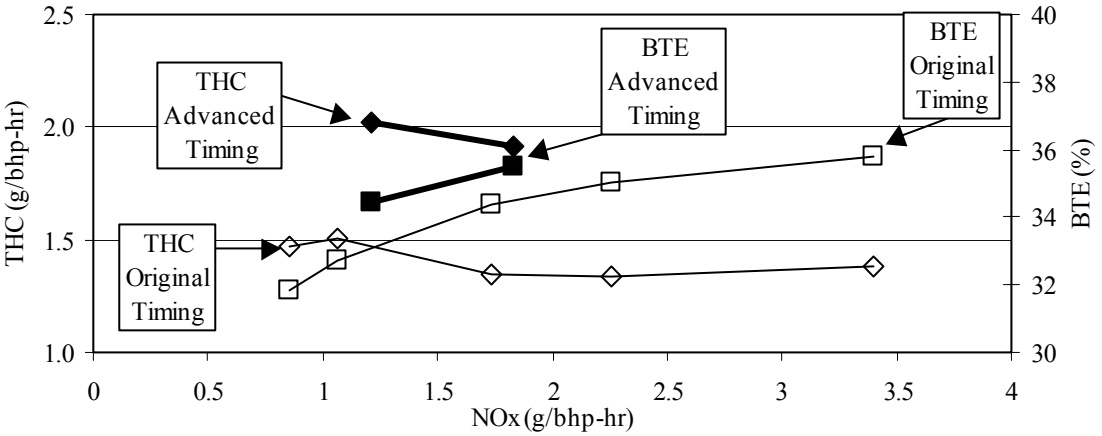

Figure 9. Comparison of Original and Advanced Cam Timing At 1950 rpm, 100% Load, and Various Ignition Timings

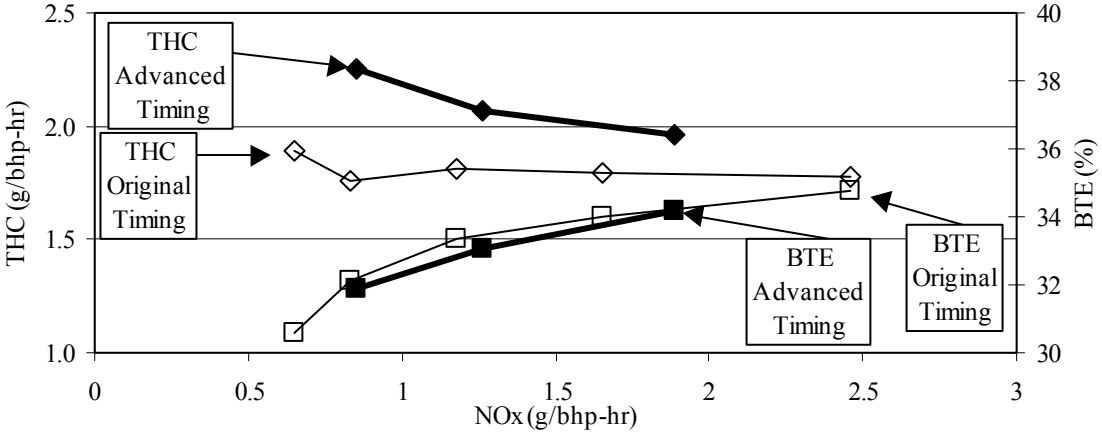

Figure 10. Comparison of Original and Advanced Cam Timing At 1950 rpm, 75% Load, and Various Ignition Timings

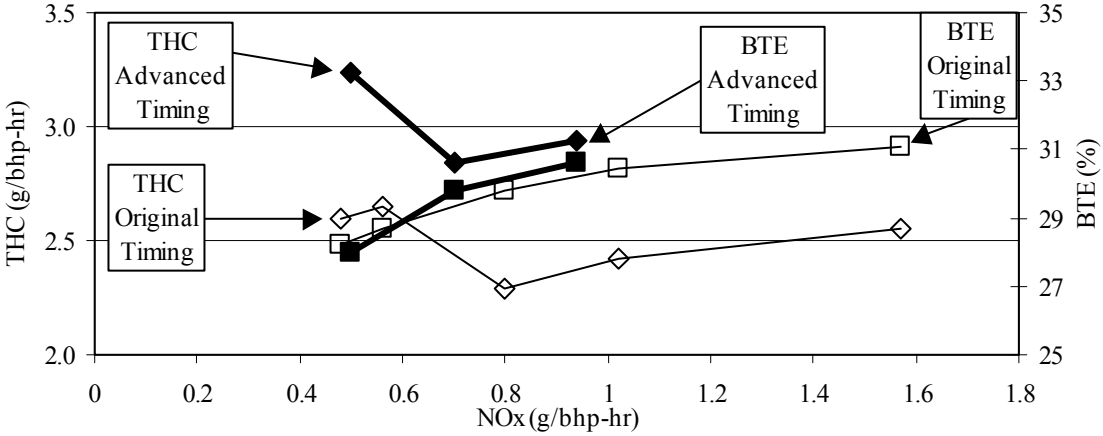

Figure 11. Comparison of Original and Advanced Cam Timing At 1950 rpm, 50% Load, and Various Ignition Timings

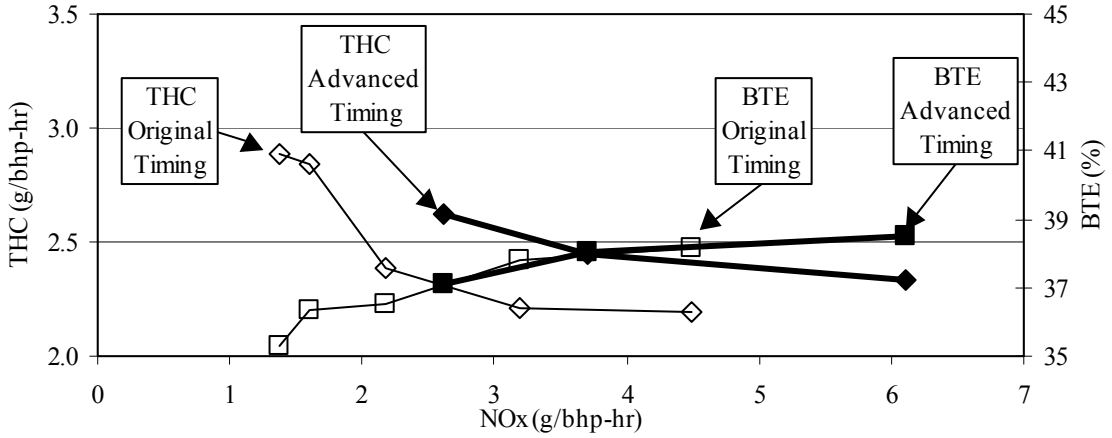

Figure 12. Comparison of Original and Advanced Cam Timing At 1500 rpm, 100% Load, and Various Ignition Timings

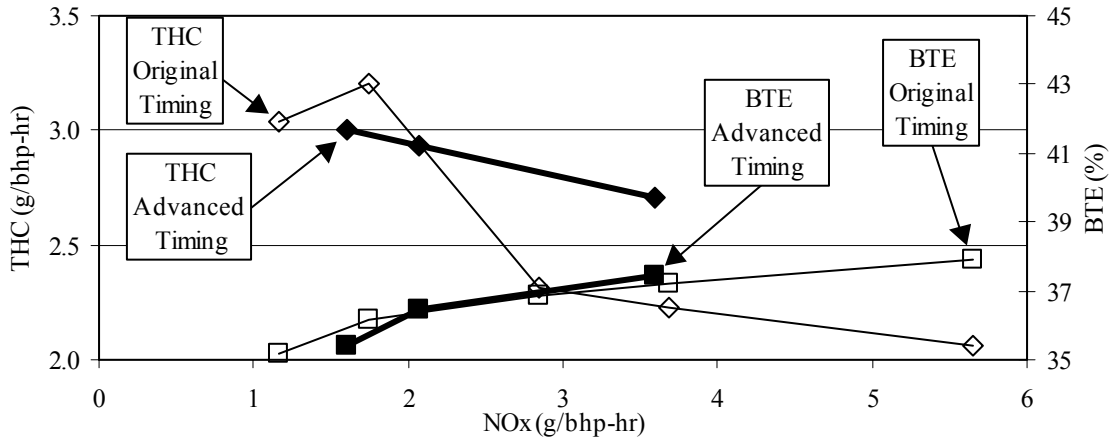

Figure 13. Comparison of Original and Advanced Cam Timing At 1500 rpm, 75% Load, and Various Ignition Timings

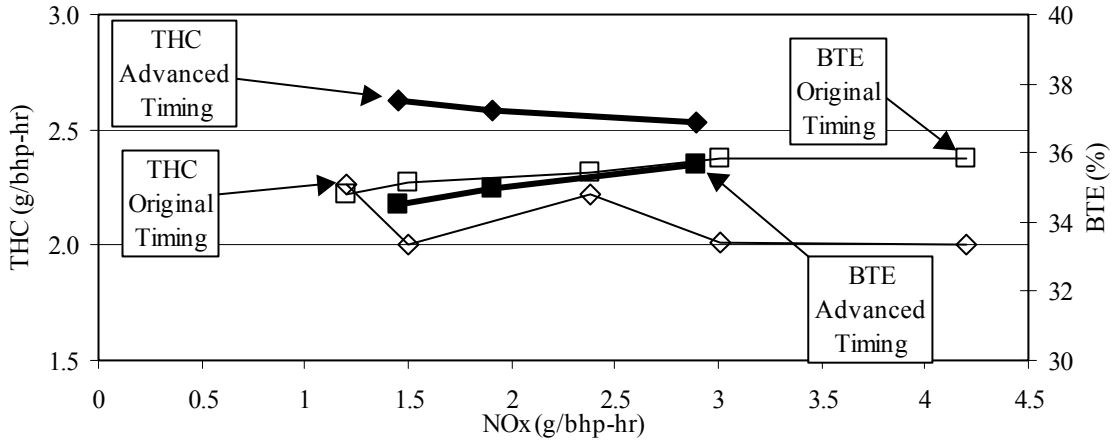

Figure 14. Comparison of Original and Advanced Cam Timing At 1500 rpm, 50% Load, and Various Ignition Timings

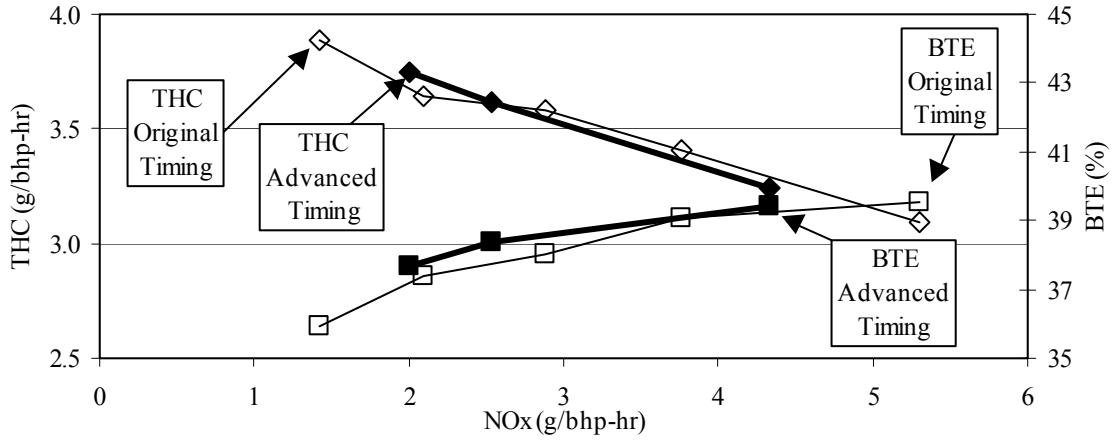

Figure 15. Comparison of Original and Advanced Cam Timing At 1250 rpm, 100% Load, and Various Ignition Timings

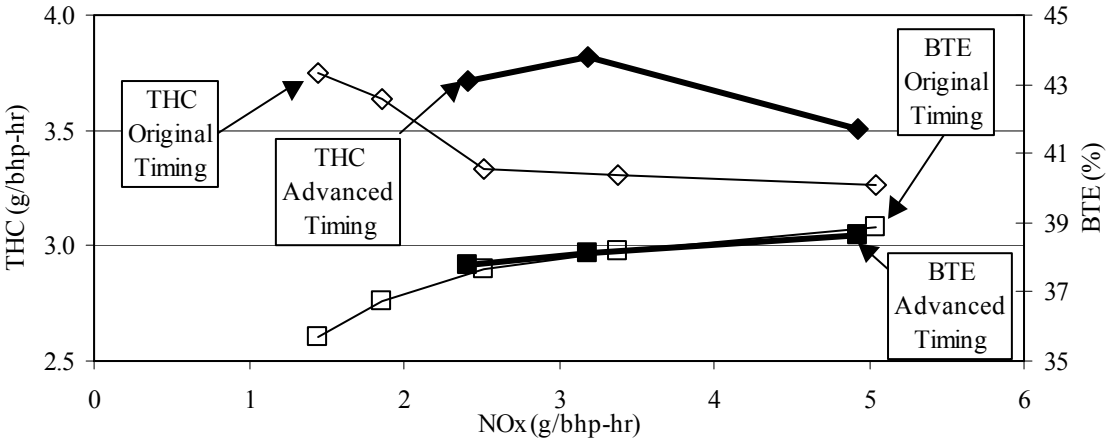

Figure 16. Comparison of Original and Advanced Cam Timing At 1250 rpm, 75% Load, and Various Ignition Timings

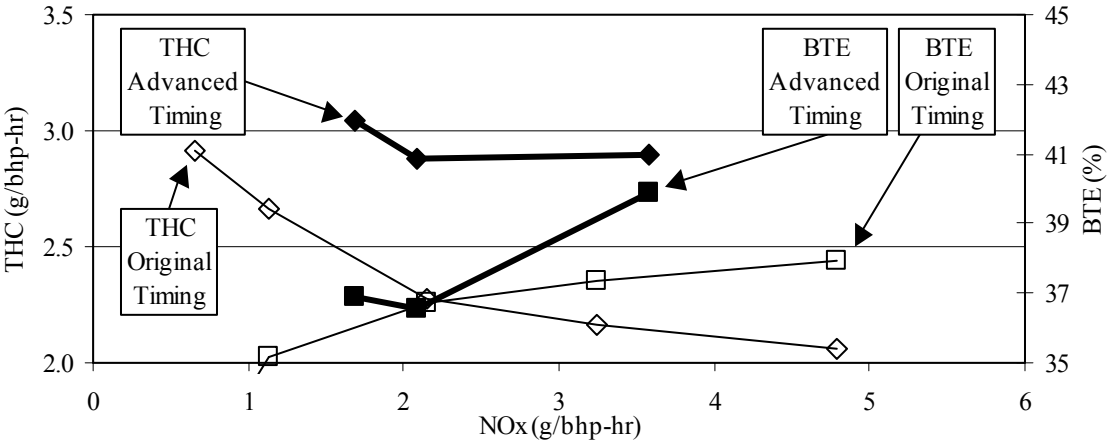

Figure 17. Comparison of Original and Advanced Cam Timing At 1250 rpm, 50% Load, and Various Ignition Timings.

The results of the knock testing are shown in Table 5 and in Figures 18 through 22. Figures 18 through 20 show tests at equivalence ratios between 0.65 and 0.75 for engine speed of 1900, 1500, and 1250 rpm. Also shown on the graphs as reference are the points of MBT and MBT-6 ignition timings at an equivalence ratio of 0.65. Figures 21 and 22 show tests at equivalence ratios between 0.80 and 0.85 for engine speeds of 1100 and 1000 rpm. There are no ignition timing points shown on these graphs since timing are selected to provide sufficient boost for low speed torque.

Table 5. Results of Knock Testing

Engine Speed (rpm)	Equivalence Ratio	Ignition Timing at Presence of Knock for 105 deg F After Intercooler Temperature (deg BTDC)	Ignition Timing at Presence of Knock for 150 deg F After Intercooler Temperature (deg BTDC)
1900	0.65	30	23
1900	0.70	23	19
1900	0.75	19	15
1500	0.65	25	20
1500	0.70	22	17
1500	0.75	18	16
1250	0.67	23	18
1250	0.70	22	17
1250	0.75	19	15
1100	0.80	18	15
1100	0.85	14	10
1000	0.80	19	12
1000	0.85	17	9

4.4.2 Lean-Limit Testing

Lean-limit testing for the Mack E7G engine was presented in the final report *Mack LNG Engine Development for Long-Haul Truck*, SwRI Project No. 03-7816, and is presented again here. Results are based on an engine rated at 350 bhp at 1900 rpm.

Lean-limit tests were conducted at engine speeds of 1250 and 1900 rpm, and 100% load. Cylinder pressure data were recorded from the #2 cylinder, and the COV_{imep} was calculated over 50 engine cycles. The lean limit is defined as the equivalence ratio where the COV_{imep} exceeds 5%. Tests were performed at three ignition timings: MBT, MBT-3, and MBT-6, and the equivalence ratio was lowered until audible misfire was detected. Figure 23 shows the results for 1250 rpm. At an ignition timing of 16 degrees BTDC, the lean limit is at an equivalence ratio of approximately 0.58. Figure 24 shows the results for 1900 rpm. At an ignition timing of 21 deg BTDC, the lean limit is at an equivalence ratio of approximately 0.60. Table 6 shows the results of the lean-limit tests. The run numbers refer to the recorded data included in Appendix A.

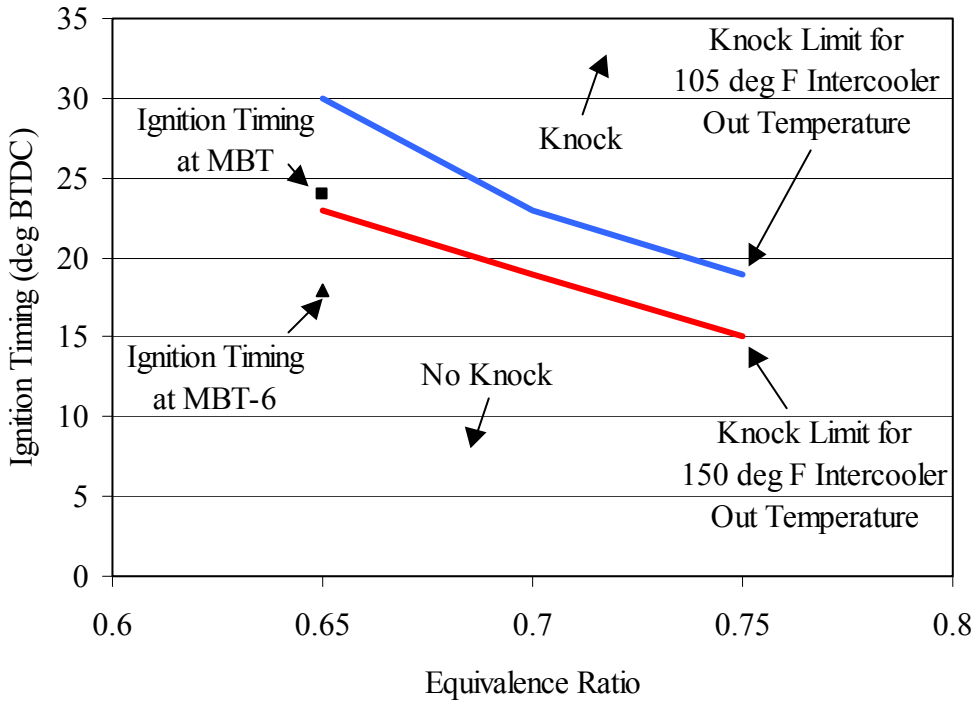

Figure 18. Knock Limit at 1900 rpm, 967 ft-lb.

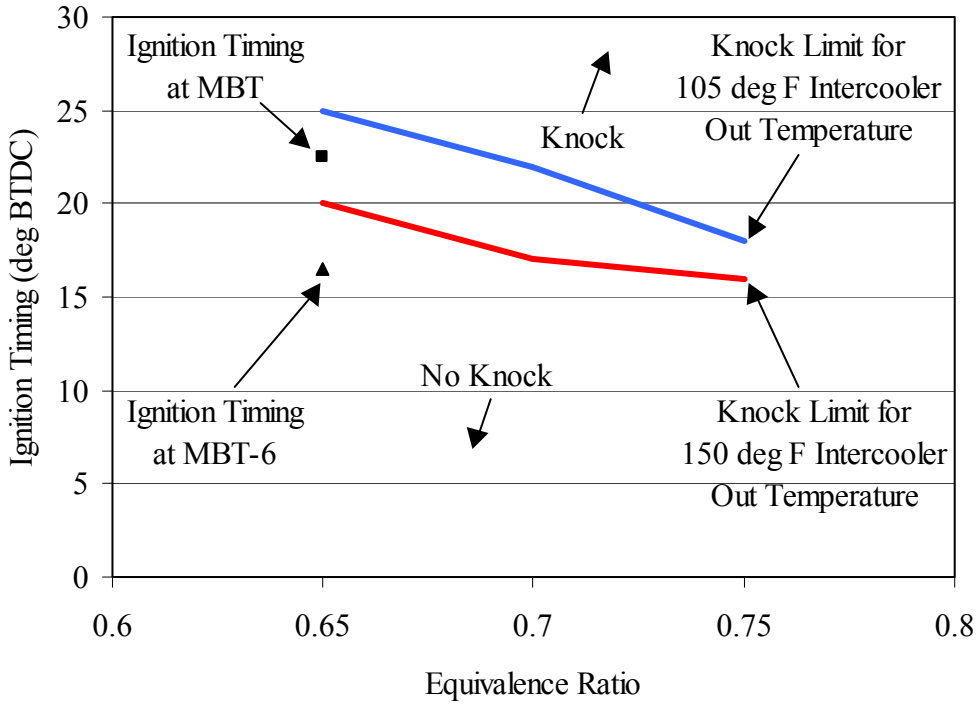

Figure 19. Knock Limit at 1500 rpm, 1175 ft-lb.

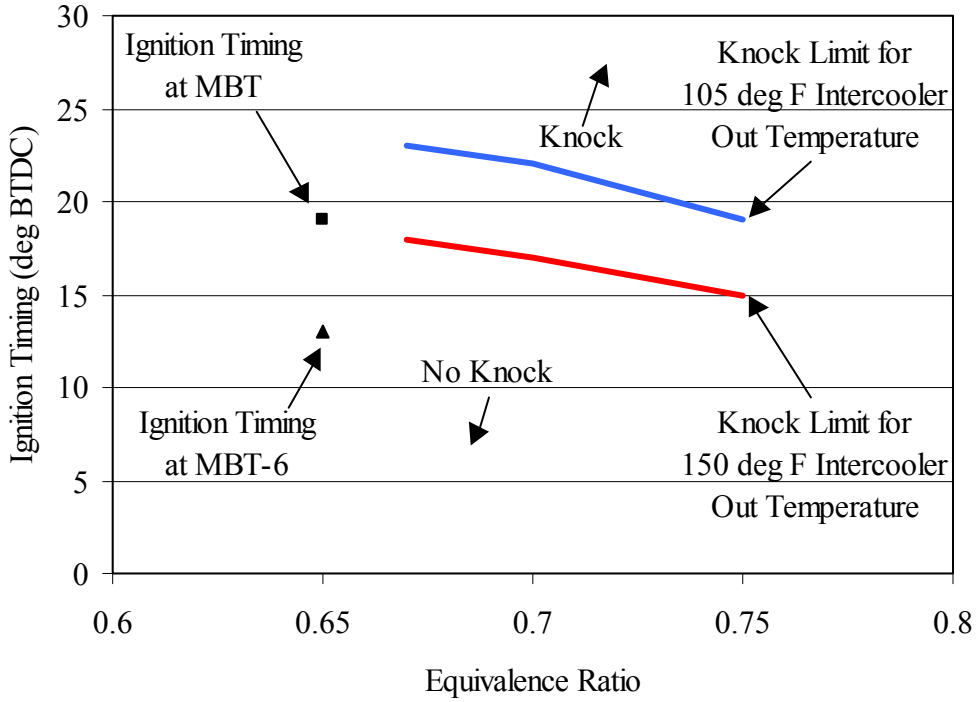

Figure 20. Knock Limit at 1250 rpm, 1250 ft-lb.

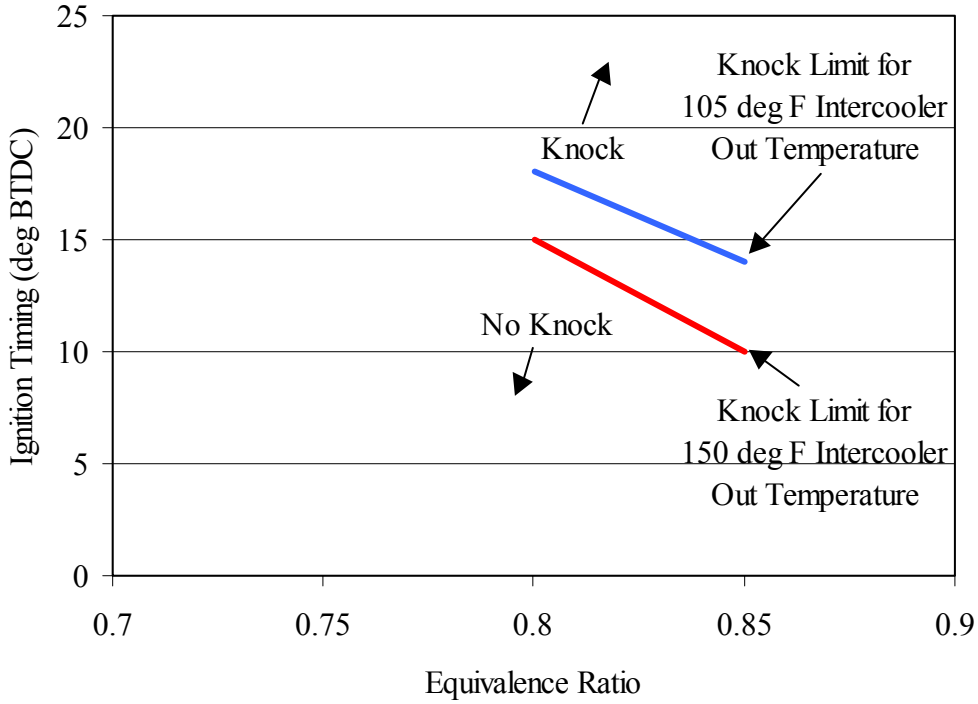

Figure 21. Knock Limit at 1100 rpm, 1230 ft-lb.

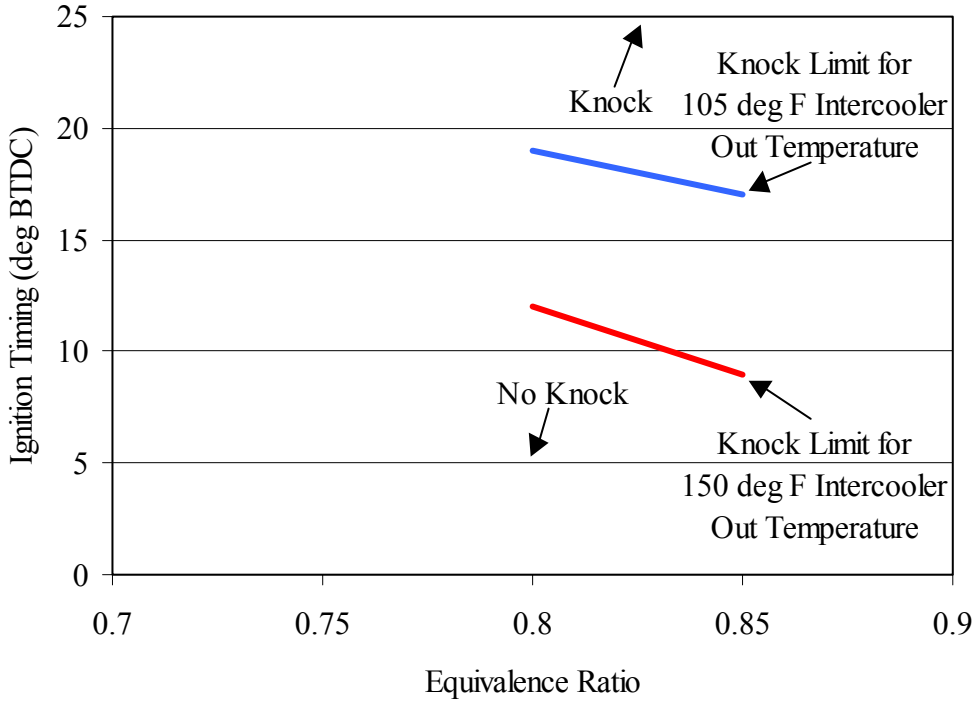

Figure 22. Knock Limit at 1000 rpm, 1115 ft-lb.

Table 6. Lean Limit Test Results

1250 RPM				1900 RPM			
Run Number	Ignition Timing (°BTDC)	Equiv. Ratio	COV_{imep} (%)	Run Number	Ignition Timing (°BTDC)	Equiv. Ratio	COV_{imep} (%)
866	19	0.65	1.24	844	24	0.65	1.62
867	16	0.65	1.93	845	21	0.65	2.06
868	13	0.65	3.58	846	18	0.65	2.93
869	19	0.67	1.24	847	24	0.67	1.21
870	16	0.67	1.77	848	21	0.67	2.00
871	13	0.67	2.23	849	18	0.67	2.22
872	19	0.64	1.55	850	24	0.64	1.99
873	16	0.64	2.31	851	21	0.64	2.95
874	13	0.64	4.82	852	18	0.64	3.53
875	19	0.63	1.69	853	24	0.63	2.11
876	16	0.63	2.09	854	21	0.63	2.49
877	13	0.63	4.11	855	18	0.63	3.88
878	19	0.62	1.96	856	24	0.62	1.80
879	16	0.62	4.21	857	21	0.62	3.36
880	13	0.62	4.27	858	18	0.62	4.53
881	19	0.61	1.98	859	24	0.61	2.79
882	16	0.61	3.51	860	21	0.61	3.88
883	13	0.61	5.55	861	18	0.61	5.31
884	19	0.60	3.08	862	24	0.60	3.36
885	16	0.60	3.45	863	21	0.60	4.74
886	13	0.60	7.32	864	18	0.60	6.32
887	19	0.59	2.51	865	24	0.59	4.89
888	16	0.59	3.76				
889	13	0.59	5.38				
890	19	0.58	4.06				
891	16	0.58	5.53				

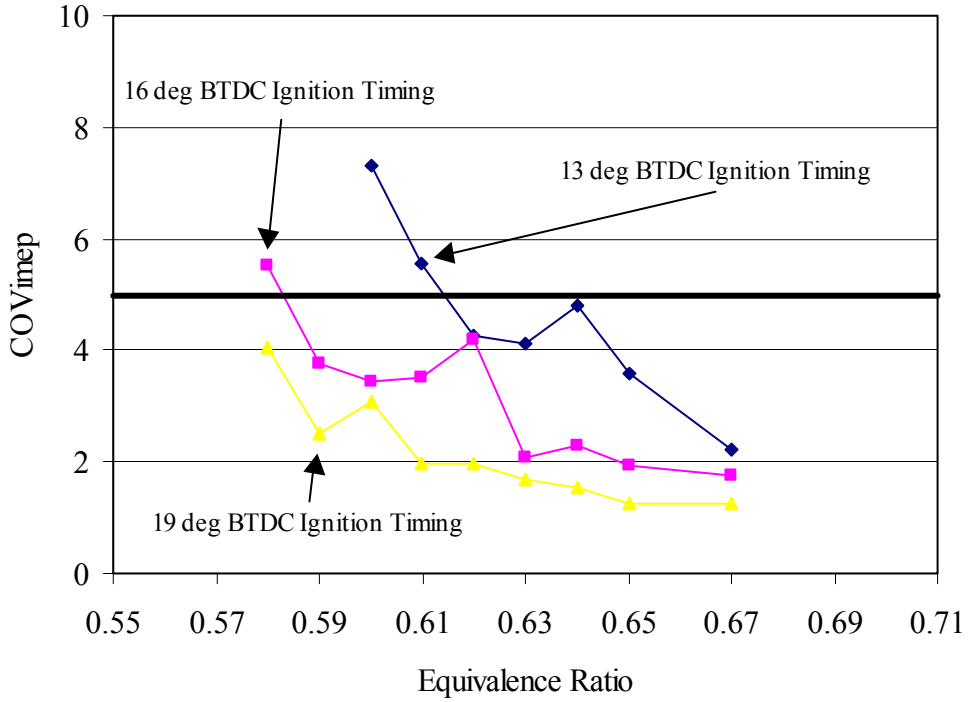

Figure 23. Lean Limit Tests at 1250 rpm, 1250 ft-lb

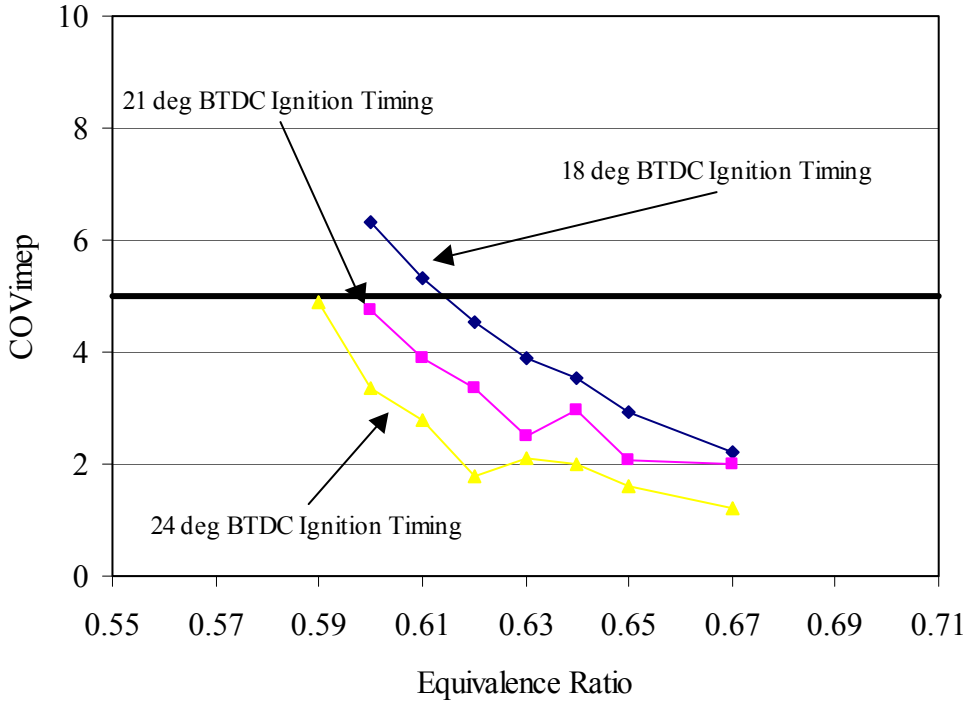

Figure 24. Lean Limit Tests at 1900 rpm, 967 ft-lb

4.4.3 Calibration

Steady-state tests of the Mack E7G engine included calibration of boost control, volumetric efficiency, equivalence ratio, and ignition timing. Transient tests included further calibration of equivalence ratio and ignition timing, calibration of boost control to rematch the 325 bhp torque curve with the change in ignition timing at WOT, and calibration of the turbo lag compensation.

Turbocharger boost determines the power output of the engine for a given throttle position. It is controlled through a pneumatic wastegate controller. Since Mack Trucks builds the engines and vehicles, a source of pressurized air can be made available on the truck for the engine controller to use under any operating condition. In the test stand, shop air was used to simulate the constant source of pressurized air. The pressurized air to the wastegate actuator is controlled through a pulse width modulated solenoid valve. The engine controller determines the amount of turbocharger boost based on throttle position and engine speed through a lookup table. An electronic throttle is used on this engine with a throttle command of 0.5 to 4.5 volts.

At throttle positions of less than 2.0 volts, the wastegate is fully opened to minimize throttling losses. At positions of 2.0 to about 4.0 volts, the turbocharger boost is set to minimize the pressure drop across the throttle. At throttle positions over 4.0 volts, the turbocharger boost is set to match the 325 bhp torque curve.

Volumetric efficiency (VE) is used to determine the open-loop fueling rate to the engine for the desired equivalence ratio. Corrections to the volumetric efficiency (VE) are accomplished through closed-loop control based on feedback from the universal exhaust gas oxygen (UEGO) sensor. A closed-loop multiplier performs immediate corrections to the VE to maintain the correct equivalence ratio. An adaptive loop multiplier, which is saved in a table, performs longer term corrections. The engine was operated at steady-state conditions with the adaptive loop multiplier set to zero, and the volumetric efficiency table adjusted to maintain a closed-loop multiplier of less than 1.00%.

The equivalence ratio table is used for air/fuel ratio control of the lean burn engine. As equivalence ratio is lowered from stoichiometric, the efficiency increases and the NO_x emissions decrease. If the equivalence ratio is too low, the hydrocarbon emissions increase, efficiency decreases, and misfires are possible. Equivalence ratio was set for lean operation with a margin above the misfire limit for the higher engine speeds where turbo boost was sufficient to run lean, and was set for power and driveability at lower engine speeds where turbo boost was not sufficient to run lean (particularly at WOT). Further refinements to the equivalence ratio table were performed during transient emissions testing. These included a lower equivalence ratio at idle to reduce NO_x emissions on the transient emissions test cycle, and lower equivalence ratios at low speeds, including low to mid loads to reduce NO_x emissions for the West Virginia University central business district (CBD) cycle on a chassis dyno.

Ignition timing is set as a compromise between efficiency and NO_x emissions. The best efficiency is at MBT timing, but to meet the NO_x emissions goals, retarded timings are required. A 12-mode steady-state prediction for NO_x emissions was used to determine the initial ignition-timing table for transient emissions testing. The 12-mode test is shown in Table 7. Results of the 12-mode test for ignition timing retarded the same amount at all 12 test points and are shown in Table 8. The 12-mode results for the initial ignition timing table for transient emissions testing is shown in Table 9. The transient emissions test with the initial ignition timing table was 2.86 g/bhp-hr. Ignition timing was modified to lower the NO_x emissions on the transient test to 2.15 g/bhp-hr.

Table 7. Test Points for the 12-Mode Steady-State Prediction for Transient Emissions

Mode	Engine Speed (%)	Load (%)	Weight (%)	Engine Speed (rpm)	*Torque* (ft-lb)	MBT (°BTDC)
1	0	CITT	8.8	600	160	20
2	50	83	2.6	1300	963	22
3	50	100	2.1	1300	1160	21
4	67	73	3.4	1520	896	26
5	83	50	7.0	1730	485	28
6	83	73	5.5	1730	805	27
7	83	100	11.9	1730	970	23
8	100	33	5.1	1950	287	30
9	100	50	9.6	1950	435	27
10	100	67	7.2	1950	583	26
11	100	83	16.8	1950	722	26
12	100	100	20.0	1950	870	23

Table 8. Predicted FTP Transient Results

Ignition Timing (°BTDC)	$BSNO_x$ (g/bhp-hr)	BSTHC (g/bhp-hr)	BSCO (g/bhp-hr)	BTE (%)
MBT	4.18	1.75	1.15	35.1
MBT-3	2.93	1.77	1.14	34.6
MBT-5	2.12	1.85	1.14	34.2
MBT-7	1.58	1.79	1.12	33.5

Table 9. Ignition Timing Based on Steady-State Tests

Mode	Ignition Timing (°BTDC)	$BSNO_x$ (g/bhp-hr)	BTE (%)
1	MBT	0.52	26.8
2	MBT-7	2.14	37.9
3	MBT-7	2.10	37.8
4	MBT-7	3.10	38.3
5	MBT-5	1.67	33.6
6	MBT-7	2.63	37
7	MBT-7	1.73	36.4
8	MBT	3.00	30
9	MBT-5	1.34	31.5
10	MBT-5	1.75	34.4
11	MBT-5	2.09	35.3
12	MBT-5	1.45	34.9
Prediction		1.86	34.1

Recorded data for the steady-state tests are included in Appendix B. Tables with the final calibration to be used for certification are included in Appendix C.

4.5 Durability Testing

The first durability test was reported in the final report for Task 2 - 1000-Hour Super Thermal Cycle Test, SwRI Project No. 03-7501-002, and is included in Appendix D. The second durability test was reported in the final report for the 1000-Hour Super Thermal Cycle Test on a Mack E-7 Natural Gas Fueled Engine, SwRI Project No. 03-1248, and is included in Appendix E.

4.6 Data Logger

A data logger was installed on a refuse truck for in service use. The data logger recorded information from the vehicle and the engine. A list of data recorded is shown in Table 10. Due to harsh environmental conditions, the fuel system pressure sensors added for data logging failed. The fuel pressure used by the engine controller was still operational. Data for engine speed, vehicle speed, and MAP for a typical day are shown in Figures 25-27. Most of the occurrences occur at idle (600 rpm, 0 mph, 8 psia), followed by packing (1200 rpm, 0 mph, 11 psia). There were 395 total minutes of data logging time for this day, 31 minutes were used for packing and 122 minutes were used for idling.

Histograms for data recorded from 4/23/98 to 6/29/98 are included in Appendix F. In the period from 4/23/98 to 6/29/98 the data logger recorded 2909 miles with 2063 gallons of LNG used for a fuel economy of 1.41 mpg, which is a diesel equivalent fuel economy of 2.28 mpg. Of the 2063 gallons used, 227 gallons were used at idle and 236 gallons were used for packing, which represents 11.0% and 11.4% of the total fuel used, respectively.

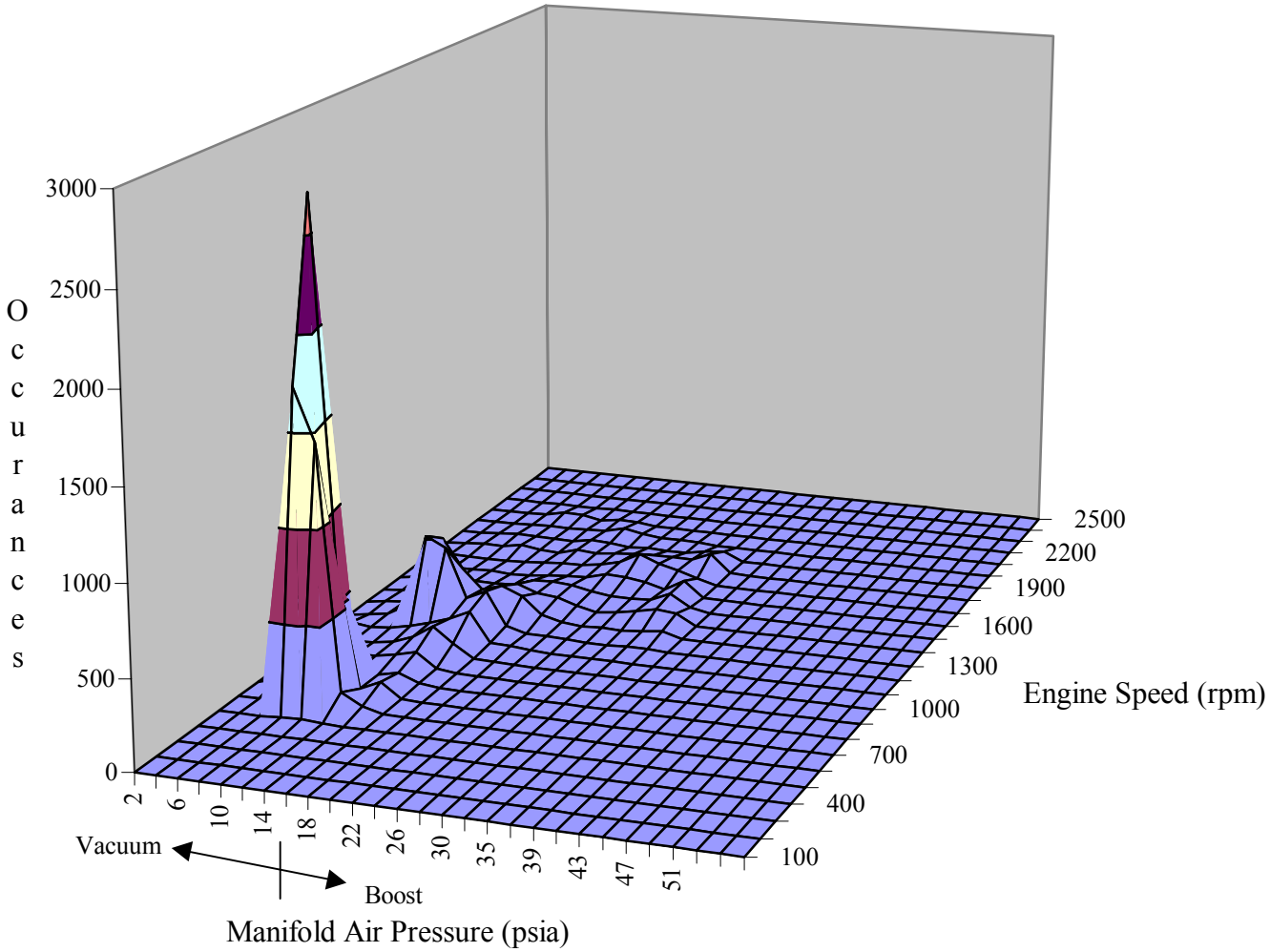

Figure 25. Engine Speed vs. Manifold Air Pressure for One Day of Operation

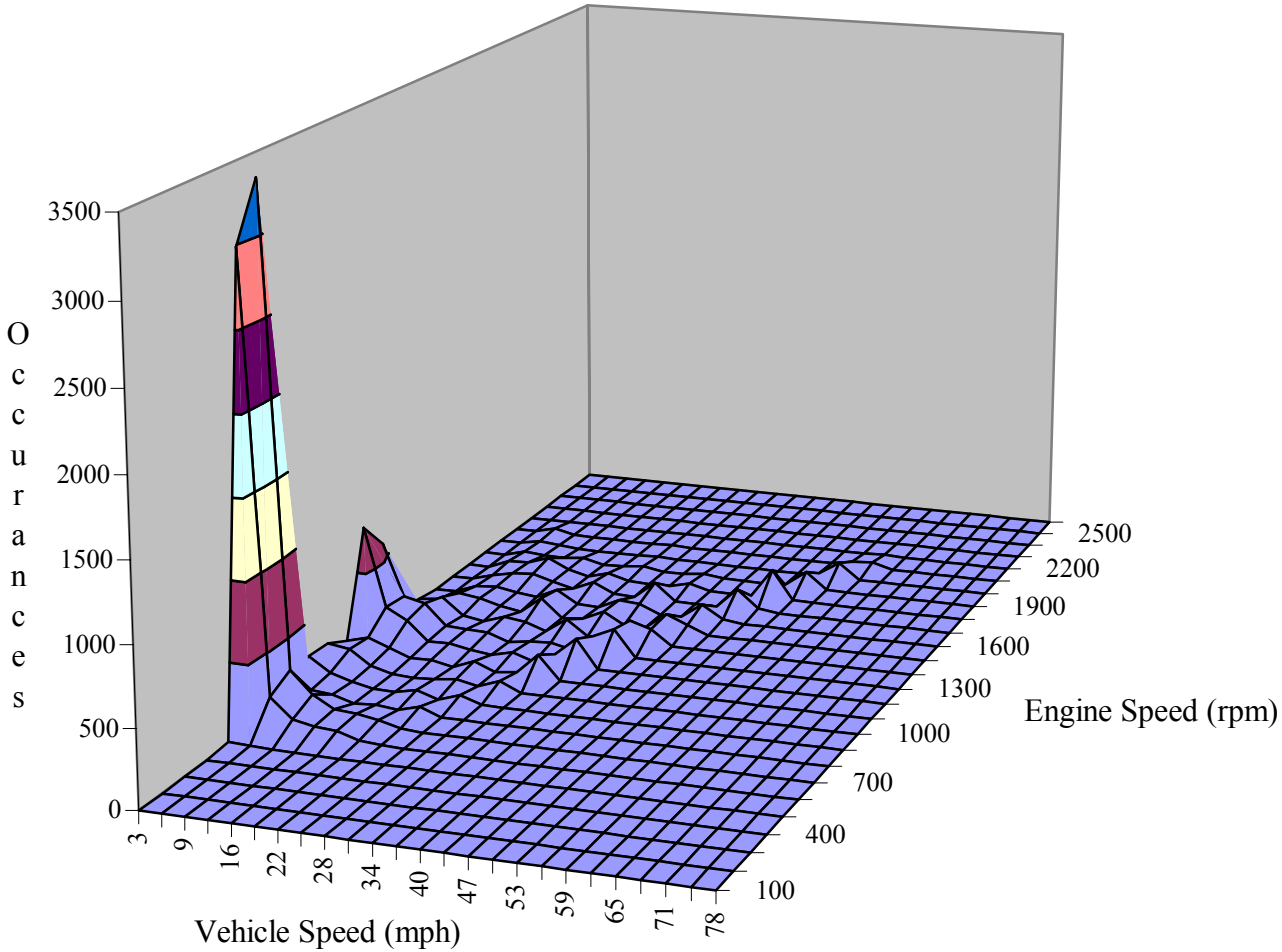

Figure 26. Engine Speed vs. Vehicle Speed for One Day of Operation

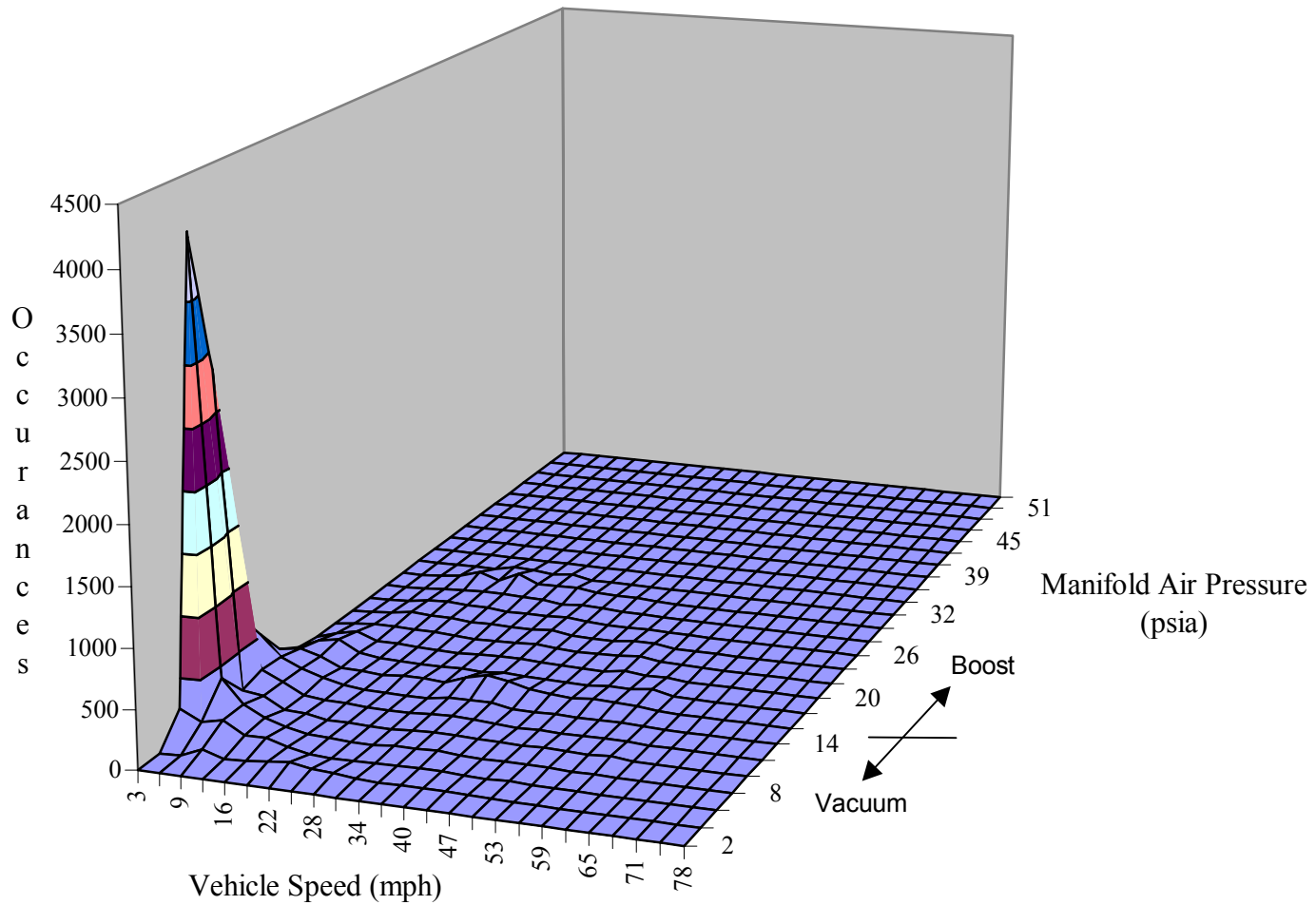

Figure 27. Manifold Air Pressure vs. Vehicle Speed for One Day of Operation

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Table 10. Data Recorded on the Data Logger

Time	Battery (volts)	Turbo Lag Compensation Enable (%)
Date	Barometric Pressure (psia)	Turbo Lag Compensation Enrichment (%)
Odometer Reading (miles)	Equivalence Ratio Feedback	Turbo Lag Compensation Retard (deg)
Vehicle Speed (mph)	Equivalence Ratio Command	Close Loop Multiplier (%)
Engine Speed (rpm)	Equivalence Ratio Modifier for ECT	Adaptive Loop Multiplier (%)
Fuel Flow (lb/hr):	#1 Tank Pressure (psig)	Manifold Air Pressure Signal (volts)
Instantaneous Fuel Economy (mpg)	#2 Tank Pressure (psig)	Preturbine Pressure Signal (volts)
Cumulative Fuel Economy (mpg)	Fuel Pressure Before Vaporizer (psig)	Exhaust Back Pressure Signal (volts)
Manifold Air Pressure (psia)	Fuel Pressure After Vaporizer (psig)	Gas Pressure Signal (volts)
Exhaust Back Pressure (psia)	Fuel Pressure at Regulator (psig)	Manifold Air Temp Signal (volts)
Preturbine Pressure (psia)	Fuel Pressure at Filter (psig)	Engine Coolant Temp Signal (volts)
Manifold Air Temp (deg F)	Air Pressure Before Intercooler (psia)	Gas Temperature Signal (volts)
Engine Coolant Temp (deaf)	Air Pressure After Intercooler (psia)	UEGO Signal (volts)
Gas Pressure (psia)	Relative Humidity (%)	UEGO Pumping Signal (volts)
Gas Temperature (deg F)	EMC Run Time (sec)	UEGO Heater Signal (volts)
Actual Foot Pedal Position (volts)	Ignition Timing (deg BTDC)	UEGO Resistor Signal (volts)
Normalized Foot Pedal Position (volts)	Injection Pulse Width (ms)	ECM Control Mode
Throttle Position Command (volts)	Uncorrected Fuel Flow (mg/inj)	ECM Run Mode
Throttle Position Feedback (volts)	Predicted Volumetric Efficiency (%)	UEGO Mode
Ambient Air Temp (deg F)	Volumetric Efficiency Modification (%)	Fault Codes
Oil Temp (deg F)	Actual Volumetric Efficiency (%)	Cumulative Fuel Usage (gal)
Exhaust Temp (deg F)	Change in Manifold Air Pressure (psia/s)	Idle Fuel Usage (gal)
Data Logger Temp (deg F)	Boost Control PWM (%)	Packing Fuel Usage (gal)

4.7 Transient Emissions Testing

Results from the transient emissions testing were reported in the final report for the Transient Emissions Testing on a Mack E7G Engine, SwRI Project No. 03-2377, and is included in Appendix G. The emissions certification levels for the final calibration, with a deterioration factor, are shown in Table 11. Screen shots from the engine controller for this calibration are included in Appendix C. CARB certification gas was used for these tests. The objectives of this project were NO_x+NMHC emissions of less than 2.5 g/bhp-hr on a natural gas with 99% methane. The use of CARB certification gas increases both the NO_x and NMHC emissions. CARB gas has 90% methane along with 4% ethane and 2% butane. Ethane and

butane increase the flame speed and therefore increase NO_x emissions. Ethane and butane also increase the NMHC emissions since the unburned fuel has an increased amount of NMHCs. The final calibration was selected for NO_x emissions below 2.5 g/bhp-hr with acceptable driveability. NO_x emissions below 2.0 g/bhp-hr are possible on the transient emissions tests, but driveability problems were noted in the field due to the amount of timing retard required for the lower emissions combined with humidity effects. A summary of the NO_x emissions and fuel economy over the transient test cycle is presented in Table 12. The calibration used for the results in Table 9 was the initial calibration for the transient emissions testing. The NO_x emissions for this test was 2.86 g/bhp-hr. Similar trends were noted at lower NO_x emissions levels. Table 12 shows that the transient from idle uses 9% of the time in the cycle, yet accounts for 41% of the NO_x emissions. This is due to the steep torque rise of this engine and the high equivalence ratios used during the WOT transient from idle. The high equivalence ratios are used to improve driveability. This calibration, where the high equivalence ratios are high, will not pass 2002 emissions for natural gas fueled engines due to high steady-state NO_x emissions. In 2002, natural gas engines will have the same limit on steady-state emissions over the entire operating range as diesel engines.

Table 11. 325 bhp Transient Emissions Results

Emission	**Emission Level (g/bhp-hr)**
HC/OMHCE	3.1
NMHC/OMNMHC	0.324
NMHC+ NO_x	2.53
Carbon Monoxide	1.4
Oxides of Nitrogen	2.2
Particulates	0.03
Formaldehyde	0.136

Table 12. Summary for the FTP Results for NO_x Emissions at 2.86 g/bhp-hr

Description	**Idle**	**Mid-High Speed Mid Load**	**High Speed High Load**	**Transient from Idle**	**Remainder**
Occurrences	42%	25%	10%	9%	14%
Total Contribution to NO_x Emissions	12%	18%	17%	41%	12%
Average Diluted NO_x Emissions	7.3 ppm	18.8 ppm	43.1 ppm	119.5 ppm	22.1 ppm
Total Contribution to Fuel Usage	12%	27%	38%	7%	16%

The previous version of this engine was rated at 300 bhp and had NO_x emissions of 2.95 g/bhp-hr with no deterioration factor and a brake specific fuel consumption of 0.474 lb/bhp-hr. This final calibration for this engine has NO_x emissions of 2.2 g/bhp-hr and a brake specific fuel consumption of 0.400 lb/bhp-hr. Actual driving cycle fuel economy comparisons are not readily available since the previous version of this engine was installed in a refuse hauler which was at a different location as the current version. A summary of the comparison of the previous and current version of the engine is shown in Table 13.

Table 13. Comparison of Previous and Current Version of the Engine

	Previous Version	Current Version
Power (bhp)	300	325
Torque (ft-lb)	1100	1180
NO_x (g/bhp-hr)	2.95	2.20
BSFC (lb/bhp-hr)	0.474	0.400

A calibration with a 350-bhp rating was tested for transient emissions. The emissions certification levels for the final calibration, with a deterioration factor, are shown in Table 14. Screen shots from the engine controller for this calibration are included in Appendix H. CARB certification gas was used for these tests.

Table 14. 350 bhp Transient Emissions Results

Emission	Emission Level (g/bhp-hr)
HC/OMHCE	2.9
NMHC/OMNMHC	0.276
NMHC+ NO_x	2.60
Carbon Monoxide	1.3
Oxides of Nitrogen	2.3
Particulates	0.03
Formaldehyde	0.116

January 2000 • NREL/SR-540-26935

Subcontractor Report

Mack LNG Vehicle Development: Appendices

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San Antonio, Texas

National Renewable Energy Laboratory

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Golden, Colorado 80401-3393

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Mack LNG Vehicle Development: Appendices

Southwest Research Institute
San Antonio, Texas

NREL Technical Monitor: Mike Frailey

Prepared under Subcontract No. AAC-5-15249-01

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MACK LNG VEHICLE DEVELOPMENT

DRAFT AND CONFIDENTIAL
FINAL REPORT

SwRI Project No. 03-7276

Prepared for:

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July 8, 1999

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EXECUTIVE SUMMARY

The goal of this project was to install a production ready, state-of-the-art engine control system on the Mack E7G natural gas engine to improve efficiency and lower exhaust emissions. In addition, the power rating was increased from 300 bhp to 325 bhp. The emissions targets were NO_x+NMHC of less than 2.5 g/bhp-hr (with a mandatory NO_x of less than 2.5 g/bhp-hr) and particulate matter of less than 0.05 g/bhp-hr on 99% methane. Durability and field testing were also conducted.

A Woodward OH-1 state-of-the-art engine controller was successfully installed on the Mack E7G engine and a calibration for the Mack engine was developed. Knock tolerance testing and misfire limit testing were conducted to aid in the development of the calibration. The first 1000-hour durability test was conducted with partial funding from this project, and a second 1000-hour durability test to address the concerns from the first test was successfully completed. A data logger was installed on an in-service refuse hauler and engine and vehicle operation was successfully recorded.

The brake specific fuel consumption over the transient emissions test cycle was decreased from 0.474 lb/bhp-hr on the previous version of this engine to 0.400 lb/bhp-hr on the current version. The NO_x emissions over the transient emissions test cycle were decreased from 2.95 g/bhp-hr to 2.20 g/bhp-hr. The NO_x+NMHC emissions were 2.53 g/bhp-hr and particulate matter was 0.03 g/bhp-hr on the current version of this engine. Emissions for the current version of this engine include the deterioration factor, whereas emissions from the previous version are results without deterioration. CARB certification gas was used for the transient emissions testing on the current version of this engine. NO_x+NMHC emissions are expected to decrease on a 99% methane fuel. Actual driving cycle fuel economy comparisons are not readily available since the previous version of this engine was installed in a refuse hauler, which was at a different location. Further development of this engine should include efficiency improvements and NO_x reductions.

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1.0 BACKGROUND

This project was a continuation of the development of a natural gas refuse hauler. A compressed natural gas (CNG) Mack MR demonstration vehicle was operated for nearly a year in revenue service on a previous project. Engine performance, emissions, driveability, and durability were acceptable for a demonstration vehicle; however, several areas of improvement were identified. These included vehicle range, refueling time, driving cycle fuel economy, and installation of improved and production-ready natural gas specific engine control hardware.

Vehicle range and refueling time can be improved by operating the vehicle on liquefied natural gas (LNG). Efforts on this project concentrated on minimizing throttling losses and increasing the NO_x efficiency tradeoff by using a state-of-the-art engine controller.

The original objectives of this project were to:

1. Improve the driving cycle thermal efficiency of the engine,
2. Install and aid in the development of a state-of-the-art engine control system,
3. Assess control system and engine integrity through a 480-hour durability test,
4. Calibrate the engine to exactly meet the diesel torque curve of the 300 bhp engine,
5. Conduct transient emissions testing to verify that exhaust emissions are lower than the 1998 EPA emissions targets with NO_x emissions being less than 2.0 g/bhp-hr,
6. Monitor the vehicle through a three-month field test using an on-board data logger equipped with a cellular telephone, and
7. Provide detailed drawings, manuals, and training to Mack personnel so that Mack can develop a full understanding of the engine control system and be capable of producing six identical vehicles.

The objectives had been revised as follows:

3. A 1000-hour durability test was performed. This project funded up to the amount provided in the contract, and the remainder was funded by Mack Trucks.
4. The engine was calibrated to a 325 bhp at 1950 rpm and 1180 ft-lb at 1250 rpm torque curve.
5. The PM target had been revised to 0.05 g/bhp-hr, and there was an additional target for NO_x+NMHC of less than 2.5 g/bhp-hr.

2.0 CONCLUSIONS

Following the successful completion of the project, several conclusions regarding the technical content of the program were made.

1. In comparing the previous demonstration engine to the current engine developed in this project:

   a. Peak power was increased from 300 bhp to 325 bhp to match the 325 bhp diesel torque curve.
   b. Peak torque was increased from 1100 ft-lb to 1180 ft-lb to match the 325 bhp diesel torque curve.
   c. The NO_x emissions over the transient emissions test cycle decreased from 2.95 g/bhp-hr to 2.20 g/bhp-hr.
   d. The brake specific fuel consumption over the transient emissions test cycle decreased from 0.474 lb/bhp-hr to 0.400 lb/bhp-hr, which is an increase in efficiency.
   e. A comparison of in-use fuel economy was not possible due to the different driving cycles of the previous demonstration engine and the current engine.

2. A state-of-the-art engine control system was successfully integrated onto the engine.

3. Control system and engine integrity were assessed through a 1000-hour durability test which indicated a problem with the piston, and a subsequent 1000-hour durability test was conducted on a separate project at SwRI with revised pistons which confirmed the problem was solved.

4. The NO_x+NMHC emissions were 2.53 g/bhp-hr with the deterioration factor and 2.40 g/bhp-hr without the deterioration factor on CARB gas; emissions on 99% methane were not conducted with the final calibration, but were expected to be below the 2.5 g/bhp-hr target, even with the deterioration factor.

5. A vehicle was successfully monitored using an on-board data logger.

6. Mack has produced six identical engines with this state-of-the-art control system and all associated engine and vehicle modifications.

7. Durability of the cylinder heads, including valve recession, was greatly improved from the previous engine (one of the problem areas from the final report for the previous engine). Funding to test head durability was provided by Mack Trucks.

3.0 RECOMMENDATIONS

Recommendations for further development of this engine are as follows:

1. Lower NO_x emissions are possible on this engine with:

   a. Humidity compensation to allow for a calibration with lower NO_x emissions on the transient test cycle (which has been demonstrated on this engine) without producing driveability problems in the field.
   b. Decreased equivalence ratio at the lower engine speeds and full load to reduce NO_x emissions during transients from idle along with alternative turbo lag compensation methods to retain driveability.

2. Higher thermal efficiency for this engine is possible with:

   a. Humidity compensation to allow for equivalence ratios closer to the lean-limit.
   b. Turbo lag compensation methods to reduce transient NO_x, which can allow for higher NO_x, and therefore higher efficiency over the driving cycle of the engine.

3. Investigation of other methods to improve the NO_x efficiency trade-off of this engine.

Higher thermal efficiency and improved NO_x efficiency trade-offs are being investigated and developed under the current "Efficiency Enhancements for the Mack E7G Natural Gas-Fueled Engine" program.

4.0 TECHNICAL DISCUSSION

This section describes the results of the project.

4.1 Engine Specifications

The Mack E7 engine (S/N 1P0144) was used for calibration development on this project. This engine was used on the previous Mack natural gas engine project, but was rebuilt with new cylinder liners, new pistons with an 11.5:1 compression ratio (replaces pistons with a 10.5:1 compression ratio), new piston rings, new cylinder heads with higher swirl, and a new camshaft. Engine specifications are shown in Table 1.

Table 1. Engine Specifications

Engine Model	E7G-325
Engine Serial Number	1P1044
Engine Displacement (in^3/liter)	728/12
Bore and Stroke (in/mm)	4.875/123.8 x 6.5/165.1
Ignition System Contoller Supplier	MESA/Woodward Governor Company
Ignition System Coil Supplier	Nippondenso
Ignition System Type	Inductive, Coil on Plug (non-waste spark)
Ignition System Timing Sensor	Electro, K Coil Originally. Bosch Currently
Spark Plug Supplier	Champion
Spark Plug Model	RX501PYP/2H6
Fuel Metering System Supplier	MESA/Woodward Governor Company
Fuel Injector Type	Servojet SP021
Number of Injectors	8
Throttle Supplier	Woodward Governor Company
Throttle Model	FloTech, 68mm
Throttle Type	Electronic, Analog
UEGO Sensor	Honda version of the NGK
Turbocharger	Mack 631GCX5146M, Garrett GT40-88 Compressor Trim, A/R = 52/88mm, 0.58 Turbine Trim, A/R = 78/77mm, 1.05

A Mesa Gas Engine Management (GEM) controller was selected for this project. The Mesa heavy-duty natural gas business was bought by Woodward Governor Company, and the controller is now called the On Highway-1 (OH-1). The OH-1 uses a state-of-the-art speed-density control strategy that provides excellent driveability and response without the aid of a mass air flow sensor. Table 2 shows the capabilities of the OH-1. It is a closed-loop lean burn strategy with adaptive learn. It includes advanced turbo lag compensation, electronic wastegate control, an electronic throttle, high-energy inductive ignition system, full diagnostics, and reduced power engine protection. Fuel is inducted upstream of the throttle. Pseudo-continuous fuel metering is accomplished through single point injection using eight PWM fuel injectors that supply a common manifold. The injectors are fired sequentially in pairs and fuel flow is governed by modulating the pulse width of the fuel injector drive signals. A drive-by-wire throttle is utilized for speed governing, overboost protection, and driveability enhancements.

Table 2. Woodward OH-1 Capabilities

Capability	Description
Diagnostics	Advanced diagnostics for easy debugging with limp home mode for component failure
Drive-By-Wire	Idle speed control, packing speed control, speed governing, load limiting during component failure, throttle opening during deceleration for reduced oil consumption
Cold Start	Fuel enrichment and ignition timing advance to avoid lean misfire during cold engine operation with boost limits
Equivalence Ratio Control	A volumetric efficiency table with adaptive learn to determine fueling rate with an UEGO sensor for closed-loop control
Manifold Filling Calibration	Predictions for air flow during transients for more accurate equivalence ratio control
Turbo Lag Compensation	Fuel enrichment and ignition timing retard to reduce turbo lag without increasing NO_x emissions
Boost Control Calibration	Controls turbocharger wastegate to determine power for a given throttle position, also used to reduce throttling losses by using the wastegate for load control with an open throttle
Ignition Timing Calibration	Table to determine ignition timing for various speeds and loads
Equivalence Ratio Calibration	Table to determine equivalence ratio for various speeds and loads

Part-load fuel economy was increased by the use of a "delta-P" load control strategy. With this strategy, the throttle on the engine is kept as wide open as possible, and load is modulated by wastegate control. Foot pedal position is used to determine load. The pressure differential (delta-P) across the throttle is minimized at part loads, thereby reducing pumping losses and increasing efficiency. The fuel is shut off during deceleration and braking conditions to provide additional improvements in fuel economy. Under these conditions, the throttle is opened, thereby increasing manifold air pressure and reducing oil consumption.

4.2 Air/Fuel Mixing

A study was conducted to look at the effects of the mixing ring and elbow (mixing elbow) on lean-limit and cylinder to cylinder equivalence ratios. The mixing ring is an annular manifold around the inlet pipe to the engine. It is located after the intercooler and before the throttle. To aid in the air/fuel mixing, a 90° elbow is connected between the mixing ring and the throttle. Eight configurations were tested as shown in Table 3. The seven engine operating conditions were 100, 50, and 25 percent load at both 1250 and 1950 rpm, and an idle condition. Equivalence ratio was measured for each individual cylinder with an UEGO sensor. The equivalence ratios for all six cylinders were averaged and a standard error was calculated. The results are shown in Table 3 for the leanest equivalence ratio without audible misfire at 1950 rpm and 100% load, and the average of the seven standard errors for the seven engine operating conditions. Results for each load condition are shown in Figures 1-8. Elbow number 3 was selected for this engine because of its lowest lean-limit and low average standard error.

Table 3. Description and Results of the Mixing Elbow Configurations

ELBOW NUMBER	1	2	3	4	5	6	7	8
64 mm Spacer Between Elbow and Throttle	No	No	Yes	Yes	Yes	Yes	No	No
152 mm Spacer Between Elbow and Mixing Ring	No	No	No	No	Yes	Yes	Yes	Yes
Number of Holes in Mixing Ring	18	9	9	18	18	9	9	18
Equivalence Ratio Limit w/o Audible Misfire at 1950 rpm, 100% Load	0.62	0.62	0.59	0.62	0.62	0.61	0.60	0.63
Average of the Standard Error of the Seven Load Conditions	0.0127	0.0041	0.0037	0.0066	0.0129	0.0044	0.0032	0.0053

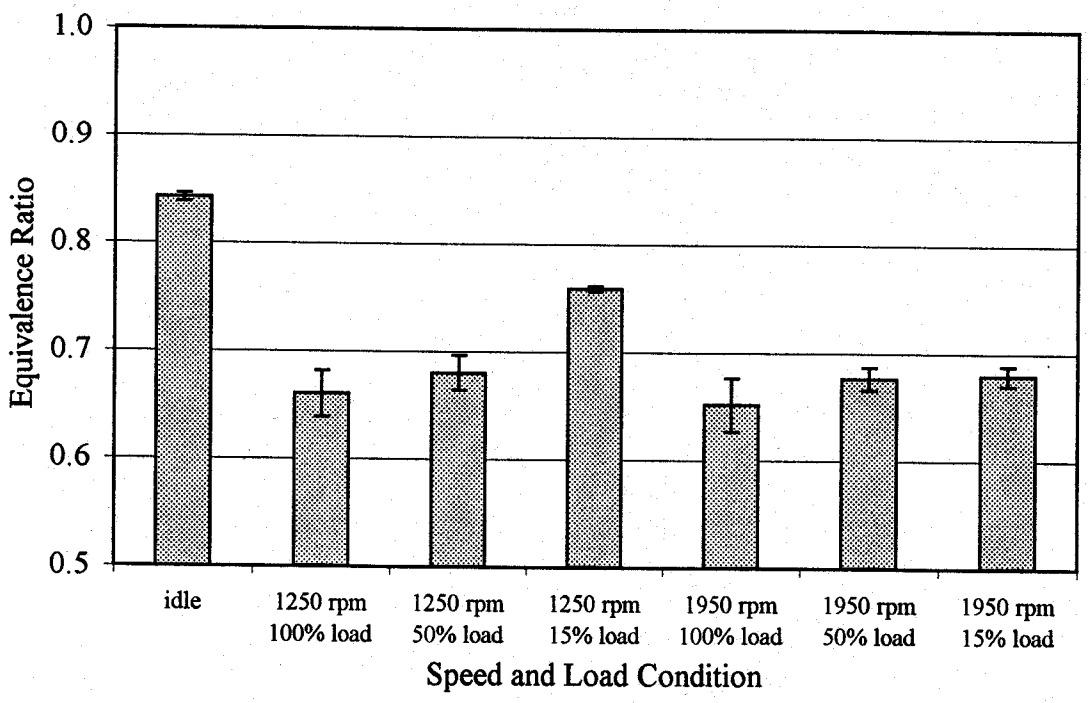

Figure 1. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 1.

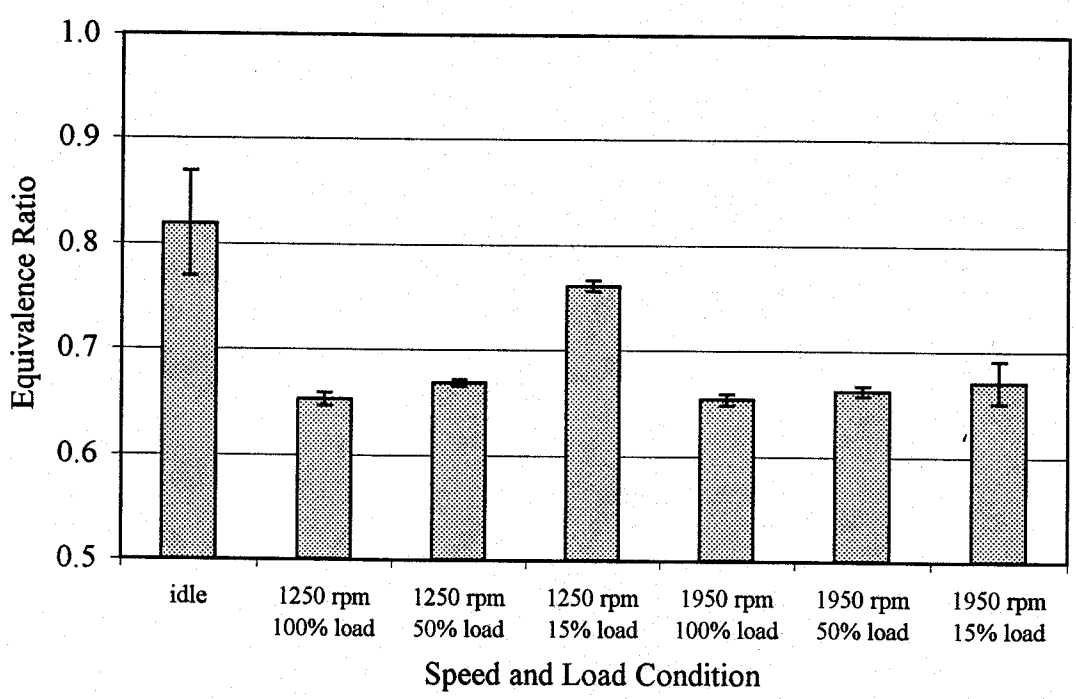

Figure 2. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 2.

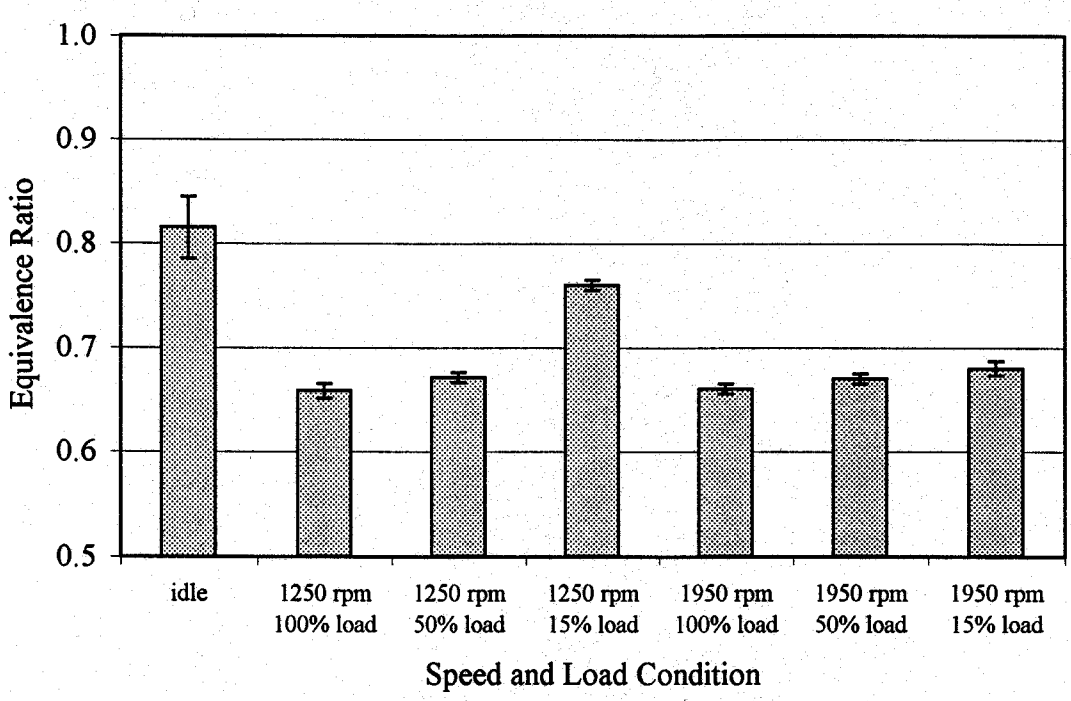

Figure 3. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 3.

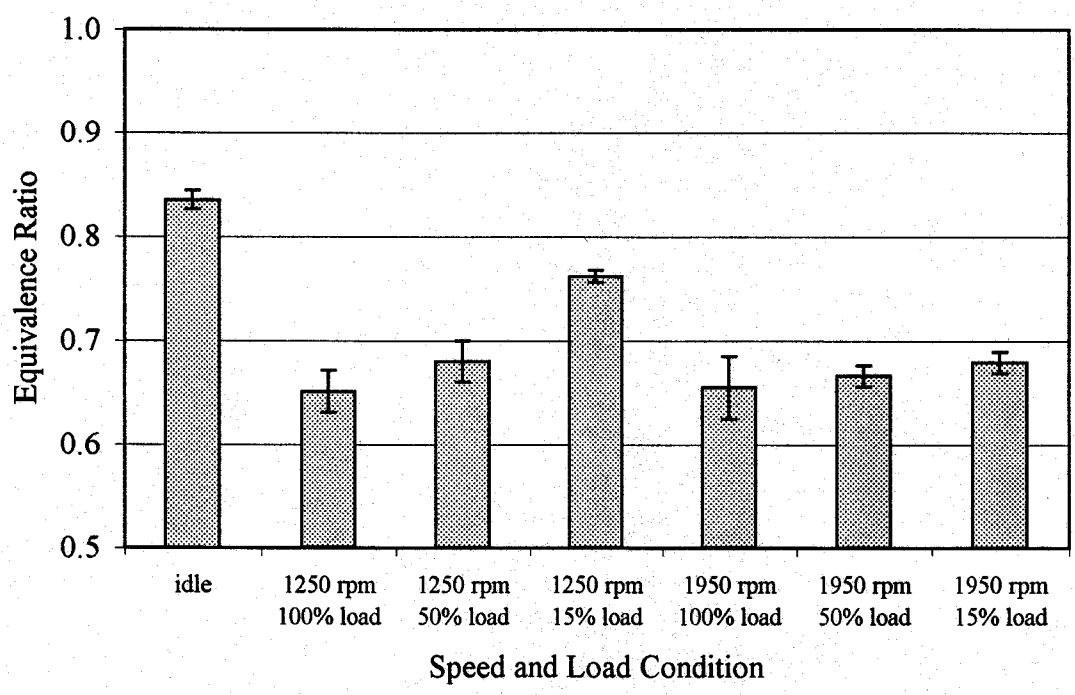

Figure 4. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 4.

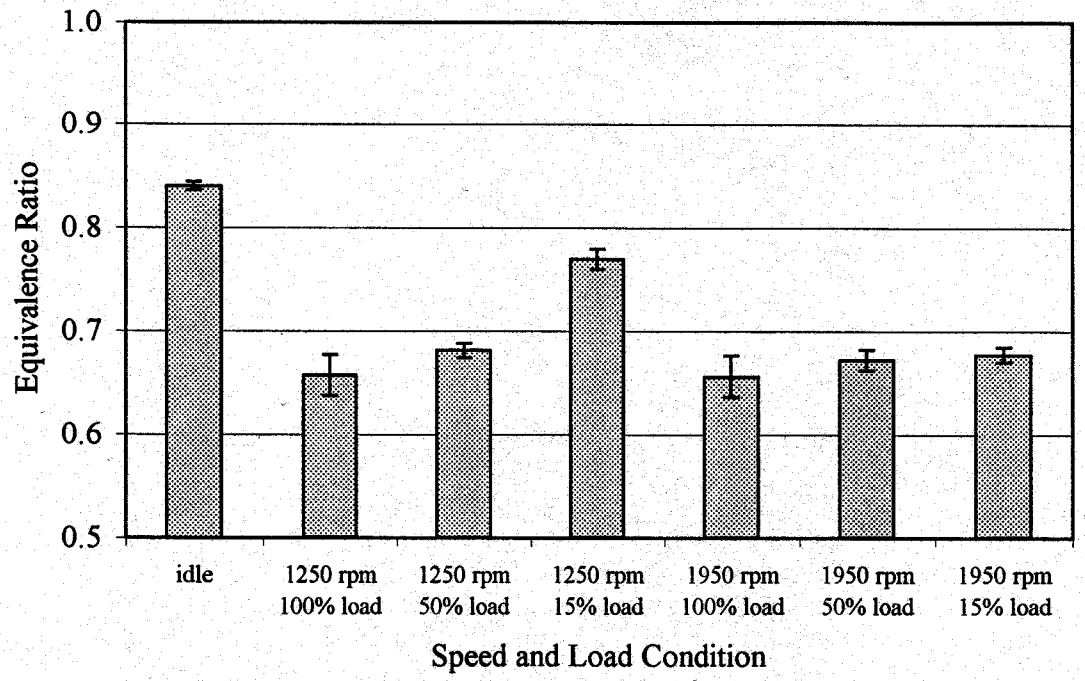

Figure 5. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 5.

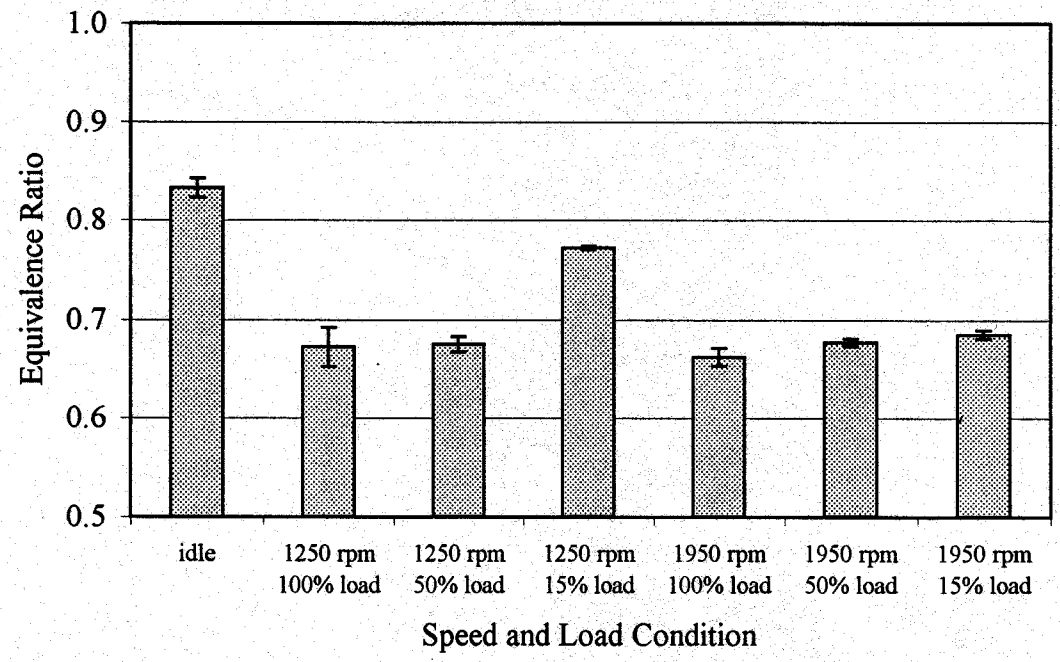

Figure 6. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 6.

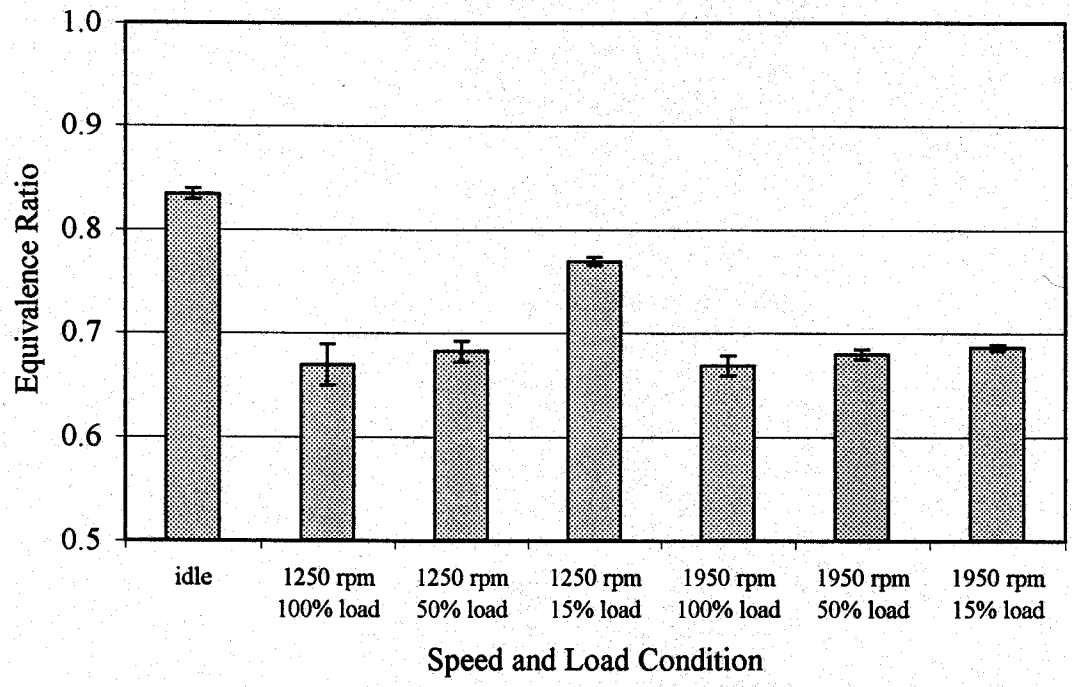

Figure 7. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 7.

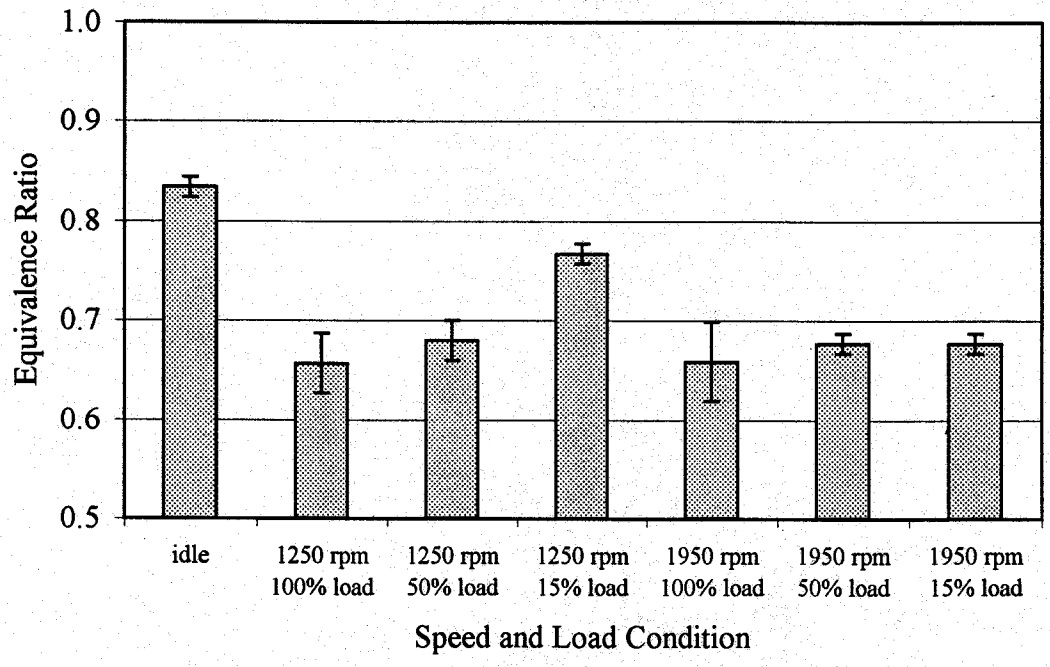

Figure 8. Average Equivalence Ratios and the Standard Error for the Six Cylinders using Mixing Elbow Number 8.

4.3 Cam Timing

Another project, funded by Mack Trucks, was being conducted concurrently with this project. A separate engine was used for each project, and one engine showed higher torque at low engine speeds than the other engine. Mack Trucks had mis-machined a cam gear such that it advanced the cam by one tooth. Therefore, a study was conducted to determine the optimal cam timing for this engine. The cam profile for this engine is the same as the diesel engine it was derived from. The cam timing was tested at the original diesel cam timing and advanced one tooth on the cam gear. With an 84 tooth cam gear, one tooth advanced is 8.57 crank angle degrees. Figures 9-17 show the results for 1950, 1500, and 1250 rpm at 100, 75, and 50% load. For either cam timing, the efficiencies are about the same for a given NO_x level, whereas the HC emissions are lower with the original cam timing. With the advanced cam timing, higher torque at 1100 rpm at WOT were noted. The advanced cam timing was selected for this engine for the higher low speed torque capability.

4.4 Steady-State Engine Mapping

Engine mapping included knock tolerance testing, lean-limit testing, and calibration of the engine controller tables.

4.4.1 Knock Tolerance Testing

Knock tolerance testing for the Mack E7G engine was presented in the final report for the Mack LNG Engine Development for Long-Haul Truck, SwRI Project No. 03-7816, and is presented again here. Results are based on an engine rated at 350 bhp at 1900 rpm.

Knock testing was performed to determine the highest intake manifold air temperature, highest equivalence ratio and the most advance ignition timing possible without the engine knocking. The testing was conducted at various equivalence ratios, 105 and 150 deg F air temperature after the intercooler, and 200 deg F coolant out temperature. Ignition timing was advanced until the pressure signal from the #2 cylinder showed presence of knock. The composition of the natural gas fuel used for knock testing is shown in Table 4.

Table 4. Gas Composition for Knock Testing

Gas	Volume (%)
Methane	85.1
Ethane	9.0
Propane	2.4
Nitrogen	3.5

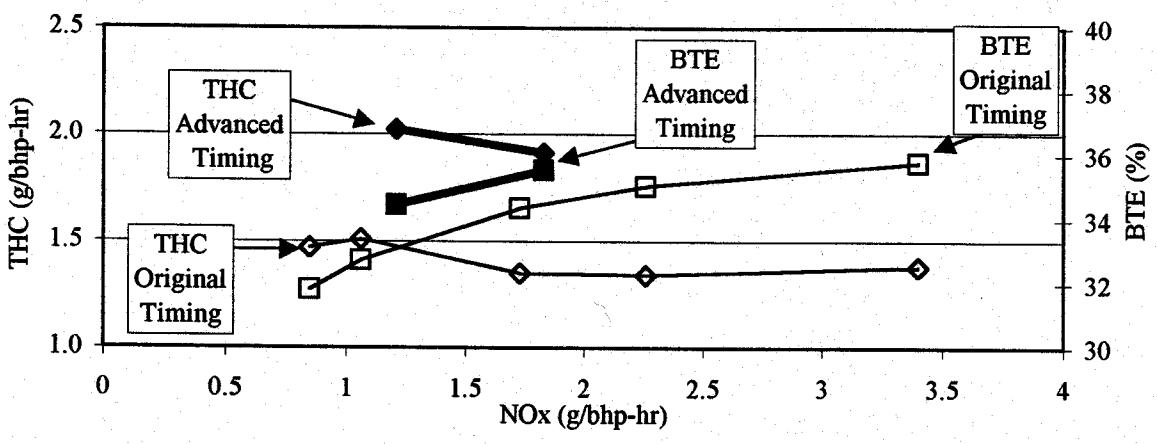

Figure 9. Comparison of Original and Advanced Cam Timing at 1950 rpm, 100% Load, and Various Ignition Timings

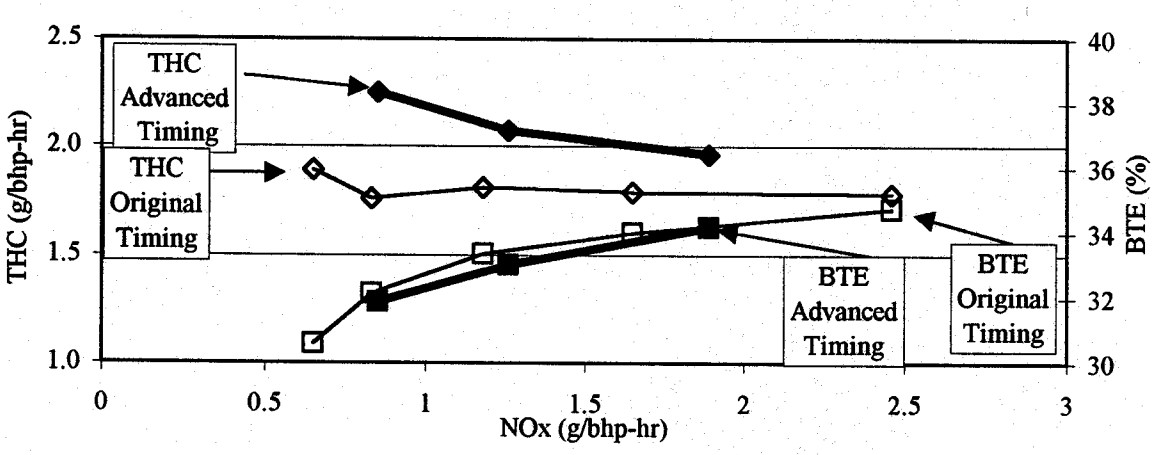

Figure 10. Comparison of Original and Advanced Cam Timing at 1950 rpm, 75% Load, and Various Ignition Timings

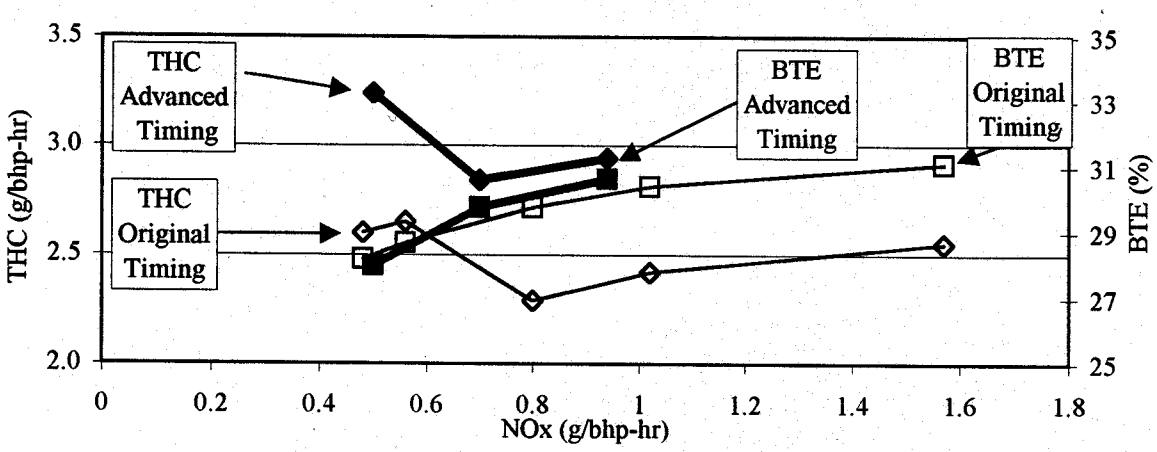

Figure 11. Comparison of Original and Advanced Cam Timing at 1950 rpm, 50% Load, and Various Ignition Timings

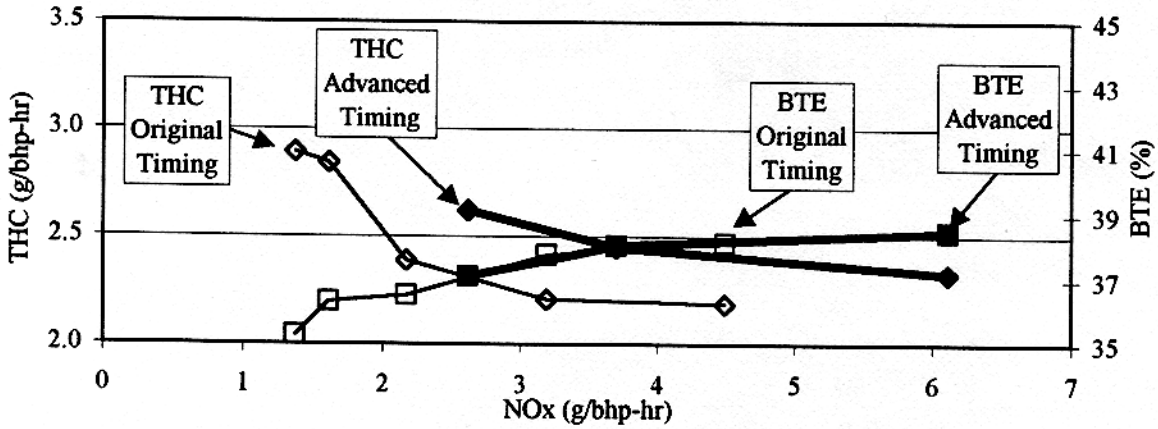

Figure 12. Comparison of Original and Advanced Cam Timing at 1500 rpm, 100% Load, and Various Ignition Timings

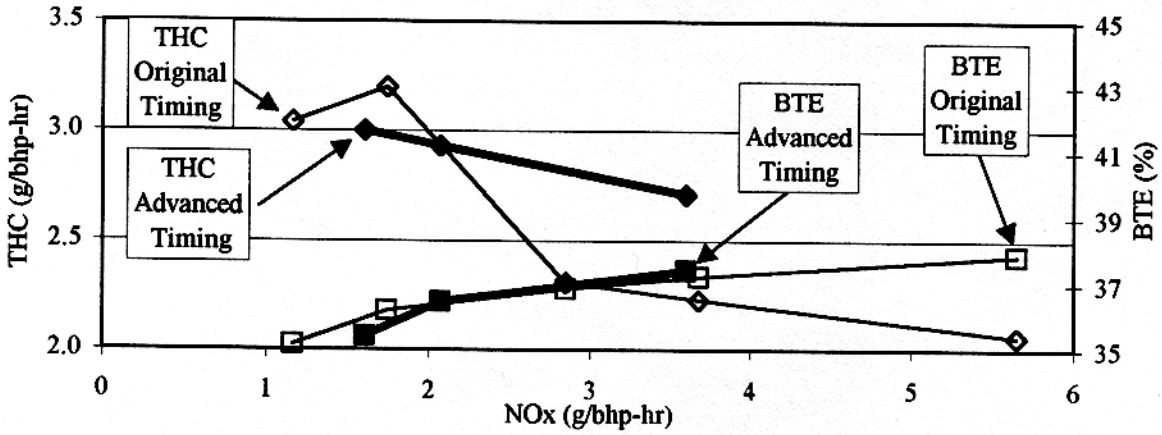

Figure 13. Comparison of Original and Advanced Cam Timing at 1500 rpm, 75% Load, and Various Ignition Timings

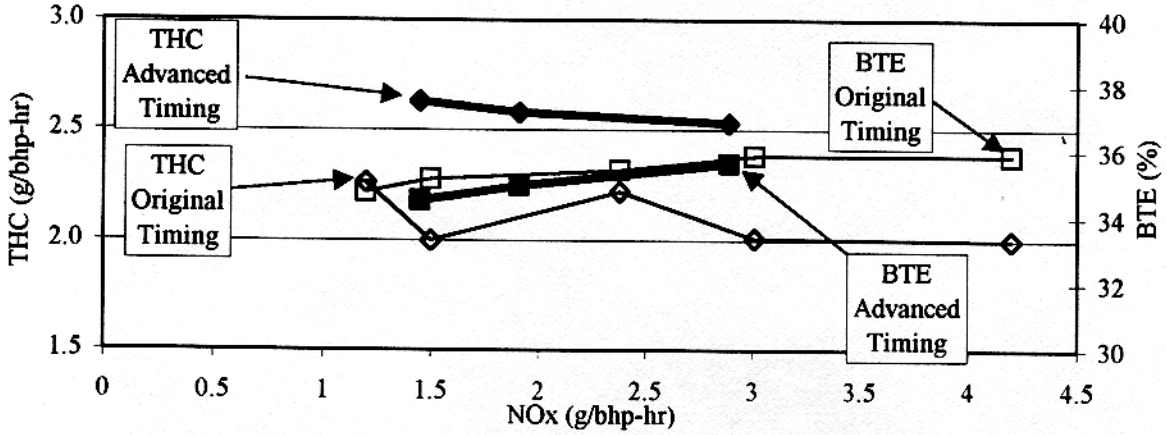

Figure 14. Comparison of Original and Advanced Cam Timing at 1500 rpm, 50% Load, and Various Ignition Timings

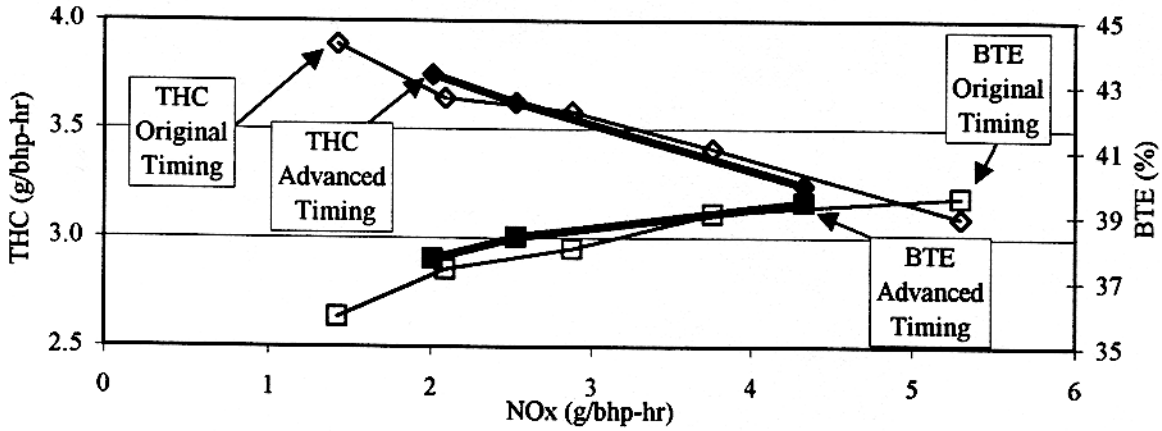

Figure 15. Comparison of Original and Advanced Cam Timing at 1250 rpm, 100% Load, and Various Ignition Timings

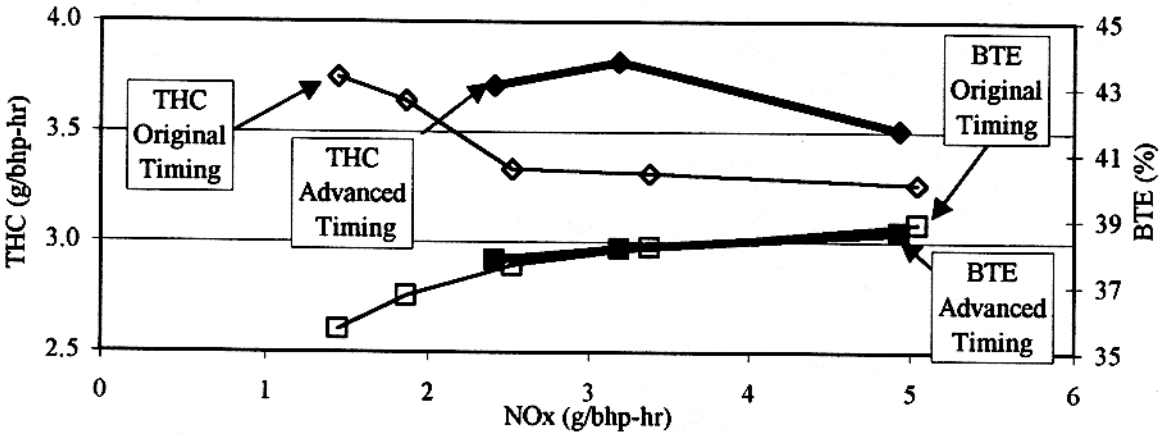

Figure 16. Comparison of Original and Advanced Cam Timing at 1250 rpm, 75% Load, and Various Ignition Timings

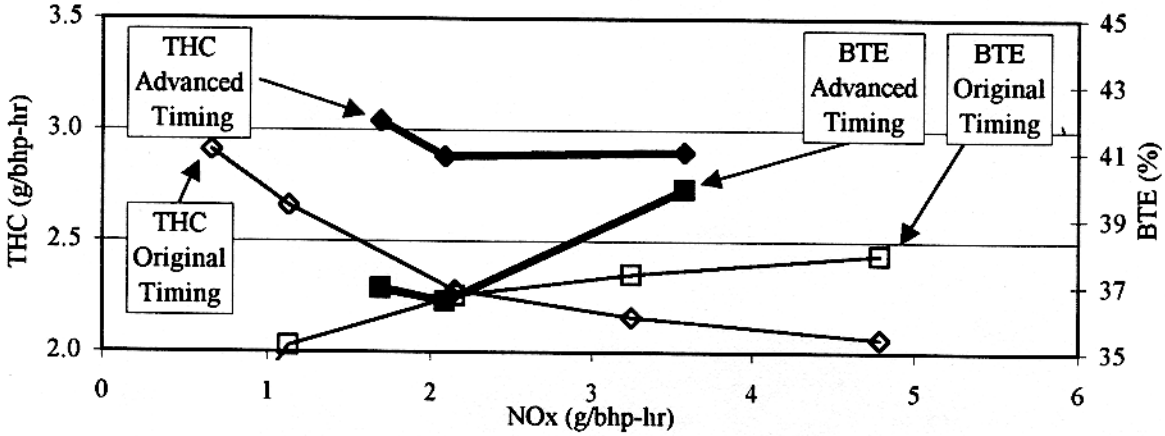

Figure 17. Comparison of Original and Advanced Cam Timing at 1250 rpm, 50% Load, and Various Ignition Timings

The results of the knock testing are shown in Table 5 and in Figures 18-22. Figures 18-20 show tests at equivalence ratios between 0.65 and 0.75 for engine speed of 1900, 1500, and 1250 rpm. Also shown on the graphs as reference are the points of MBT and MBT-6 ignition timings at an equivalence ratio of 0.65. Figures 21 and 22 show tests at equivalence ratios between 0.80 and 0.85 for engine speeds of 1100 and 1000 rpm. There are no ignition timing points shown on these graphs since timing are selected to provide sufficient boost for low speed torque.

Table 5. Results of Knock Testing

Engine Speed (rpm)	Equivalence Ratio	Ignition Timing at Presence of Knock for 105 deg F After Intercooler Temperature (deg BTDC)	Ignition Timing at Presence of Knock for 150 deg F After Intercooler Temperature (deg BTDC)
1900	0.65	30	23
1900	0.70	23	19
1900	0.75	19	15
1500	0.65	25	20
1500	0.70	22	17
1500	0.75	18	16
1250	0.67	23	18
1250	0.70	22	17
1250	0.75	19	15
1100	0.80	18	15
1100	0.85	14	10
1000	0.80	19	12
1000	0.85	17	9

4.4.2 Lean-Limit Testing

Lean-limit testing for the Mack E7G engine was presented in the final report for the Mack LNG Engine Development for Long-Haul Truck, SwRI Project No. 03-7816, and is presented again here. Results are based on an engine rated at 350 bhp at 1900 rpm.

Lean limit tests were conducted at engine speeds of 1250 and 1900 rpm, and 100% load. Cylinder pressure data were recorded from the #2 cylinder, and the COV_{imep} was calculated over 50 engine cycles. The lean limit is defined as the equivalence ratio where the COV_{imep} exceeds 5%. Tests were performed at three ignition timings: MBT, MBT-3, and MBT-6, and the equivalence ratio was lowered until audible misfire was detected. Figure 23 shows the results for 1250 rpm. At an ignition timing of 16 degrees BTDC, the lean limit is at an equivalence ratio of approximately 0.58. Figure 24 shows the results for 1900 rpm. At an ignition timing of 21

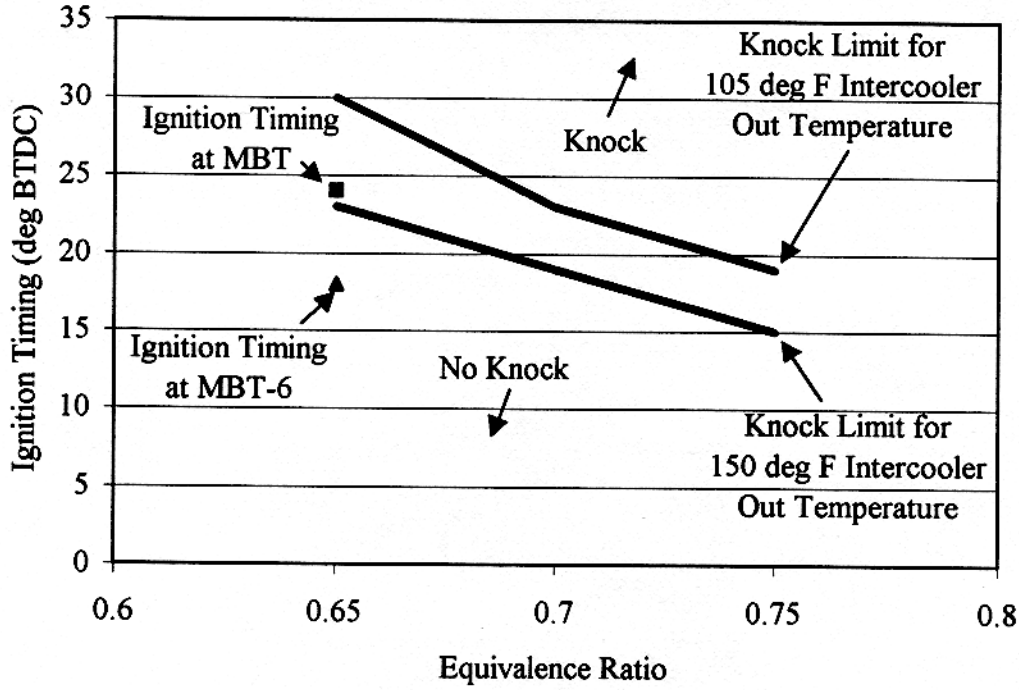

Figure 18. Knock Limit at 1900 rpm, 967 ft-lb

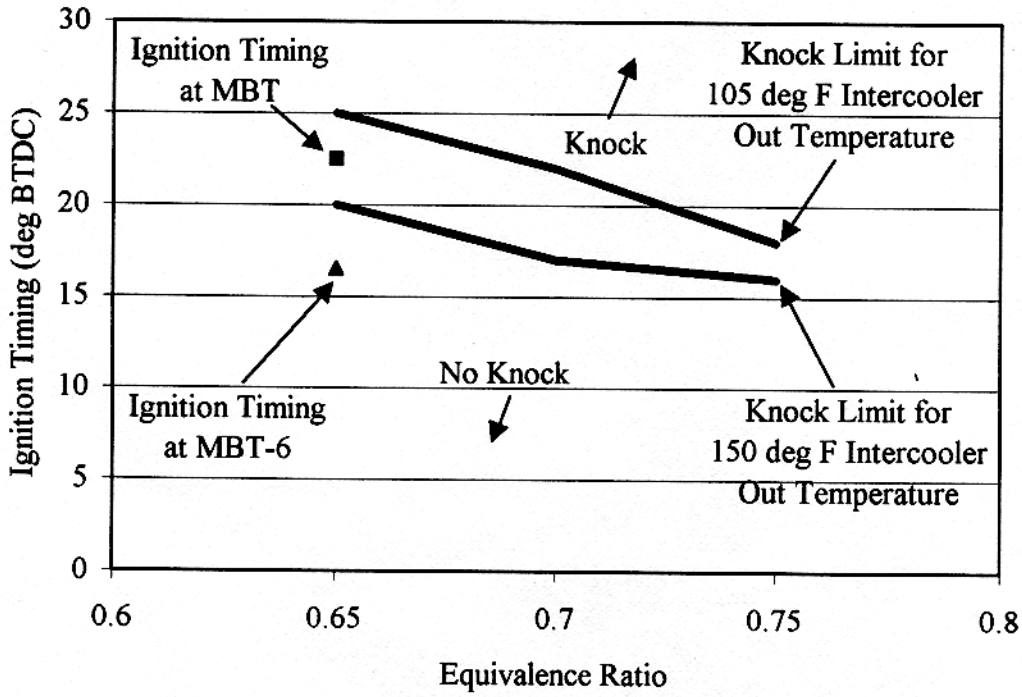

Figure 19. Knock Limit at 1500 rpm, 1175 ft-lb

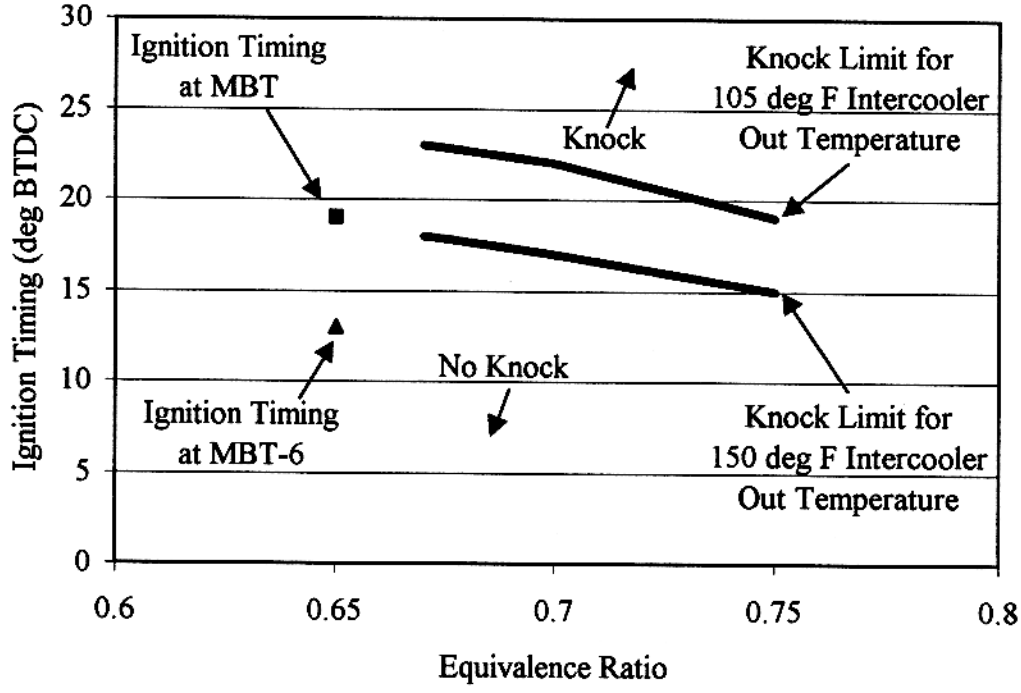

Figure 20. Knock Limit at 1250 rpm, 1250 ft-lb

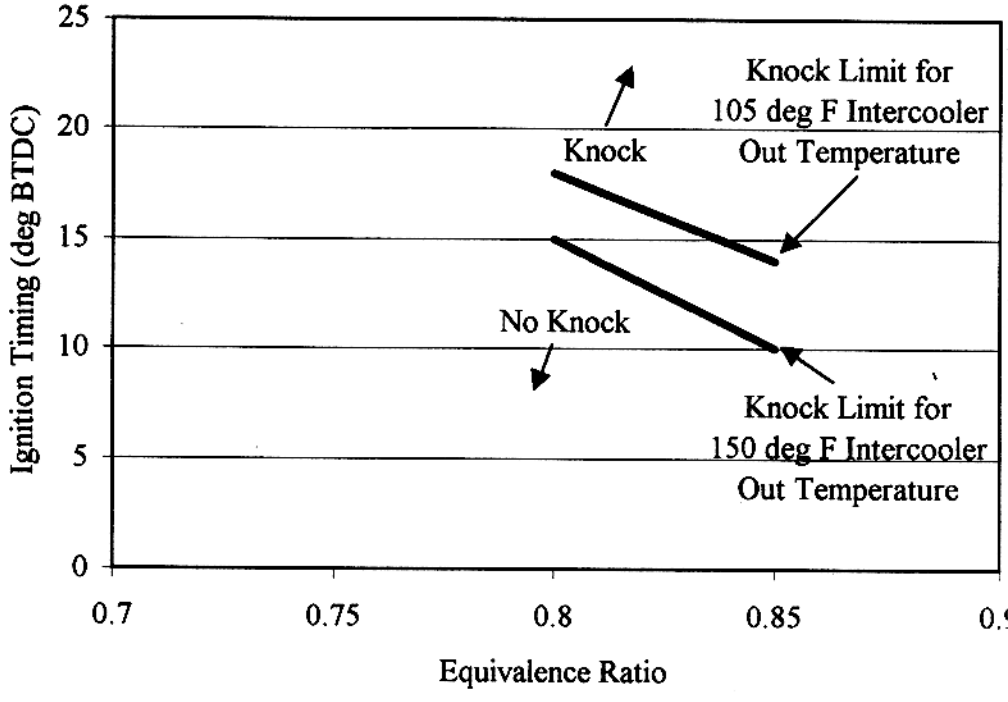

Figure 21. Knock Limit at 1100 rpm, 1230 ft-lb

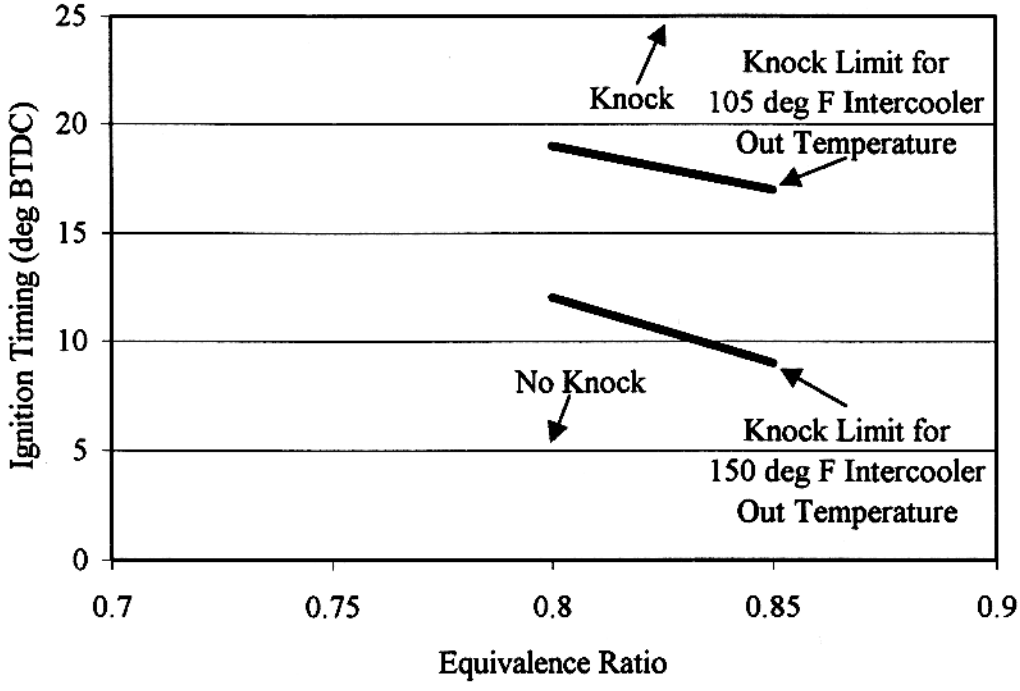

Figure 22. Knock Limit at 1000 rpm, 1115 ft-lb

degrees BTDC, the lean limit is at an equivalence ratio of approximately 0.60. Table 6 shows the results of the lean limit tests. The run numbers refer to the recorded data included in Appendix A.

Table 6. Lean Limit Test Results

1250 RPM				1900 RPM			
Run Number	Ignition Timing (°BTDC)	Equiv. Ratio	COV_{imep} (%)	Run Number	Ignition Timing (°BTDC)	Equiv. Ratio	COV_{imep} (%)
866	19	0.65	1.24	844	24	0.65	1.62
867	16	0.65	1.93	845	21	0.65	2.06
868	13	0.65	3.58	846	18	0.65	2.93
869	19	0.67	1.24	847	24	0.67	1.21
870	16	0.67	1.77	848	21	0.67	2.00
871	13	0.67	2.23	849	18	0.67	2.22
872	19	0.64	1.55	850	24	0.64	1.99
873	16	0.64	2.31	851	21	0.64	2.95
874	13	0.64	4.82	852	18	0.64	3.53
875	19	0.63	1.69	853	24	0.63	2.11
876	16	0.63	2.09	854	21	0.63	2.49
877	13	0.63	4.11	855	18	0.63	3.88
878	19	0.62	1.96	856	24	0.62	1.80
879	16	0.62	4.21	857	21	0.62	3.36
880	13	0.62	4.27	858	18	0.62	4.53
881	19	0.61	1.98	859	24	0.61	2.79
882	16	0.61	3.51	860	21	0.61	3.88
883	13	0.61	5.55	861	18	0.61	5.31
884	19	0.60	3.08	862	24	0.60	3.36
885	16	0.60	3.45	863	21	0.60	4.74
886	13	0.60	7.32	864	18	0.60	6.32
887	19	0.59	2.51	865	24	0.59	4.89
888	16	0.59	3.76				
889	13	0.59	5.38				
890	19	0.58	4.06				
891	16	0.58	5.53				

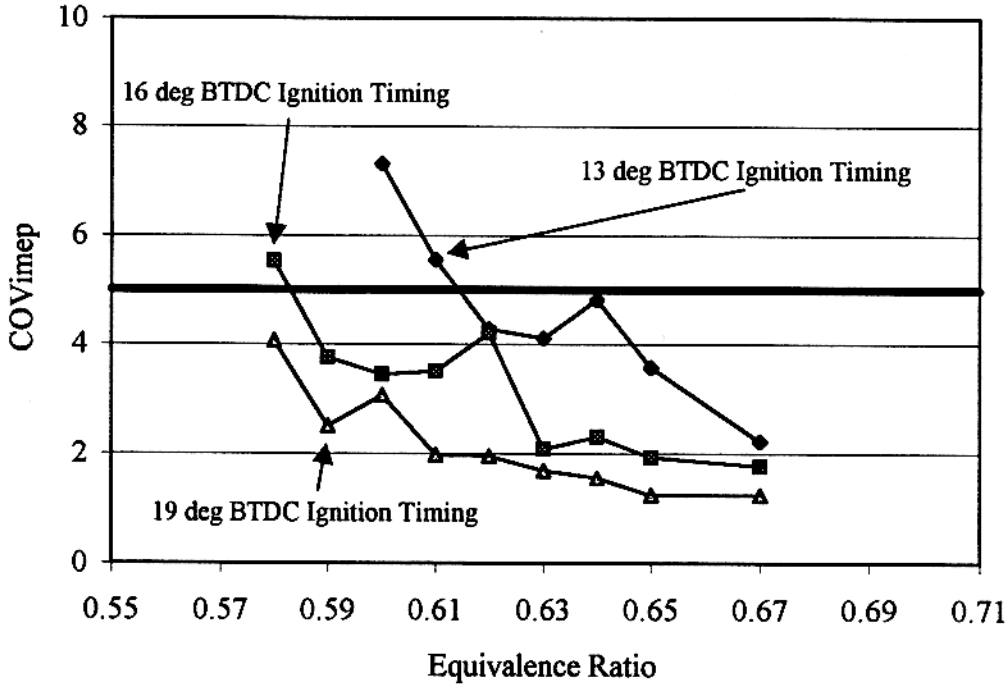

Figure 23. Lean Limit Tests at 1250 rpm, 1250 ft-lb

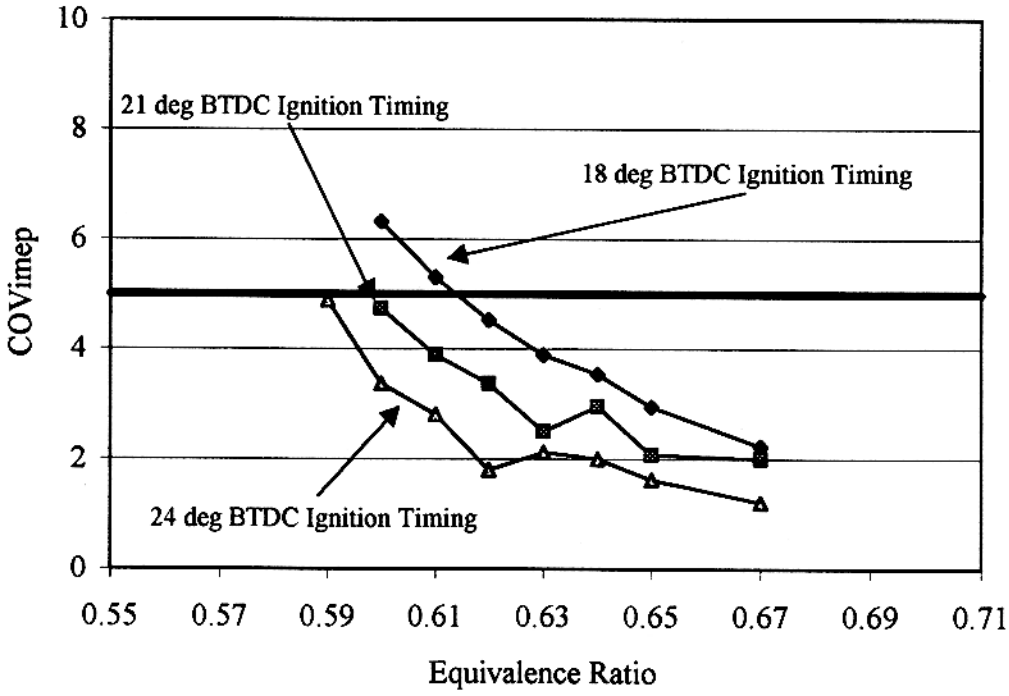

Figure 24. Lean Limit Tests at 1900 rpm, 967 ft-lb

4.4.3 Calibration

Steady-state tests of the Mack E7G engine included calibration of boost control, volumetric efficiency, equivalence ratio, and ignition timing. Transient tests included further calibration of equivalence ratio and ignition timing, calibration of boost control to rematch the 325 bhp torque curve with the change in ignition timing at WOT, and calibration of the turbo lag compensation.

Turbocharger boost determines the power output of the engine for a given throttle position. It is controlled through a pneumatic wastegate controller. Since Mack Trucks builds the engine and the vehicle, a source of pressurized air can be made available on the truck for the engine controller to use under any operating condition. In the test stand, shop air was used to simulate the constant source of pressurized air. The pressurized air to the wastegate actuator is controlled through a pulse width modulated solenoid valve. The engine controller determines the amount of turbocharger boost based on throttle position and engine speed through a look up table. An electronic throttle is used on this engine with a throttle command of 0.5 to 4.5 volts.

At throttle positions of less than 2.0 volts, the wastegate is fully opened to minimize throttling losses. At positions of 2.0 to about 4.0 volts, the turbocharger boost is set to minimize the pressure drop across the throttle. At throttle positions over 4.0 volts, the turbocharger boost is set to match the 325 bhp torque curve.

Volumetric efficiency (VE) is used to determine the open-loop fueling rate to the engine for the desired equivalence ratio. Corrections to the VE are accomplished through closed-loop control based on feedback from the universal exhaust gas oxygen (UEGO) sensor. A closed-loop multiplier performs immediate corrections to the VE to maintain the correct equivalence ratio. An adaptive loop multiplier, which is saved in a table, performs longer term corrections. The engine was operated at steady-state conditions with the adaptive loop multiplier set to zero, and the volumetric efficiency table adjusted to maintain a closed-loop multiplier of less than 1.00%.

The equivalence ratio table is used for air/fuel ratio control of the lean burn engine. As equivalence ratio is lowered from stoichiometric, the efficiency increases and the NO_x emissions decrease. If the equivalence ratio is too low, the hydrocarbon emissions increase, efficiency decreases, and misfires are possible. Equivalence ratio was set for lean operation with a margin above the misfire limit for the higher engine speeds where turbo boost was sufficient to run lean, and was set for power and driveability at lower engine speeds where turbo boost was not sufficient to run lean (particularly at WOT). Further refinements to the equivalence ratio table were performed during transient emissions testing. These included a lower equivalence ratio at idle to reduce NO_x emissions on the transient emissions test cycle, and lower equivalence ratios at low speeds, including low to mid loads to reduce NO_x emissions for the West Virginia University CBD cycle on a chassis dyno.

Ignition timing is set as a compromise between efficiency and NO_x emissions. The best efficiency is at MBT timing, but to meet the NO_x emissions goals, retarded timings are required. A 12-mode steady-state prediction for NO_x emissions was used to determine the initial ignition-timing table for transient emissions testing. The 12-mode test is shown in Table 7. Results of

the 12-mode test for ignition timing retarded the same amount at all 12 test points and are shown in Table 8. The 12-mode results for the initial ignition timing table for transient emissions testing is shown in Table 9. The transient emissions test with the initial ignition timing table was 2.86 g/bhp-hr. Ignition timing was modified to lower the NO_x emissions on the transient test to 2.15 g/bhp-hr.

Table 7. Test Points for the 12-Mode Steady-State Prediction for Transient Emissions

Mode	Engine Speed (%)	Load (%)	Weight (%)	Engine Speed (rpm)	Torque (ft-lb)	MBT (°BTDC)
1	0	CITT	8.8	600	160	20
2	50	83	2.6	1300	963	22
3	50	100	2.1	1300	1160	21
4	67	73	3.4	1520	896	26
5	83	50	7.0	1730	485	28
6	83	73	5.5	1730	805	27
7	83	100	11.9	1730	970	23
8	100	33	5.1	1950	287	30
9	100	50	9.6	1950	435	27
10	100	67	7.2	1950	583	26
11	100	83	16.8	1950	722	26
12	100	100	20.0	1950	870	23

Table 8. Predicted FTP Transient Results

Ignition Timing (°BTDC)	$BSNO_x$ (g/bhp-hr)	BSTHC (g/bhp-hr)	BSCO (g/bhp-hr)	BTE (%)
MBT	4.18	1.75	1.15	35.1
MBT-3	2.93	1.77	1.14	34.6
MBT-5	2.12	1.85	1.14	34.2
MBT-7	1.58	1.79	1.12	33.5

Table 9. Ignition Timing Based on Steady-state Tests

Mode	Ignition Timing (°BTDC)	$BSNO_x$ (g/bhp-hr)	BTE (%)
1	MBT	0.52	26.8
2	MBT-7	2.14	37.9
3	MBT-7	2.10	37.8
4	MBT-7	3.10	38.3
5	MBT-5	1.67	33.6
6	MBT-7	2.63	37
7	MBT-7	1.73	36.4
8	MBT	3.00	30
9	MBT-5	1.34	31.5
10	MBT-5	1.75	34.4
11	MBT-5	2.09	35.3
12	MBT-5	1.45	34.9
Prediction		1.86	34.1

Recorded data for the steady-state tests are included in Appendix B. Tables with the final calibration to be used for certification are included in Appendix C.

4.5 Durability Testing

The first durability test was reported in the final report for Task 2 - 1000-Hour Super Thermal Cycle Test, SwRI Project No. 03-7501-002, and is included in Appendix D. The second durability test was reported in the final report for the 1000-Hour Super Thermal Cycle Test on a Mack E-7 Natural Gas Fueled Engine, SwRI Project No. 03-1248, and is included in Appendix E.

4.6 Data Logger

A data logger was installed on a refuse truck for in service use. The data logger recorded information from the vehicle and the engine. A list of data recorded is shown in Table 10. Due to harsh environmental conditions, the fuel system pressure sensors added for data logging failed. The fuel pressure used by the engine controller was still operational. Data for engine speed, vehicle speed, and MAP for a typical day are shown in Figures 25-27. Most of the occurrences occur at idle (600 rpm, 0 mph, 8 psia), followed by packing (1200 rpm, 0 mph, 11 psia). There were 395 total minutes of data logging time for this day, 31 minutes were used for packing and 122 minutes were used for idling.

Histograms for data recorded from 4/23/98 to 6/29/98 are included in Appendix F. In the period from 4/23/98 to 6/29/98 the data logger recorded 2909 miles with 2063 gallons of LNG used for a fuel economy of 1.41 mpg, which is a diesel equivalent fuel economy of 2.28 mpg. Of the 2063 gallons used, 227 gallons were used at idle and 236 gallons were used for packing, which represents 11.0% and 11.4% of the total fuel used, respectively.

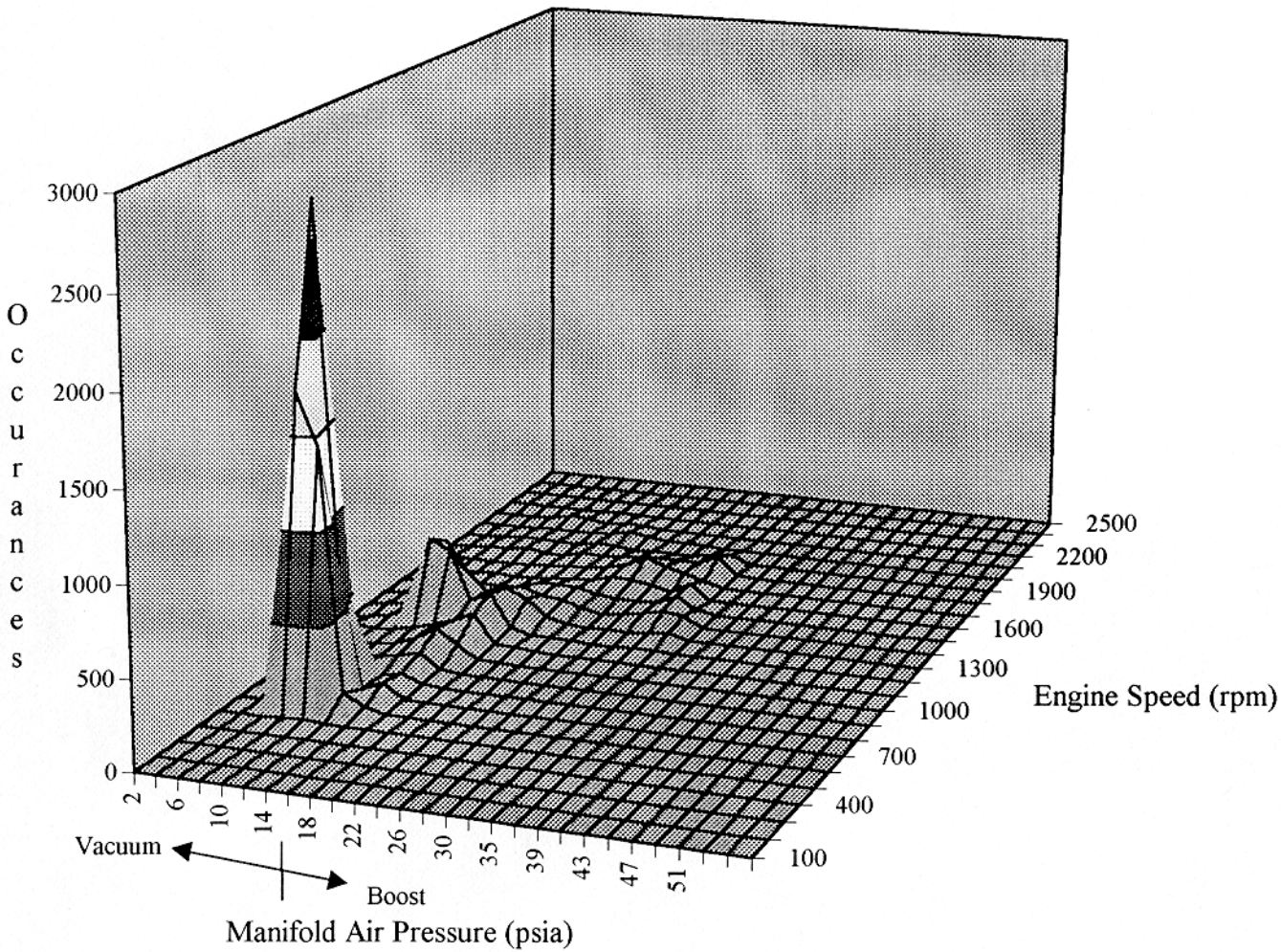

Figure 25. Engine Speed vs. Manifold Air Pressure for One Day of Operation

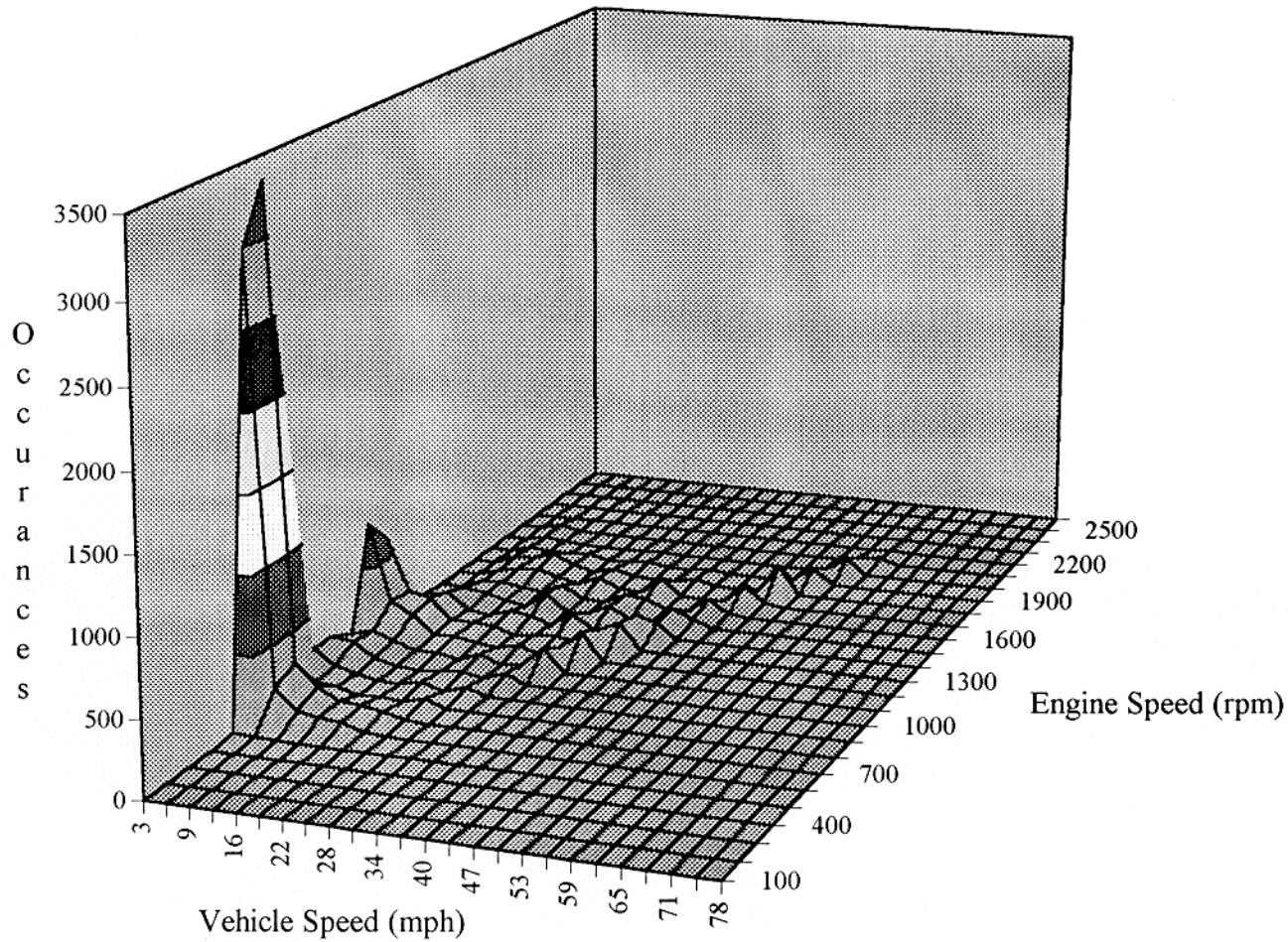

Figure 26. Engine Speed vs. Vehicle Speed for One Day of Operation

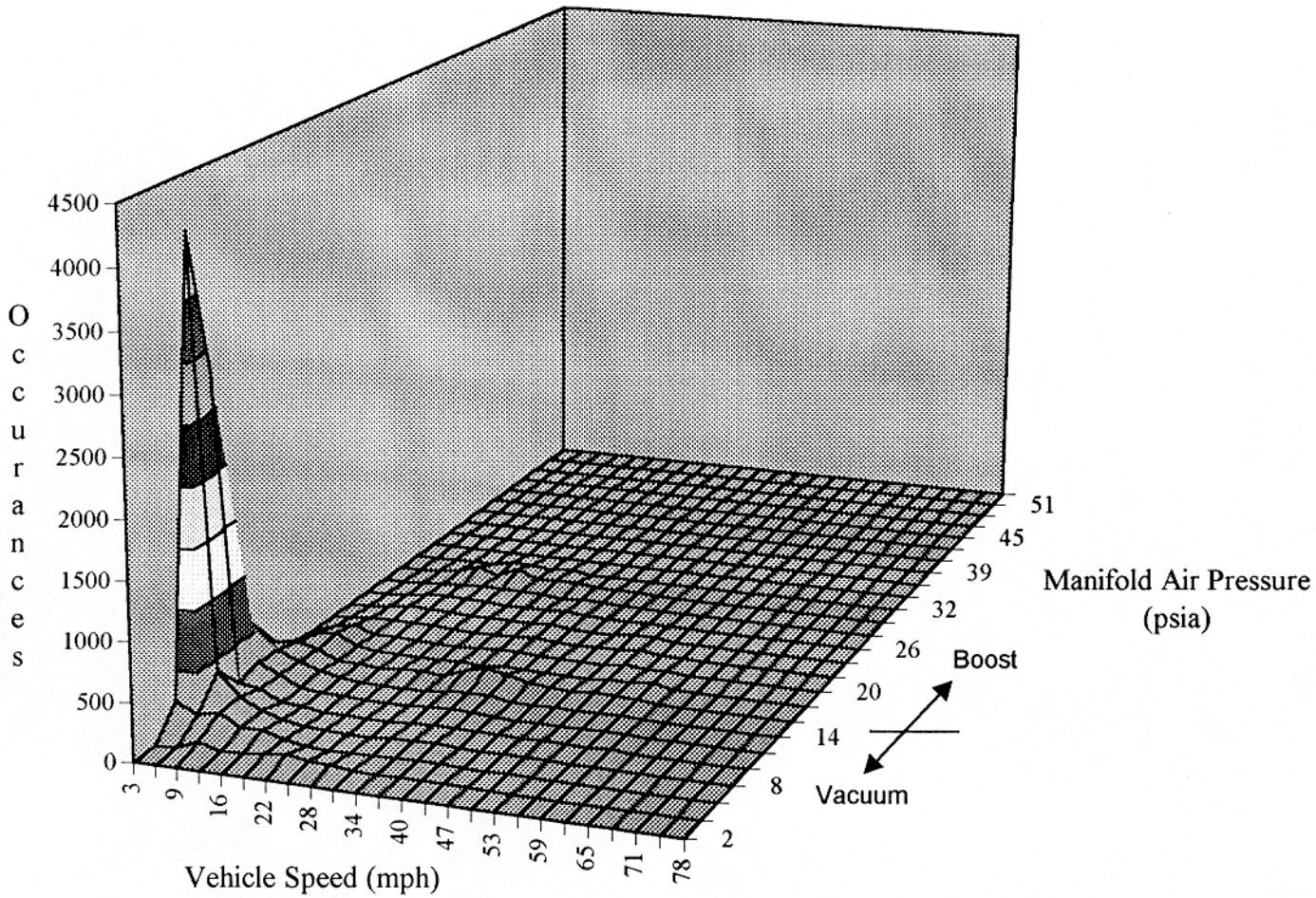

Figure 27. Manifold Air Pressure vs. Vehicle Speed for One Day of Operation

Table 10. Data Recorded on the Data Logger

Time	Battery (volts)	Turbo Lag Compensation Enable (%)
Date	Barometric Pressure (psia)	Turbo Lag Compensation Enrichment (%)
Odometer Reading (miles)	Equivalence Ratio Feedback	Turbo Lag Compensation Retard (deg)
Vehicle Speed (mph)	Equivalence Ratio Command	Close Loop Multiplier (%)
Engine Speed (rpm)	Equivalence Ratio Modifier for ECT	Adaptive Loop Multiplier (%)
Fuel Flow (lb/hr):	#1 Tank Pressure (psig)	Manifold Air Pressure Signal (volts)
Instantaneous Fuel Economy (mpg)	#2 Tank Pressure (psig)	Preturbine Pressure Signal (volts)
Cumulative Fuel Economy (mpg)	Fuel Pressure Before Vaporizer (psig)	Exhaust Back Pressure Signal (volts)
Manifold Air Pressure (psia)	Fuel Pressure After Vaporizer (psig)	Gas Pressure Signal (volts)
Exhaust Back Pressure (psia)	Fuel Pressure at Regulator (psig)	Manifold Air Temp Signal (volts)
Preturbine Pressure (psia)	Fuel Pressure at Filter (psig)	Engine Coolant Temp Signal (volts)
Manifold Air Temp (degF)	Air Pressure Before Intercooler (psia)	Gas Temperature Signal (volts)
Engine Coolant Temp (degF)	Air Pressure After Intercooler (psia)	UEGO Signal (volts)
Gas Pressure (psia)	Relative Humidity (%)	UEGO Pumping Signal (volts)
Gas Temperature (degF)	EMC Run Time (sec)	UEGO Heater Signal (volts)
Actual Foot Pedal Position (volts)	Ignition Timing (deg BTDC)	UEGO Resistor Signal (volts)
Normalized Foot Pedal Position (volts)	Injection Pulse Width (ms)	ECM Control Mode
Throttle Position Command (volts)	Uncorrected Fuel Flow (mg/inj)	ECM Run Mode
Throttle Position Feedback (volts)	Predicted Volumetric Efficiency (%)	UEGO Mode
Ambient Air Temp (degF)	Volumetric Efficiency Modification (%)	Fault Codes
Oil Temp (degF)	Actual Volumetric Efficiency (%)	Cumulative Fuel Usage (gal)
Exhaust Temp (degF)	Change in Manifold Air Pressure (psia/s)	Idle Fuel Usage (gal)
Data Logger Temp (degF)	Boost Control PWM (%)	Packing Fuel Usage (gal)

4.7 Transient Emissions Testing

Results from the transient emissions testing were reported in the final report for the Transient Emissions Testing on a Mack E7G Engine, SwRI Project No. 03-2377, and is included in Appendix G. The emissions certification levels for the final calibration, with a deterioration factor, are shown in Table 11. Screen shots from the engine controller for this calibration are included in Appendix C. CARB certification gas was used for these tests. The objectives of this project were NO_x+NMHC emissions of less than 2.5 g/bhp-hr on a natural gas with 99% methane. The use of CARB certification gas increases both the NO_x and NMHC emissions. CARB gas has 90% methane along with 4% ethane and 2% butane. Ethane and butane increase the flame speed and therefore increase NO_x emissions. Ethane and butane also increase the NMHC emissions since the unburned fuel has an increased amount of NMHCs. The final calibration was selected for NO_x emissions below 2.5 g/bhp-hr with acceptable driveability. NO_x

emissions below 2.0 g/bhp-hr are possible on the transient emissions tests, but driveability problems were noted in the field due to the amount of timing retard required for the lower emissions combined with humidity effects. A summary of the NO_x emissions and fuel economy over the transient test cycle is presented in Table 12. The calibration used for the results in Table 9 was the initial calibration for the transient emissions testing. The NO_x emissions for this test was 2.86 g/bhp-hr. Similar trends were noted at lower NO_x emissions levels. Table 12 shows that the transient from idle uses 9% of the time in the cycle, yet accounts for 41% of the NO_x emissions. This is due to the steep torque rise of this engine and the high equivalence ratios used during the WOT transient from idle. The high equivalence ratios are used to improve driveability. This calibration, where the high equivalence ratios are high, will not pass 2002 emissions for natural gas fueled engines due to high steady state NO_x emissions. In 2002, natural gas engines will have the same limit on steady state emissions over the entire operating range as diesel engines.

Table 11. 325 bhp Transient Emissions Results.

Emission	Emission Level (g/bhp-hr)
HC/OMHCE	3.1
NMHC/OMNMHC	0.324
NMHC+ NO_x	2.53
Carbon Monoxide	1.4
Oxides of Nitrogen	2.2
Particulates	0.03
Formaldehyde	0.136

Table 12. Summary for the FTP Results for NO_x Emissions at 2.86 g/bhp-hr

Description	Idle	Mid-High Speed Mid Load	High Speed High Load	Transient from Idle	Remainder
Occurrences	42%	25%	10%	9%	14%
Total Contribution to NO_x Emissions	12%	18%	17%	41%	12%
Average Diluted NO_x Emissions	7.3 ppm	18.8 ppm	43.1 ppm	119.5 ppm	22.1 ppm
Total Contribution to Fuel Usage	12%	27%	38%	7%	16%

The previous version of this engine was rated at 300 bhp and had NO_x emissions of 2.95 g/bhp-hr with no deterioration factor and a brake specific fuel consumption of 0.474 lb/bhp-hr. This final calibration for this engine has NO_x emissions of 2.2 g/bhp-hr and a brake specific fuel consumption of 0.400 lb/bhp-hr. Actual driving cycle fuel economy comparisons are not readily available since the previous version of this engine was installed in a refuse hauler which was at a different location as the current version. A summary of the comparison of the previous and current version of the engine is shown in Table 13.

Table 13. Comparison of Previous and Current Version of the Engine

	Previous Version	Current Version
Power (bhp)	300	325
Torque (ft-lb)	1100	1180
NO_x (g/bhp-hr)	2.95	2.20
BSFC (lb/bhp-hr)	0.474	0.400

A calibration with a 350 bhp rating was tested for transient emissions. The emissions certification levels for the final calibration, with a deterioration factor, are shown in Table 14. Screen shots from the engine controller for this calibration are included in Appendix H. CARB certification gas was used for these tests.

Table 14. 350 bhp Transient Emissions Results.

Emission	Emission Level (g/bhp-hr)
HC/OMHCE	2.9
NMHC/OMNMHC	0.276
NMHC+ NO_x	2.60
Carbon Monoxide	1.3
Oxides of Nitrogen	2.3
Particulates	0.03
Formaldehyde	0.116

APPENDIX A

RECORDED DATA FOR LEAN LIMIT TESTS

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	844	845	846	847	848
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 18	MAR., 18	MAR., 18	MAR., 18	MAR., 18
Time (Seconds)	15:18:48	15:29:58	15:36:56	15:50:43	15:54:33
Ignition Timing	23.5	20.5	17.5	23.5	20.5

***** Engine Performance Data *****

Engine Speed (rpm)	1900	1892	1895	1897	1903
Torque (ft/lbs)	1010.1	981.3	948.7	1046.6	1025.7
BHP	365.4	353.4	342.3	377.9	371.6
BSFC (#/BHp-Hr)	.331	.342	.354	.327	.333
BTE (%)	37.5	36.3	35.0	37.8	37.1
BMEP (psi)	209.25	203.27	196.52	216.80	212.47
N.G. Flow (lbs/Hr)	121.01	120.71	121.35	123.56	123.90
NG Flow/E+6 (BTU/Hr)	2.481	2.475	2.488	2.542	2.549
Air Flow (#/Hr)	3080.2	3086.9	3098.5	3073.0	3079.9
Volumetric Eff (%)	87.8	88.1	88.1	87.6	87.7
Equivalence Ratio	.648	.645	.646	.665	.665
O2 Volts	2.992	2.992	2.992	2.992	2.992
Equiv O2	.990	.990	.990	.990	.990
GEM Equiv. Ratio	.65	.65	.65	.67	.67
GEM Vol. Eff.	82.20	82.70	82.60	82.60	82.60

***** Engine Temperature Data *****

Water In (Deg F)	190	187	189	186	186
Water Out (Deg F)	199	197	198	195	196
Oil Sump (Deg F)	238	238	238	241	240
Intake @ LFE (Deg F)	69	69	69	69	69
Boost B4 IC (Deg F)	277	277	278	278	277
Boost AF IC (Deg F)	104	102	103	103	103
Pre-Turbine (Deg F)	1199	1226	1259	1209	1232
Stack (Deg F)	1011	1038	1068	1023	1046
Exhaust 1 (Deg F)	1145	1173	1202	1158	1181
Exhaust 2 (Deg F)	1126	1152	1183	1139	1161
Exhaust 3 (Deg F)	1121	1147	1178	1131	1155
Exhaust 4 (Deg F)	1121	1148	1180	1132	1155
Exhaust 5 (Deg F)	1101	1126	1157	1110	1131
Exhaust 6 (Deg F)	1085	1110	1141	1097	1117
Gas @ Meter (Deg F)	67	64	65	65	64
Dyno H2O (Deg F)	108	108	108	112	112

***** Engine Pressures Data *****

Main Oil Pres (psig)	47.6	47.7	47.7	47.3	47.4
Fuel Pressure (psig)	80.5	80.6	80.3	80.3	80.3
Compress Out (psig)	20.53	20.45	20.62	20.49	20.47
Inlet Manifold(psig)	18.36	18.29	18.46	18.36	18.32
Inlet Manifold(psia)	32.72	32.64	32.81	32.71	32.67
Pre-Turbine (psig)	19.15	19.08	19.21	19.06	18.97
Exhaust Bk Pr ("HG)	4.54	4.73	4.88	4.64	4.72
LFE Filter Pr ("H2O)	1.35	1.38	1.25	1.24	1.24
LFE Delta Pr ("H2O)	5.65	5.66	5.68	5.64	5.65
H (lbH2O/lbAir)	.0026	.0026	.0026	.0025	.0025
RH (out) (%)	15.67	15.78	15.60	14.94	14.96
Barometer ("Hg)	29.22	29.22	29.22	29.21	29.22

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.38	95.38	95.38	95.44	95.44
NG % Ethane	2.37	2.37	2.37	2.44	2.44
NG % Propane	.28	.28	.28	.32	.32
NG % CO2	.98	.98	.98	.98	.98
NG % Nitrogen	.86	.86	.86	.65	.65
Butane Actual(%)	.12	.12	.12	.16	.16
MWT	16.88	16.88	16.88	16.90	16.90
Fuel LHV	20504.	20504.	20504.	20573.	20573.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	849	850	851	852	853
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 18	MAR., 18	MAR., 18	MAR., 18	MAR., 18
Time (Seconds)	15:57:52	16:01:44	16:04:59	16:08:15	16:12:39
Ignition Timing	17.5	23.5	20.5	17.5	23.5

***** Engine Performance Data *****

Engine Speed (rpm)	1902	1898	1900	1899	1898
Torque (ft/lbs)	998.1	976.8	947.5	912.2	955.6
BHP	361.5	353.0	342.7	329.8	345.3
BSFC (#/BHp-Hr)	.343	.337	.349	.365	.343
BTE (%)	36.1	36.7	35.4	33.9	36.1
BMEP (psi)	206.75	202.35	196.27	188.97	197.96
N.G. Flow (lbs/Hr)	123.95	119.13	119.72	120.40	118.42
NG Flow/E+6 (BTU/Hr)	2.550	2.451	2.463	2.477	2.436
Air Flow (#/Hr)	3076.8	3088.3	3102.1	3110.3	3097.0
Volumetric Eff (%)	87.7	87.6	87.9	88.1	87.7
Equivalence Ratio	.666	.638	.638	.640	.632
O2 Volts	2.992	2.992	2.992	2.992	2.992
Equiv O2	.990	.990	.990	.990	.990
GEM Equiv. Ratio	.67	.64	.64	.64	.63
GEM Vol. Eff.	82.60	82.60	82.60	82.60	82.60

***** Engine Temperature Data *****

Water In (Deg F)	187	185	184	184	183
Water Out (Deg F)	195	194	193	193	192
Oil Sump (Deg F)	239	238	236	235	234
Intake @ LFE (Deg F)	69	69	70	69	69
Boost B4 IC (Deg F)	276	278	280	278	278
Boost AF IC (Deg F)	103	103	103	103	102
Pre-Turbine (Deg F)	1260	1196	1224	1259	1194
Stack (Deg F)	1073	1010	1034	1068	1006
Exhaust 1 (Deg F)	1206	1146	1173	1203	1143
Exhaust 2 (Deg F)	1188	1125	1150	1181	1120
Exhaust 3 (Deg F)	1182	1123	1149	1181	1121
Exhaust 4 (Deg F)	1181	1121	1148	1181	1120
Exhaust 5 (Deg F)	1157	1099	1125	1158	1098
Exhaust 6 (Deg F)	1142	1084	1109	1140	1081
Gas @ Meter (Deg F)	63	63	64	65	66
Dyno H2O (Deg F)	111	110	110	108	110

***** Engine Pressures Data *****

Main Oil Pres (psig)	47.7	48.0	48.5	49.0	49.1
Fuel Pressure (psig)	80.4	80.9	80.7	80.6	81.0
Compress Out (psig)	20.47	20.61	20.63	20.71	20.68
Inlet Manifold(psig)	18.32	18.43	18.42	18.43	18.45
Inlet Manifold(psia)	32.67	32.78	32.76	32.78	32.79
Pre-Turbine (psig)	18.97	19.37	19.31	19.27	19.40
Exhaust Bk Pr ("HG)	4.83	4.68	4.76	4.91	4.67
LFE Filter Pr ("H2O)	1.24	1.25	1.26	1.26	1.25
LFE Delta Pr ("H2O)	5.63	5.67	5.71	5.71	5.68
H (lbH2O/lbAir)	.0025	.0025	.0025	.0025	.0025
RH (out) (%)	14.92	14.93	14.87	14.65	14.62
Barometer ("Hg)	29.22	29.21	29.21	29.22	29.21

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****					
NG % Methane	95.44	95.44	95.44	95.44	95.44
NG % Ethane	2.44	2.44	2.44	2.44	2.44
NG % Propane	.32	.32	.32	.32	.32
NG % CO2	.98	.98	.98	.98	.98
NG % Nitrogen	.65	.65	.65	.65	.65
Butane Actual(%)	.16	.16	.16	.16	.16
MWT	16.90	16.90	16.90	16.90	16.90
Fuel LHV	20573.	20573.	20573.	20573.	20573.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	854	855	856	857	858
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..JM..>	<..RW..>	<..RW..>
Julian Day	MAR., 18	MAR., 18	MAR., 18	MAR., 18	MAR., 18
Time (Seconds)	16:15:56	16:19:57	16:23:53	16:28:36	16:31:36
Ignition Timing	20.5	17.5	23.5	20.5	17.5

***** Engine Performance Data *****

Engine Speed (rpm)	1898	1895	1900	1899	1893
Torque (ft/lbs)	920.1	884.0	933.1	891.7	855.6
BHP	332.5	319.0	337.5	322.4	308.3
BSFC (#/BHp-Hr)	.358	.372	.347	.363	.383
BTE (%)	34.6	33.3	35.6	34.1	32.3
BMEP (psi)	190.60	183.12	193.29	184.71	177.24
N.G. Flow (lbs/Hr)	118.97	118.62	117.25	117.11	118.12
NG Flow/E+6 (BTU/Hr)	2.448	2.440	2.412	2.409	2.430
Air Flow (#/Hr)	3102.6	3112.7	3105.3	3130.8	3121.7
Volumetric Eff (%)	87.8	88.3	87.8	88.5	88.6
Equivalence Ratio	.634	.630	.624	.619	.626
O2 Volts	2.992	2.992	2.992	2.992	2.992
Equiv O2	.990	.990	.990	.990	.990
GEM Equiv. Ratio	.63	.63	.62	.62	.62
GEM Vol. Eff.	82.60	82.60	82.60	82.60	82.60

***** Engine Temperature Data *****

Water In (Deg F)	184	184	184	183	184
Water Out (Deg F)	192	193	192	192	192
Oil Sump (Deg F)	234	233	233	233	232
Intake @ LFE (Deg F)	69	69	69	69	69
Boost B4 IC (Deg F)	278	278	277	279	279
Boost AF IC (Deg F)	103	103	102	103	103
Pre-Turbine (Deg F)	1226	1264	1196	1230	1266
Stack (Deg F)	1034	1073	1009	1035	1072
Exhaust 1 (Deg F)	1169	1205	1144	1174	1209
Exhaust 2 (Deg F)	1148	1182	1121	1149	1184
Exhaust 3 (Deg F)	1149	1184	1122	1150	1182
Exhaust 4 (Deg F)	1150	1187	1122	1153	1186
Exhaust 5 (Deg F)	1127	1162	1100	1131	1165
Exhaust 6 (Deg F)	1110	1142	1083	1112	1143
Gas @ Meter (Deg F)	66	64	64	63	64
Dyno H2O (Deg F)	108	107	108	107	105

***** Engine Pressures Data *****

Main Oil Pres (psig)	49.1	49.4	49.3	49.5	49.6
Fuel Pressure (psig)	80.9	81.1	81.2	81.1	81.1
Compress Out (psig)	20.73	20.68	20.62	20.66	20.64
Inlet Manifold(psig)	18.48	18.44	18.43	18.43	18.43
Inlet Manifold(psia)	32.83	32.79	32.78	32.78	32.78
Pre-Turbine (psig)	19.42	19.27	19.37	19.38	19.28
Exhaust Bk Pr ("HG)	4.80	4.91	4.68	4.78	4.92
LFE Filter Pr ("H2O)	1.26	1.26	1.26	1.27	1.26
LFE Delta Pr ("H2O)	5.69	5.71	5.69	5.75	5.73
H (lbH2O/lbAir)	.0025	.0025	.0025	.0024	.0024
RH (out) (%)	14.53	14.49	14.48	14.35	14.24
Barometer ("Hg)	29.22	29.22	29.22	29.22	29.22

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.44	95.44	95.44	95.44	95.44
NG % Ethane	2.44	2.44	2.44	2.44	2.44
NG % Propane	.32	.32	.32	.32	.32
NG % CO2	.98	.98	.98	.98	.98
NG % Nitrogen	.65	.65	.65	.65	.65
Butane Actual(%)	.16	.16	.16	.16	.16
MWT	16.90	16.90	16.90	16.90	16.90
Fuel LHV	20573.	20573.	20573.	20573.	20573.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	859	860	861	862	863
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 18	MAR., 18	MAR., 18	MAR., 18	MAR., 18
Time (Seconds)	16:35:51	16:39:51	16:43:32	16:47:39	16:50:43
Ignition Timing	23.5	20.5	17.5	23.5	20.5

***** Engine Performance Data *****

Engine Speed (rpm)	1902	1902	1899	1904	1899
Torque (ft/lbs)	908.4	858.8	804.3	868.1	828.7
BHP	329.0	311.1	290.8	314.6	299.6
BSFC (#/BHp-Hr)	.354	.375	.401	.363	.385
BTE (%)	35.0	33.0	30.8	34.0	32.1
BMEP (psi)	188.17	177.90	166.61	179.84	171.67
N.G. Flow (lbs/Hr)	116.38	116.53	116.54	114.12	115.42
NG Flow/E+6 (BTU/Hr)	2.394	2.397	2.402	2.352	2.379
Air Flow (#/Hr)	3102.7	3111.5	3103.8	3091.9	3124.5
Volumetric Eff (%)	87.9	88.2	88.5	88.2	88.5
Equivalence Ratio	.620	.619	.622	.611	.612
O2 Volts	2.992	2.992	2.992	2.992	2.992
Equiv O2	.990	.990	.990	.990	.990
GEM Equiv. Ratio	.61	.61	.61	.60	.60
GEM Vol. Eff.	82.60	82.60	82.60	82.60	82.60

***** Engine Temperature Data *****

Water In (Deg F)	183	186	187	186	186
Water Out (Deg F)	191	194	195	195	194
Oil Sump (Deg F)	232	232	232	233	233
Intake @ LFE (Deg F)	69	69	69	69	69
Boost B4 IC (Deg F)	277	277	276	274	278
Boost AF IC (Deg F)	102	102	102	101	103
Pre-Turbine (Deg F)	1197	1232	1266	1196	1227
Stack (Deg F)	1007	1039	1077	1010	1036
Exhaust 1 (Deg F)	1144	1179	1215	1147	1183
Exhaust 2 (Deg F)	1120	1150	1188	1119	1153
Exhaust 3 (Deg F)	1119	1148	1181	1119	1146
Exhaust 4 (Deg F)	1122	1154	1183	1120	1146
Exhaust 5 (Deg F)	1101	1133	1163	1099	1125
Exhaust 6 (Deg F)	1082	1114	1149	1081	1112
Gas @ Meter (Deg F)	65	66	67	69	70
Dyno H2O (Deg F)	107	105	103	105	103

***** Engine Pressures Data *****

Main Oil Pres (psig)	49.8	49.8	49.8	49.7	49.6
Fuel Pressure (psig)	81.2	81.1	81.0	81.3	81.3
Compress Out (psig)	20.58	20.48	20.35	20.18	20.57
Inlet Manifold(psig)	18.31	18.24	18.12	17.95	18.35
Inlet Manifold(psia)	32.66	32.59	32.47	32.30	32.70
Pre-Turbine (psig)	19.39	19.28	19.02	19.01	19.35
Exhaust Bk Pr ("HG)	4.69	4.80	4.89	4.61	4.79
LFE Filter Pr ("H2O)	1.26	1.26	1.26	1.24	1.27
LFE Delta Pr ("H2O)	5.69	5.70	5.69	5.67	5.73
H (lbH2O/lbAir)	.0024	.0024	.0024	.0024	.0024
RH (out) (%)	14.23	14.23	14.19	14.14	14.12
Barometer ("Hg)	29.22	29.22	29.22	29.22	29.22

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.44	95.44	95.68	95.68	95.68
NG % Ethane	2.44	2.44	2.35	2.35	2.35
NG % Propane	.32	.32	.27	.27	.27
NG % CO2	.98	.98	.99	.99	.99
NG % Nitrogen	.65	.65	.54	.54	.54
Butane Actual(%)	.16	.16	.17	.17	.17
MWT	16.90	16.90	16.86	16.86	16.86
Fuel LHV	20573.	20573.	20608.	20608.	20608.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	864	865	866	867	868
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..JM..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 18	MAR., 18	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	16:53:28	16:57:19	09:06:10	09:10:42	09:16:26
Ignition Timing	17.5	23.5	19.0	16.0	13.0

***** Engine Performance Data *****

Engine Speed (rpm)	1903	1902	1255	1232	1254
Torque (ft/lbs)	725.5	774.1	1275.4	1256.8	1213.8
BHP	262.8	280.4	304.7	294.8	289.7
BSFC (#/BHp-Hr)	.436	.401	.322	.334	.341
BTE (%)	28.3	30.8	38.5	37.1	36.3
BMEP (psi)	150.28	160.36	264.19	260.35	251.43
N.G. Flow (lbs/Hr)	114.66	112.33	98.01	98.44	98.88
NG Flow/E+6 (BTU/Hr)	2.363	2.315	2.013	2.022	2.031
Air Flow (#/Hr)	3133.6	3130.4	2401.2	2420.2	2433.6
Volumetric Eff (%)	88.5	88.4	93.0	95.6	94.4
Equivalence Ratio	.606	.594	.674	.672	.671
O2 Volts	2.992	2.992	2.993	2.993	2.993
Equiv O2	.990	.990	.989	.989	.989
GEM Equiv. Ratio	.60	.59	.65	.65	.65
GEM Vol. Eff.	82.60	82.60	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	185	183	186	186	187
Water Out (Deg F)	194	191	196	196	197
Oil Sump (Deg F)	232	230	229	229	228
Intake @ LFE (Deg F)	69	69	57	57	57
Boost B4 IC (Deg F)	278	279	281	281	281
Boost AF IC (Deg F)	103	103	103	103	102
Pre-Turbine (Deg F)	1236	1166	1101	1124	1161
Stack (Deg F)	1056	989	912	934	973
Exhaust 1 (Deg F)	1217	1151	1042	1062	1090
Exhaust 2 (Deg F)	1186	1121	1040	1062	1094
Exhaust 3 (Deg F)	1163	1103	1025	1050	1082
Exhaust 4 (Deg F)	1137	1075	1024	1045	1080
Exhaust 5 (Deg F)	1119	1063	999	1019	1053
Exhaust 6 (Deg F)	1130	1070	967	984	1016
Gas @ Meter (Deg F)	69	67	55	55	57
Dyno H2O (Deg F)	100	101	109	108	107

***** Engine Pressures Data *****

Main Oil Pres (psig)	50.2	50.9	29.6	29.6	29.8
Fuel Pressure (psig)	81.3	81.7	83.7	83.6	83.5
Compress Out (psig)	20.71	20.62	22.97	22.99	23.03
Inlet Manifold(psig)	18.39	18.34	21.90	21.85	21.85
Inlet Manifold(psia)	32.74	32.69	36.36	36.31	36.31
Pre-Turbine (psig)	19.38	19.51	15.30	15.21	15.21
Exhaust Bk Pr ("HG)	4.93	4.67	2.61	2.64	2.72
LFE Filter Pr ("H2O)	1.27	1.27	.78	.78	.79
LFE Delta Pr ("H2O)	5.75	5.74	4.15	4.19	4.21
H (lbH2O/lbAir)	.0024	.0024	.0021	.0021	.0020
RH (out) (%)	14.14	14.07	19.26	18.60	18.39
Barometer ("Hg)	29.22	29.22	29.44	29.44	29.44

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****					
NG % Methane	95.68	95.68	95.01	95.01	95.01
NG % Ethane	2.35	2.35	2.62	2.62	2.62
NG % Propane	.27	.27	.46	.46	.46
NG % CO2	.99	.99	1.02	1.02	1.02
NG % Nitrogen	.54	.54	.65	.65	.65
Butane Actual(%)	.17	.17	.24	.24	.24
MWT	16.86	16.86	17.00	17.00	17.00
Fuel LHV	20608.	20608.	20541.	20541.	20541.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	869	870	871	872	873
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 19	MAR., 19	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	09:27:05	09:31:51	09:35:21	09:40:13	09:44:34
Ignition Timing	19.0	16.0	13.0	19.0	16.0

***** Engine Performance Data *****

Engine Speed (rpm)	1253	1243	1254	1243	1253
Torque (ft/lbs)	1330.8	1314.6	1279.9	1264.6	1238.8
BHP	317.6	311.1	305.6	299.4	295.6
BSFC (#/BHp-Hr)	.315	.323	.331	.322	.328
BTE (%)	39.3	38.3	37.4	38.5	37.8
BMEP (psi)	275.67	272.33	265.14	261.97	256.63
N.G. Flow (lbs/Hr)	100.18	100.63	101.13	96.47	97.00
NG Flow/E+6 (BTU/Hr)	2.058	2.067	2.077	1.982	1.992
Air Flow (#/Hr)	2395.5	2405.7	2423.2	2418.0	2426.9
Volumetric Eff (%)	93.1	94.3	94.1	94.4	93.9
Equivalence Ratio	.690	.691	.689	.659	.660
O2 Volts	2.993	2.993	2.993	2.993	2.993
Equiv O2	.989	.989	.989	.989	.989
GEM Equiv. Ratio	.67	.67	.67	.64	.64
GEM Vol. Eff.	86.20	86.20	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	187	186	187	185	184
Water Out (Deg F)	197	197	197	195	194
Oil Sump (Deg F)	231	232	231	230	228
Intake @ LFE (Deg F)	57	57	57	57	57
Boost B4 IC (Deg F)	281	280	281	281	280
Boost AF IC (Deg F)	102	102	102	102	102
Pre-Turbine (Deg F)	1115	1135	1167	1098	1118
Stack (Deg F)	926	947	979	909	928
Exhaust 1 (Deg F)	1051	1068	1094	1035	1055
Exhaust 2 (Deg F)	1052	1071	1100	1036	1055
Exhaust 3 (Deg F)	1040	1061	1088	1026	1045
Exhaust 4 (Deg F)	1036	1055	1085	1021	1040
Exhaust 5 (Deg F)	1011	1029	1059	998	1014
Exhaust 6 (Deg F)	979	996	1021	963	978
Gas @ Meter (Deg F)	56	55	55	56	57
Dyno H2O (Deg F)	109	109	108	107	106

***** Engine Pressures Data *****

Main Oil Pres (psig)	29.2	29.2	29.3	29.5	29.9
Fuel Pressure (psig)	83.4	83.5	83.4	84.0	83.8
Compress Out (psig)	22.95	22.98	23.04	23.02	23.01
Inlet Manifold(psig)	21.85	21.84	21.88	21.86	21.89
Inlet Manifold(psia)	36.31	36.31	36.34	36.32	36.35
Pre-Turbine (psig)	15.16	15.14	15.16	15.32	15.33
Exhaust Bk Pr ("HG)	2.59	2.64	2.72	2.60	2.65
LFE Filter Pr ("H2O)	.77	.78	.79	.78	.80
LFE Delta Pr ("H2O)	4.14	4.16	4.19	4.18	4.20
H (lbH2O/lbAir)	.0020	.0020	.0020	.0020	.0020
RH (out) (%)	18.20	18.27	18.37	18.47	18.24
Barometer ("Hg)	29.44	29.44	29.44	29.44	29.44

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.01	95.01	95.01	95.01	95.01
NG % Ethane	2.62	2.62	2.62	2.62	2.62
NG % Propane	.46	.46	.46	.46	.46
NG % CO2	1.02	1.02	1.02	1.02	1.02
NG % Nitrogen	.65	.65	.65	.65	.65
Butane Actual(%)	.24	.24	.24	.24	.24
MWT	17.00	17.00	17.00	17.00	17.00
Fuel LHV	20541.	20541.	20541.	20541.	20541.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	874	875	876	877	878
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 19	MAR., 19	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	09:48:36	09:53:27	09:57:49	10:01:33	10:06:40
Ignition Timing	13.0	19.0	16.0	13.0	19.0

***** Engine Performance Data *****

Engine Speed (rpm)	1242	1253	1247	1252	1244
Torque (ft/lbs)	1190.1	1242.4	1210.2	1158.6	1214.1
BHP	281.5	296.4	287.4	276.1	287.5
BSFC (#/BHp-Hr)	.345	.321	.331	.347	.327
BTE (%)	35.9	38.6	37.4	35.7	37.9
BMEP (psi)	246.54	257.37	250.70	240.00	251.50
N.G. Flow (lbs/Hr)	97.24	95.18	95.07	95.78	93.92
NG Flow/E+6 (BTU/Hr)	1.997	1.955	1.953	1.967	1.929
Air Flow (#/Hr)	2431.5	2421.1	2439.4	2445.1	2434.1
Volumetric Eff (%)	95.1	93.7	94.5	94.7	94.6
Equivalence Ratio	.660	.649	.643	.647	.637
O2 Volts	2.993	2.993	2.993	2.993	2.993
Equiv O2	.989	.989	.989	.989	.989
GEM Equiv. Ratio	.64	.63	.63	.63	.62
GEM Vol. Eff.	86.20	86.20	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	183	182	182	182	181
Water Out (Deg F)	193	192	191	192	191
Oil Sump (Deg F)	226	226	225	223	223
Intake @ LFE (Deg F)	59	58	58	59	59
Boost B4 IC (Deg F)	282	283	282	282	284
Boost AF IC (Deg F)	103	103	100	102	101
Pre-Turbine (Deg F)	1156	1093	1116	1156	1090
Stack (Deg F)	967	902	925	966	899
Exhaust 1 (Deg F)	1087	1032	1054	1088	1029
Exhaust 2 (Deg F)	1090	1031	1051	1091	1028
Exhaust 3 (Deg F)	1081	1022	1041	1081	1020
Exhaust 4 (Deg F)	1076	1019	1038	1076	1015
Exhaust 5 (Deg F)	1050	993	1013	1050	990
Exhaust 6 (Deg F)	1011	958	975	1008	954
Gas @ Meter (Deg F)	58	58	58	57	57
Dyno H2O (Deg F)	105	106	106	104	106

***** Engine Pressures Data *****

Main Oil Pres (psig)	30.2	30.3	30.5	30.7	30.7
Fuel Pressure (psig)	83.7	84.1	84.0	83.9	84.1
Compress Out (psig)	23.04	23.07	23.02	22.93	23.02
Inlet Manifold(psig)	21.89	21.93	21.90	21.85	21.86
Inlet Manifold(psia)	36.36	36.39	36.36	36.32	36.32
Pre-Turbine (psig)	15.32	15.44	15.41	15.32	15.47
Exhaust Bk Pr ("HG)	2.74	2.61	2.66	2.73	2.61
LFE Filter Pr ("H2O)	.80	.79	.81	.82	.81
LFE Delta Pr ("H2O)	4.23	4.21	4.24	4.25	4.24
H (lbH2O/lbAir)	.0020	.0021	.0021	.0021	.0021
RH (out) (%)	18.26	18.10	17.90	17.79	17.60
Barometer ("Hg)	29.44	29.44	29.44	29.44	29.44

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.01	95.01	95.01	95.01	95.01
NG % Ethane	2.62	2.62	2.62	2.62	2.62
NG % Propane	.46	.46	.46	.46	.46
NG % CO2	1.02	1.02	1.02	1.02	1.02
NG % Nitrogen	.65	.65	.65	.65	.65
Butane Actual(%)	.24	.24	.24	.24	.24
MWT	17.00	17.00	17.00	17.00	17.00
Fuel LHV	20541.	20541.	20541.	20541.	20541.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	879	880	881	882	883
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 19	MAR., 19	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	10:11:24	10:16:18	10:21:44	10:25:08	10:29:11
Ignition Timing	16.0	13.0	19.0	16.0	13.0

***** Engine Performance Data *****

Engine Speed (rpm)	1253	1254	1252	1240	1234
Torque (ft/lbs)	1181.5	1121.4	1192.1	1159.6	1096.2
BHP	281.8	267.8	284.2	273.7	257.5
BSFC (#/BHp-Hr)	.336	.354	.326	.340	.365
BTE (%)	36.9	35.0	38.0	36.4	33.9
BMEP (psi)	244.74	232.30	246.95	240.21	227.07
N.G. Flow (lbs/Hr)	94.54	94.78	92.72	93.12	94.01
NG Flow/E+6 (BTU/Hr)	1.942	1.947	1.905	1.913	1.931
Air Flow (#/Hr)	2437.4	2436.4	2426.6	2452.9	2452.4
Volumetric Eff (%)	94.0	93.9	93.8	95.5	96.1
Equivalence Ratio	.640	.642	.631	.627	.633
O2 Volts	2.993	2.992	2.992	2.992	2.992
Equiv O2	.989	.990	.989	.989	.989
GEM Equiv. Ratio	.62	.62	.61	.61	.61
GEM Vol. Eff.	86.20	86.20	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	181	182	181	181	182
Water Out (Deg F)	191	192	191	191	192
Oil Sump (Deg F)	222	222	222	222	221
Intake @ LFE (Deg F)	59	60	60	60	60
Boost B4 IC (Deg F)	283	283	284	284	285
Boost AF IC (Deg F)	101	101	101	101	103
Pre-Turbine (Deg F)	1115	1160	1088	1115	1161
Stack (Deg F)	923	973	896	922	971
Exhaust 1 (Deg F)	1053	1092	1028	1053	1096
Exhaust 2 (Deg F)	1050	1093	1023	1050	1097
Exhaust 3 (Deg F)	1041	1084	1015	1042	1088
Exhaust 4 (Deg F)	1038	1081	1013	1038	1082
Exhaust 5 (Deg F)	1014	1056	989	1013	1056
Exhaust 6 (Deg F)	975	1011	952	972	1011
Gas @ Meter (Deg F)	58	59	60	60	59
Dyno H2O (Deg F)	105	103	105	105	103

***** Engine Pressures Data *****

Main Oil Pres (psig)	30.9	30.9	30.9	31.0	30.9
Fuel Pressure (psig)	84.0	83.9	84.1	84.1	84.0
Compress Out (psig)	23.06	23.06	22.96	23.03	23.07
Inlet Manifold(psig)	21.90	21.89	21.85	21.87	21.98
Inlet Manifold(psia)	36.36	36.35	36.31	36.34	36.44
Pre-Turbine (psig)	15.44	15.36	15.49	15.45	15.42
Exhaust Bk Pr ("HG)	2.66	2.75	2.60	2.66	2.75
LFE Filter Pr ("H2O)	.81	.82	.81	.83	.83
LFE Delta Pr ("H2O)	4.25	4.25	4.25	4.29	4.29
H (lbH2O/lbAir)	.0021	.0021	.0020	.0020	.0020
RH (out) (%)	17.16	16.97	16.75	16.62	16.58
Barometer ("Hg)	29.44	29.44	29.44	29.45	29.44

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	95.01	95.01	95.01	95.01	95.01
NG % Ethane	2.62	2.62	2.62	2.62	2.62
NG % Propane	.46	.46	.46	.46	.46
NG % CO2	1.02	1.02	1.02	1.02	1.02
NG % Nitrogen	.65	.65	.65	.65	.65
Butane Actual(%)	.24	.24	.24	.24	.24
MWT	17.00	17.00	17.00	17.00	17.00
Fuel LHV	20541.	20541.	20541.	20541.	20541.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	884	885	886	887	888
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 19	MAR., 19	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	10:34:26	10:37:50	10:41:39	10:46:19	10:49:49
Ignition Timing	19.0	16.0	13.0	19.0	16.0

***** Engine Performance Data *****

Engine Speed (rpm)	1245	1243	1239	1252	1252
Torque (ft/lbs)	1167.8	1126.6	1058.6	1145.4	1107.4
BHP	276.7	266.6	249.7	273.0	263.9
BSFC (#/BHp-Hr)	.333	.349	.375	.337	.353
BTE (%)	37.4	35.6	33.2	36.9	35.2
BMEP (psi)	241.90	233.37	219.29	237.27	229.40
N.G. Flow (lbs/Hr)	92.03	93.06	93.54	91.87	93.26
NG Flow/E+6 (BTU/Hr)	1.884	1.905	1.915	1.880	1.909
Air Flow (#/Hr)	2426.9	2447.1	2492.6	2440.5	2473.8
Volumetric Eff (%)	94.6	95.5	96.5	94.2	94.7
Equivalence Ratio	.624	.626	.617	.619	.620
O2 Volts	2.992	2.992	2.992	2.992	2.992
Equiv O2	.990	.990	.990	.990	.990
GEM Equiv. Ratio	.60	.60	.60	.59	.59
GEM Vol. Eff.	86.20	86.20	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	181	182	182	182	182
Water Out (Deg F)	191	191	192	192	192
Oil Sump (Deg F)	222	221	221	221	221
Intake @ LFE (Deg F)	60	60	61	61	61
Boost B4 IC (Deg F)	284	284	287	286	287
Boost AF IC (Deg F)	103	103	103	103	103
Pre-Turbine (Deg F)	1089	1118	1172	1090	1123
Stack (Deg F)	896	924	980	899	928
Exhaust 1 (Deg F)	1026	1056	1107	1030	1062
Exhaust 2 (Deg F)	1022	1052	1107	1024	1056
Exhaust 3 (Deg F)	1015	1044	1098	1018	1048
Exhaust 4 (Deg F)	1014	1042	1093	1017	1047
Exhaust 5 (Deg F)	989	1017	1066	992	1021
Exhaust 6 (Deg F)	951	974	1019	950	978
Gas @ Meter (Deg F)	60	60	60	61	62
Dyno H2O (Deg F)	105	104	102	104	104

***** Engine Pressures Data *****

Main Oil Pres (psig)	31.0	31.0	31.0	31.1	31.1
Fuel Pressure (psig)	84.3	84.2	84.0	84.2	84.0
Compress Out (psig)	22.96	22.95	23.35	23.13	23.44
Inlet Manifold(psig)	21.80	21.85	22.23	21.98	22.27
Inlet Manifold(psia)	36.26	36.31	36.70	36.44	36.73
Pre-Turbine (psig)	15.44	15.42	15.59	15.60	15.71
Exhaust Bk Pr ("HG)	2.58	2.64	2.83	2.62	2.73
LFE Filter Pr ("H2O)	.81	.82	.86	.83	.86
LFE Delta Pr ("H2O)	4.24	4.28	4.37	4.28	4.33
H (lbH2O/lbAir)	.0020	.0020	.0021	.0020	.0021
RH (out) (%)	16.45	16.40	16.33	16.21	16.16
Barometer ("Hg)	29.45	29.45	29.45	29.45	29.45

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	94.78	94.78	94.78	94.78	94.78
NG % Ethane	2.56	2.56	2.56	2.56	2.56
NG % Propane	.52	.52	.52	.52	.52
NG % CO2	1.12	1.12	1.12	1.12	1.12
NG % Nitrogen	.71	.71	.71	.71	.71
Butane Actual(%)	.32	.32	.32	.32	.32
MWT	17.08	17.08	17.08	17.08	17.08
Fuel LHV	20469.	20469.	20469.	20469.	20469.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	889	890	891
Year	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>
Julian Day	MAR., 19	MAR., 19	MAR., 19
Time (Seconds)	10:53:47	10:58:03	11:01:58
Ignition Timing	13.0	19.0	16.0

***** Engine Performance Data *****

Engine Speed (rpm)	1237	1245	1261
Torque (ft/lbs)	1012.8	1118.5	1059.4
BHP	238.5	265.1	254.3
BSFC (#/BHp-Hr)	.390	.345	.361
BTE (%)	31.9	36.1	34.4
BMEP (psi)	209.81	231.70	219.45
N.G. Flow (lbs/Hr)	92.92	91.34	91.83
NG Flow/E+6 (BTU/Hr)	1.902	1.870	1.880
Air Flow (#/Hr)	2477.3	2473.9	2492.2
Volumetric Eff (%)	96.2	95.4	94.8
Equivalence Ratio	.617	.607	.606
O2 Volts	2.992	2.992	2.992
Equiv O2	.990	.990	.990
GEM Equiv. Ratio	.59	.58	.58
GEM Vol. Eff.	86.20	86.20	86.20

***** Engine Temperature Data *****

Water In (Deg F)	183	183	182
Water Out (Deg F)	192	192	191
Oil Sump (Deg F)	221	221	221
Intake @ LFE (Deg F)	62	61	62
Boost B4 IC (Deg F)	289	288	288
Boost AF IC (Deg F)	104	102	103
Pre-Turbine (Deg F)	1178	1095	1128
Stack (Deg F)	987	903	935
Exhaust 1 (Deg F)	1114	1035	1070
Exhaust 2 (Deg F)	1113	1029	1063
Exhaust 3 (Deg F)	1103	1024	1053
Exhaust 4 (Deg F)	1097	1021	1051
Exhaust 5 (Deg F)	1071	996	1025
Exhaust 6 (Deg F)	1026	955	982
Gas @ Meter (Deg F)	62	62	62
Dyno H2O (Deg F)	101	103	102

***** Engine Pressures Data *****

Main Oil Pres (psig)	31.1	31.2	31.2
Fuel Pressure (psig)	84.1	84.3	84.1
Compress Out (psig)	23.45	23.23	23.36
Inlet Manifold(psig)	22.24	22.07	22.15
Inlet Manifold(psia)	36.70	36.53	36.61
Pre-Turbine (psig)	15.62	15.72	15.72
Exhaust Bk Pr ("HG)	2.83	2.66	2.75
LFE Filter Pr ("H2O)	.84	.85	.86
LFE Delta Pr ("H2O)	4.36	4.35	4.39
H (lbH2O/lbAir)	.0021	.0021	.0021
RH (out) (%)	16.01	15.96	15.84
Barometer ("Hg)	29.45	29.45	29.45

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	94.78	94.78	94.78
NG % Ethane	2.56	2.56	2.56
NG % Propane	.52	.52	.52
NG % CO2	1.12	1.12	1.12
NG % Nitrogen	.71	.71	.71
Butane Actual(%)	.32	.32	.32
MWT	17.08	17.08	17.08
Fuel LHV	20469.	20469.	20469.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	1213	1214	1215	1216	1217
Year	1996	1996	1996	1996	1996
Operator Initials	<..RW..>	<..RW..>	<..RW..>	<..RW..>	<..RW..>
Julian Day	APR., 02	APR., 02	APR., 02	APR., 02	APR., 02
Time (Seconds)	14:53:52	15:07:36	15:19:11	15:33:03	15:49:17
Ignition Timing	23.0	23.0	21.0	21.0	19.0

***** Engine Performance Data *****

Engine Speed (rpm)	1897	1802	1602	1393	1245
Torque (ft/lbs)	988.5	1036.1	1126.3	1205.1	1225.9
BHP	357.0	355.6	343.5	319.7	290.5
BSFC (#/BHp-Hr)	.341	.333	.323	.319	.320
BTE (%)	36.0	36.9	38.0	38.5	38.4
BMEP (psi)	204.77	214.62	233.31	249.63	253.94
N.G. Flow (lbs/Hr)	121.73	118.52	111.05	101.96	92.99
NG Flow/E+6 (BTU/Hr)	2.521	2.455	2.300	2.111	1.925
Air Flow (#/Hr)	3094.8	2964.7	2851.4	2596.6	2297.1
Volumetric Eff (%)	88.5	88.8	91.2	92.8	93.9
Equivalence Ratio	.655	.666	.649	.654	.674
O2 Volts	.000	.000	.000	.000	.000
Equiv O2	6.615	6.615	6.615	6.615	6.615
GEM Equiv. Ratio	.65	.65	.65	.65	.65
GEM Vol. Eff.	82.60	81.60	84.60	87.00	85.90

***** Engine Temperature Data *****

Water In (Deg F)	187	187	181	183	183
Water Out (Deg F)	197	197	192	194	194
Oil Sump (Deg F)	236	239	232	230	225
Intake @ LFE (Deg F)	78	75	75	76	74
Boost B4 IC (Deg F)	292	286	295	303	297
Boost AF IC (Deg F)	108	106	107	104	105
Pre-Turbine (Deg F)	1213	1201	1169	1124	1102
Stack (Deg F)	1023	1018	977	930	912
Exhaust 1 (Deg F)	1166	1155	1121	1071	1045
Exhaust 2 (Deg F)	1140	1134	1108	1064	1040
Exhaust 3 (Deg F)	1139	1129	1097	1052	1027
Exhaust 4 (Deg F)	1138	1125	1093	1048	1023
Exhaust 5 (Deg F)	1118	1103	1073	1027	1001
Exhaust 6 (Deg F)	1094	1083	1046	995	968
Gas @ Meter (Deg F)	70	72	72	72	75
Dyno H2O (Deg F)	109	111	111	109	106

***** Engine Pressures Data *****

Main Oil Pres (psig)	48.6	44.9	39.9	34.0	30.6
Fuel Pressure (psig)	80.0	80.3	81.4	82.5	83.3
Compress Out (psig)	20.76	20.63	22.30	22.67	21.78
Inlet Manifold(psig)	18.56	18.62	20.43	21.28	20.69
Inlet Manifold(psia)	32.92	32.98	34.79	35.64	35.05
Pre-Turbine (psig)	19.49	18.48	18.10	16.94	15.16
Exhaust Bk Pr ("HG)	4.55	4.30	3.84	3.20	2.59
LFE Filter Pr ("H2O)	1.32	1.18	1.12	.97	.79
LFE Delta Pr ("H2O)	5.85	5.55	5.33	4.85	4.25
H (lbH2O/lbAir)	.0036	.0036	.0037	.0037	.0040
RH (out) (%)	16.96	16.77	17.40	17.98	19.57
Barometer ("Hg)	29.25	29.24	29.24	29.24	29.24

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	96.16	96.16	96.16	96.07	96.07
NG % Ethane	2.36	2.36	2.36	2.43	2.43
NG % Propane	.13	.13	.13	.14	.14
NG % CO2	.91	.91	.91	.92	.92
NG % Nitrogen	.40	.40	.40	.41	.41
Butane Actual(%)	.04	.04	.04	.03	.03
MWT	16.73	16.73	16.73	16.74	16.74
Fuel LHV	20713.	20713.	20713.	20702.	20702.

= Cell 04 MAC2 Project Low-Speed Data =

***** Test Cell Run Information *****		
Run Number	1218	1219
Year	1996	1996
Operator Initials	<..RW..>	<..RW..>
Julian Day	APR., 02	APR., 02
Time (Seconds)	16:01:27	16:32:24
Ignition Timing	13.0	10.0

***** Engine Performance Data *****		
Engine Speed (rpm)	1105	1008
Torque (ft/lbs)	1248.6	969.6
BHP	262.8	186.2
BSFC (#/BHp-Hr)	.323	.330
BTE (%)	38.1	37.3
BMEP (psi)	258.65	200.86
N.G. Flow (lbs/Hr)	84.77	61.48
NG Flow/E+6 (BTU/Hr)	1.755	1.272
Air Flow (#/Hr)	1747.1	1247.3
Volumetric Eff (%)	92.6	90.8
Equivalence Ratio	.808	.820
O2 Volts	.000	.000
Equiv O2	6.615	6.615
GEM Equiv. Ratio	.78	.78
GEM Vol. Eff.	84.70	885.90

***** Engine Temperature Data *****		
Water In (Deg F)	180	169
Water Out (Deg F)	193	186
Oil Sump (Deg F)	229	218
Intake @ LFE (Deg F)	73	75
Boost B4 IC (Deg F)	264	209
Boost AF IC (Deg F)	101	95
Pre-Turbine (Deg F)	1170	1131
Stack (Deg F)	1010	1011
Exhaust 1 (Deg F)	1093	1049
Exhaust 2 (Deg F)	1097	1044
Exhaust 3 (Deg F)	1074	1028
Exhaust 4 (Deg F)	1073	1026
Exhaust 5 (Deg F)	1046	999
Exhaust 6 (Deg F)	1013	970
Gas @ Meter (Deg F)	78	80
Dyno H2O (Deg F)	104	95

***** Engine Pressures Data *****		
Main Oil Pres (psig)	25.9	25.4
Fuel Pressure (psig)	84.3	87.2
Compress Out (psig)	16.94	10.25
Inlet Manifold (psig)	16.20	9.83
Inlet Manifold (psia)	30.56	24.18
Pre-Turbine (psig)	10.67	6.44
Exhaust Bk Pr ("HG)	1.95	1.20
LFE Filter Pr ("H2O)	.49	.26
LFE Delta Pr ("H2O)	3.20	2.29
H (lbH2O/lbAir)	.0037	.0039
RH (out) (%)	18.92	19.70
Barometer ("Hg)	29.23	29.23

= Cell 04 MAC2 Project Low-Speed Data =

***** Natural Gas Composition *****

NG % Methane	96.07	95.97
NG % Ethane	2.43	2.46
NG % Propane	.14	.16
NG % CO2	.92	.94
NG % Nitrogen	.41	.42
Butane Actual(%)	.03	.05
MWT	16.74	16.77
Fuel LHV	20702.	20686.

APPENDIX B

RECORDED DATA FOR STEADY-STATE TESTS

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
564	96.49	2.14	0.11	0.02	0.77	0.47	471.58	12.6	0.011	20.17	1949	33.9
565	96.49	2.14	0.11	0.02	0.77	0.47	412.22	18.1	0.0111	17.4	1699	56
566	96.49	2.14	0.11	0.02	0.77	0.47	668.94	58.9	0.0109	28.99	1704	181.5
567	96.44	2.26	0.11	0.02	0.69	0.48	950.73	93.7	0.011	38.44	1701	289.3
568	96.44	2.26	0.11	0.02	0.69	0.48	1163	119.1	0.011	46.69	1705	366.8
569	96.44	2.26	0.11	0.02	0.69	0.48	1451.8	160	0.011	58.49	1703	493.4
570	96.44	2.26	0.11	0.02	0.69	0.48	1771.1	207.4	0.0107	71.77	1700	640.9
571	96.44	2.26	0.11	0.02	0.69	0.48	2080.8	242.6	0.0106	81.4	1711	745
572	96.44	2.26	0.11	0.02	0.69	0.48	2317.5	271.9	0.0105	91.06	1698	840.9
573	96.44	2.26	0.11	0.02	0.69	0.48	2569.9	297.5	0.0102	100.04	1691	924.1
574	96.42	2.27	0.11	0.02	0.7	0.48	1644.2	167.8	0.0101	66.87	1940	454.4
575	96.42	2.27	0.11	0.02	0.7	0.48	1942.7	201.6	0.01	77.46	1955	541.4
576	96.42	2.27	0.11	0.02	0.7	0.48	2249.7	249.6	0.0101	89.11	1949	672.7
577	96.42	2.27	0.11	0.02	0.7	0.48	2532.8	281.9	0.0101	98.19	1951	758.9
578	96.42	2.27	0.11	0.02	0.7	0.48	2871.2	327.6	0.0102	111.82	1948	883.1
579	96.42	2.27	0.11	0.02	0.7	0.48	327.05	16	0.0102	14.34	1498	56.2
580	96.42	2.27	0.11	0.02	0.7	0.48	558.48	51.9	0.0103	24.14	1505	181.1
581	96.42	2.27	0.11	0.02	0.7	0.48	815.75	82	0.0102	33.47	1505	286
582	96.37	2.07	0.14	0.04	0.74	0.64	1030.9	110.7	0.0102	41.57	1497	388.3
583	96.37	2.07	0.14	0.04	0.74	0.64	1310.2	150	0.0102	53.1	1500	525.3
584	96.37	2.07	0.14	0.04	0.74	0.64	1586.2	186.5	0.01	63.6	1494	655.5
585	96.37	2.07	0.14	0.04	0.74	0.64	263.47	14.1	0.0101	12.78	1255	59.1
586	96.37	2.07	0.14	0.04	0.74	0.64	860.1	96.9	0.0101	34.88	1255	405.8
587	96.37	2.07	0.14	0.04	0.74	0.64	1108.5	131.6	0.01	44.59	1252	551.7
588	94.41	2.63	0.51	0.28	1.02	1.15	238.18	16.5	0.0016	12.25	1084	80.2
589	94.41	2.63	0.51	0.28	1.02	1.15	788.62	103.6	0.0015	36.43	1104	493.1
590	94.41	2.63	0.51	0.28	1.02	1.15	217.74	16.7	0.0016	10.64	1006	87
591	94.36	2.68	0.51	0.28	1.01	1.16	725.61	93.1	0.0015	34.38	1001	488.5
592	94.36	2.68	0.51	0.28	1.01	1.16	162.83	15.1	0.0015	8.32	798	99.2
593	94.36	2.68	0.51	0.28	1.01	1.16	289.81	38.5	0.0015	14.91	805	251.5
594	94.36	2.68	0.51	0.28	1.01	1.16	438.32	59.5	0.0015	21.81	795	393
595	94.29	2.67	0.52	0.3	1.04	1.19	583.48	82.6	0.0016	30.46	800	542.5
596	94.29	2.67	0.52	0.3	1.04	1.19	120.6	10.2	0.0015	6.7	650	82.8
597	94.29	2.67	0.52	0.3	1.04	1.19	214.37	28.9	0.0015	11.57	642	236.4

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
564	0.714	0.702	34.5	7.6	6.2	100	0.77	0.54	-8.12	3.378	51255	30
565	0.705	0.703	33.5	12.8	6.27	97	0.58	0.39	-8.05	3.377	51713	30
566	0.724	0.683	33.5	24.9	9.08	93	1.14	0.81	-5.23	3.404	52278	30
567	0.677	0.639	33.5	29.8	12.05	96	1.92	1.77	-2.26	3.462	52740	30
568	0.672	0.639	30.5	31.2	14.73	109	5.12	7.15	0.41	3.463	53311	30
569	0.674	0.635	29.5	33.5	17.97	106	7.03	10.18	3.66	3.468	53819	30
570	0.678	0.631	29.5	35.3	21.21	106	7.8	9.93	6.9	3.473	54213	30
571	0.655	0.615	28.5	36.5	24.37	107	9.82	12.56	10.06	3.494	54662	30
572	0.657	0.611	26.5	36.5	27.01	106	11.68	14.89	12.7	3.498	55515	30
573	0.651	0.609	23.5	36.4	29.68	104	14	17.3	15.37	3.501	55826	30
574	0.68	0.632	26.5	30.7	18.17	106	8.77	12.21	3.86	3.472	56393	30
575	0.667	0.626	23.5	31.8	20.94	105	10.63	14.09	6.62	3.479	56792	30
576	0.663	0.612	28.5	34.3	24.12	108	12.91	16.9	9.8	3.498	57119	30
577	0.648	0.608	26.5	35.1	26.89	107	15.34	19.83	12.57	3.503	57524	30
578	0.651	0.603	26.5	35.8	29.82	106	16.31	17.67	15.5	3.509	57908	30
579	0.733	0.706	32.5	13.7	6.18	97	0.48	0.3	-8.13	3.373	58528	30
580	0.723	0.684	34.5	26.3	9.05	102	0.83	0.53	-5.26	3.402	58891	30
581	0.686	0.628	32.5	30	12.04	103	1.45	1.26	-2.27	3.477	59340	30
582	0.672	0.625	31.5	32.7	14.8	96	4.17	5.64	0.49	3.48	59662	30
583	0.675	0.625	29.5	34.7	18.01	99	5.19	6.92	3.69	3.48	60022	30
584	0.668	0.623	28.5	36	21.17	104	6.76	9.24	6.86	3.484	60338	30
585	0.809	0.705	33.5	13.6	6.15	94	0.29	0.17	-8.16	3.374	60778	30
586	0.676	0.628	30.5	34.1	14.83	100	2.87	3.84	0.52	3.476	61054	30
587	0.67	0.626	27.5	36.2	18.1	105	4.47	6.34	3.79	3.48	61319	30
588	0.842	0.776	30.5	16.9	6.35	100	0.19	0.1	-8.05	3.279	34777	31
589	0.756	0.728	23.5	35.5	15.06	97	2.54	3.78	0.66	3.343	35404	31
590	0.8	0.783	29.5	19.6	6.28	93	0.17	0.09	-8.12	3.269	35941	31
591	0.776	0.7	18.5	33.8	15.02	87	2.18	3.28	0.62	3.381	36529	31
592	0.836	0.876	28.5	22.7	6.31	86	0.1	0.07	-8.09	3.145	37036	31
593	0.842	0.874	23.5	32.3	9.21	76	0.24	0.09	-5.19	3.147	37940	31
594	0.814	0.783	19.5	34.1	12.25	72	0.5	0.33	-2.16	3.27	38281	31
595	0.853	0.783	13	33.9	15.04	99	1.47	2.25	0.63	3.269	40493	31
596	0.908	0.875	21	19.1	6.3	93	0.06	0.06	-8.11	3.145	41520	31
597	0.882	0.874	21	31.3	9.25	88	0.18	0.11	-5.16	3.146	41906	31

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
564	1996	1.604	7.01	69.9	110	105	92	916	1061	90.2	0.08	29.15
565	1996	0.96	11.61	69	96	92	90	866	1010	90.3	0.05	29.15
566	1996	0.492	37.6	76.5	155	149	92	898	992	89.2	0.14	29.14
567	1996	0.41	59.93	82.2	221	212	104	920	1002	88.2	0.26	29.14
568	1996	0.392	75.98	83.9	271	259	167	921	1043	87.4	0.38	29.14
569	1996	0.366	102.2	85.5	341	323	199	931	1070	86.2	0.6	29.14
570	1996	0.346	132.77	88.5	416	394	192	955	1084	85	0.9	29.14
571	1996	0.335	154.32	90	488	463	216	954	1100	84.1	1.25	29.13
572	1996	0.335	174.19	90.9	549	516	240	958	1118	83.6	1.57	29.13
573	1996	0.336	191.43	91.7	607	572	260	970	1144	82.5	1.97	29.14
574	1996	0.398	94.13	84.1	388	366	222	976	1125	86.8	0.79	29.14
575	1996	0.384	112.16	85.3	461	432	236	1008	1166	85.6	1.12	29.14
576	1996	0.357	139.34	86.4	536	501	261	964	1140	83.8	1.48	29.14
577	1996	0.348	157.2	86.9	602	564	284	970	1166	82.6	1.9	29.14
578	1996	0.341	182.94	88.9	684	639	269	994	1172	81.4	2.53	29.14
579	1996	0.895	11.63	63	78	73	104	840	992	90.9	0.03	29.14
580	1996	0.465	37.51	73.6	133	124	97	853	946	90	0.09	29.14
581	1996	0.408	59.24	80.7	193	182	103	882	964	89.3	0.19	29.14
582	1996	0.375	80.43	82.3	244	229	154	879	990	88.6	0.3	29.14
583	1996	0.354	108.81	86.4	310	292	167	902	1017	87.4	0.48	29.14
584	1996	0.341	135.78	89.9	376	353	190	915	1041	85.7	0.69	29.14
585	1996	0.905	12.24	61	62	59	102	776	929	90.8	0.03	29.14
586	1996	0.36	84.07	82.3	203	191	132	833	936	89	0.24	29.14
587	1996	0.339	114.29	87.8	261	247	159	857	972	87.9	0.38	29.14
588	1996	0.74	16.61	61.8	50	53	73	732	890	91.9	0.03	29.32
589	1996	0.351	102.15	83.7	163	176	103	888	994	89.6	0.19	29.32
590	1996	0.639	18.02	60.6	45	48	70	732	885	91.6	0.03	29.32
591	1996	0.369	101.18	83.8	149	162	94	869	971	89.6	0.15	29.32
592	1996	0.551	20.56	56.2	34	36	70	692	839	91.6	0.02	29.32
593	1996	0.387	52.1	66.8	60	65	62	752	878	90.8	0.05	29.32
594	1996	0.366	81.4	76.1	90	98	62	800	917	89.8	0.15	29.32
595	1996	0.369	112.39	86.6	121	130	88	891	994	90.3	0.21	29.33
596	1996	0.654	17.16	52.3	25	27	73	579	737	91.6	0	29.33
597	1996	0.4	48.96	63.3	44	48	66	658	790	90.9	0.09	29.33

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
564	62.97	0.3	16.7	0.72	60.3	1051	942	949	944	927	954	168
565	62.68	0.299	16.7	0.72	61.3	996	898	899	891	878	915	163
566	61.63	0.294	16.7	0.7	70.1	976	905	924	913	892	910	162
567	62.26	0.289	16.73	0.66	69.7	956	899	919	913	889	906	170
568	60.96	0.286	16.73	0.66	75.2	1001	942	957	953	936	943	178
569	58.03	0.283	16.73	0.66	75.2	1015	970	983	979	962	962	186
570	54.16	0.28	16.73	0.66	76.1	1009	983	990	994	977	965	177
571	52.89	0.28	16.73	0.65	80.1	1026	1006	1009	1015	997	980	186
572	49.52	0.282	16.73	0.65	82.1	1048	1031	1033	1037	1017	999	181
573	48.29	0.28	16.73	0.65	81	1076	1066	1063	1064	1044	1024	181
574	48.06	0.29	16.73	0.66	74.9	1081	1030	1045	1033	1021	1022	176
575	48.65	0.285	16.73	0.66	81.3	1116	1073	1084	1076	1060	1055	181
576	49	0.28	16.73	0.65	81.3	1082	1054	1061	1056	1041	1034	183
577	48.15	0.278	16.73	0.65	80.4	1106	1082	1087	1084	1068	1058	187
578	47.95	0.276	16.73	0.65	80.9	1113	1095	1096	1095	1076	1063	181
579	47.43	0.302	16.73	0.72	60.9	959	880	897	881	853	901	160
580	47.38	0.298	16.73	0.7	67.5	931	867	891	876	852	868	147
581	46.02	0.294	16.73	0.66	67	915	869	888	882	855	864	158
582	45.83	0.29	16.66	0.65	66.1	942	890	908	904	880	886	168
583	45.61	0.286	16.66	0.65	77	951	916	929	929	905	899	178
584	45.52	0.281	16.66	0.65	77.5	965	942	946	953	930	915	174
585	45.99	0.296	16.66	0.72	65.1	914	836	832	858	824	851	140
586	46.4	0.291	16.66	0.65	71.1	888	841	859	854	829	828	135
587	46.75	0.287	16.66	0.65	79.5	906	873	885	885	860	850	156
588	29.47	0.335	16.37	0.79	76.3	883	816	852	839	803	840	103
589	29.99	0.321	16.37	0.75	81.3	937	887	909	901	873	872	130
590	29.47	0.325	16.37	0.8	77.5	886	811	841	830	797	812	111
591	29.81	0.317	16.37	0.72	81.6	917	870	892	882	853	848	107
592	29.73	0.322	16.37	0.89	69.4	844	767	783	801	764	793	95
593	29.85	0.319	16.37	0.89	68.7	863	802	822	820	796	826	89
594	30.62	0.315	16.37	0.8	72.5	858	811	838	841	800	801	92
595	29.59	0.316	16.35	0.8	76.8	909	870	898	897	864	851	127
596	29.69	0.322	16.35	0.89	61.2	747	680	700	720	692	680	74
597	29.92	0.321	16.35	0.89	65.6	792	733	770	764	729	720	75

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
564	182	208	104	72	62.7	0.3568	1.17	2729	852.2	7.99	65.4	7.03
565	180	204	103	71	55	0.3096	1.01	2261	655.1	8	100.1	6.93
566	183	206	98	72	53.4	0.524	1.74	1334	413.5	7.84	454.8	7.12
567	185	209	98	72	51.8	0.7056	2.61	1304	368.6	7.3	342.6	8.01
568	187	214	110	73	49.7	0.8675	3.35	1136	351.7	7.31	362.2	7.98
569	192	219	107	75	47.5	1.0994	4.48	986	340.8	7.33	531.1	7.96
570	187	222	106	74	46.3	1.3614	5.85	821	346.5	7.32	915.2	7.96
571	194	226	107	74	45	1.5441	7.25	872	334.9	7.15	726.3	8.22
572	190	228	106	77	43.9	1.7157	8.5	867	326.8	7.13	635.2	8.27
573	190	228	104	76	43.5	1.9015	9.95	909	318.7	7.11	498.5	8.29
574	186	224	106	76	55	1.226	5.3	1009	352.6	7.28	264.6	8.02
575	190	225	105	78	54.6	1.4427	6.62	876	342.8	7.27	200	8.07
576	191	228	107	79	52.8	1.6901	8.27	800	334.9	7.14	425.1	8.26
577	195	233	107	78	50.9	1.8784	9.69	707	327.2	7.16	415.5	8.24
578	191	233	106	79	50.8	2.1512	11.75	720	328	7.13	505.4	8.28
579	179	207	107	78	47.7	0.252	0.84	2264	644	7.96	69.7	6.99
580	181	202	106	78	47.7	0.4302	1.47	1361	411.2	7.79	404.5	7.21
581	182	204	105	78	46.3	0.6056	2.25	1445	384.1	7.12	209.6	8.28
582	185	207	101	77	44.4	0.761	2.97	1276	358.3	7.13	341.6	8.27
583	189	212	102	77	42.5	0.9878	3.99	1085	343.4	7.17	559.5	8.21
584	187	215	104	77	41.3	1.2021	5.09	1075	347.2	7.16	776.7	8.23
585	178	204	109	78	39.4	0.2293	0.68	3745	595.5	7.75	77	7.26
586	181	201	103	77	37.6	0.6365	2.38	1236	356.4	7.16	394.7	8.23
587	183	204	105	76	35.9	0.8249	3.23	1080	357.9	7.16	717.5	8.23
588	177	198	110	45	33.6	0.1943	0.42	1497	559.1	9.14	304.7	5.15
589	182	201	96	43	31.5	0.6026	1.78	518	242.2	8.68	3642.4	5.74
590	178	198	106	41	30.4	0.1738	0.34	1894	561.8	9.2	463.7	5
591	181	197	90	40	28.6	0.5769	1.62	598	280.1	8.32	1707.1	6.43
592	178	195	108	41	23.1	0.1374	0.32	3453	580.4	10.17	889	3.27
593	181	194	87	42	23	0.2483	0.43	905	398.8	10.31	3446	2.88
594	181	195	80	42	22.3	0.3679	0.74	600	247	9.3	3444.8	4.67
595	179	202	99	43	21	0.5116	1.18	548	163.4	9.32	4589.8	4.55
596	179	188	123	43	18.5	0.1105	0.27	3347	582.6	9.99	208.4	3.51
597	181	189	101	42	18	0.1917	0.5	844	299.1	10.31	2533.7	2.82

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
598	94.29	2.67	0.52	0.3	1.04	1.19	337.16	45.9	0.0015	16.73	650	370.5
599	94.29	2.67	0.52	0.3	1.04	1.19	487.82	65.4	0.0015	23.52	649	529.4
600	95.06	2.24	0.32	0.18	0.98	1.21	1701.4	168.9	0.0019	67.08	1945	456.1
601	95.06	2.24	0.32	0.18	0.98	1.21	1702.7	159.6	0.0019	67.32	1944	431.2
602	95.06	2.24	0.32	0.18	0.98	1.21	2016.8	208.6	0.002	78.73	1948	562.5
603	95.06	2.24	0.32	0.18	0.98	1.21	2024.5	197.1	0.002	79.57	1948	531.5
604	95.06	2.24	0.32	0.18	0.98	1.21	2306.4	247.3	0.0019	88.67	1944	668.3
605	95.06	2.24	0.32	0.18	0.98	1.21	2310.1	239.7	0.0019	90.09	1944	647.4
606	95.05	2.26	0.34	0.19	1.01	1.17	2587.3	285.5	0.002	100.5	1946	770.5
607	95.05	2.26	0.34	0.19	1.01	1.17	2605.6	269	0.0019	101.17	1942	727.7
608	95.05	2.26	0.34	0.19	1.01	1.17	2965.5	335.7	0.002	114.37	1948	905.2
609	95.05	2.26	0.34	0.19	1.01	1.17	2951.1	320.2	0.0021	114.99	1948	863.4
610	95.05	2.26	0.34	0.19	1.01	1.17	397.98	15.4	0.0017	17.03	1726	46.7
611	95.05	2.26	0.34	0.19	1.01	1.17	397.68	15.4	0.0017	17.4	1674	48.3
612	95.15	2.2	0.33	0.18	1	1.14	682.76	59.6	0.0017	29.36	1708	183.3
613	95.15	2.2	0.33	0.18	1	1.14	689.03	58	0.0017	29.62	1705	178.7
614	95.15	2.2	0.33	0.18	1	1.14	980.34	97.4	0.0018	39.64	1694	302
615	95.15	2.2	0.33	0.18	1	1.14	989.67	95.1	0.0018	39.7	1692	295.1
616	94.18	2.83	0.55	0.33	1.28	0.83	1184.9	115.3	0.0027	46.39	1694	357.6
617	94.18	2.83	0.55	0.33	1.28	0.83	1213.9	115.3	0.0028	47.68	1688	358.9
618	94.18	2.83	0.55	0.33	1.28	0.83	1512.6	160.1	0.0028	59.93	1696	495.8
619	94.18	2.83	0.55	0.33	1.28	0.83	1526.7	154.7	0.0026	60.32	1691	480.5
620	95.53	2.14	0.3	0.19	1.47	0.37	1841	203.7	0.0027	71.22	1697	630.5
621	95.53	2.14	0.3	0.19	1.47	0.37	1852.9	193.8	0.0027	71.61	1698	599.7
622	95.53	2.14	0.3	0.19	1.47	0.37	2118.9	239.9	0.0028	81.42	1698	742.1
623	95.53	2.14	0.3	0.19	1.47	0.37	2228.3	246.1	0.0028	85.76	1696	761.8
624	95.53	2.14	0.3	0.19	1.47	0.37	2359.2	270.2	0.0028	90.36	1697	836.1
625	95.53	2.14	0.3	0.19	1.47	0.37	2377.3	258.1	0.0028	90.83	1691	801.5
626	95.53	2.14	0.3	0.19	1.47	0.37	2667.5	307.1	0.003	102.47	1703	947
627	95.53	2.14	0.3	0.19	1.47	0.37	2669.9	293	0.003	103.75	1698	906.3
628	95.48	2.14	0.26	0.16	1.54	0.43	346.28	16.6	0.0029	15.06	1504	58
629	95.48	2.14	0.26	0.16	1.54	0.43	348.63	15.8	0.0029	15.18	1506	55
630	95.48	2.14	0.26	0.16	1.54	0.43	604.3	56.2	0.0029	26.32	1508	195.6
631	95.48	2.14	0.26	0.16	1.54	0.43	613.87	54.5	0.003	26.38	1511	189.4

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
598	0.811	0.783	16	34.3	12.17	80	0.44	0.39	-2.24	3.269	42262	31
599	0.788	0.734	16	34.8	15.03	75	1.16	1.84	0.63	3.336	42731	31
600	0.646	0.607	26	31.4	18.21	105	8.76	12.28	3.83	3.504	51060	31
601	0.648	0.607	21	29.6	18.23	104	8.7	12.3	3.85	3.505	51434	31
602	0.64	0.602	24	33.1	21.3	105	10.69	14.29	6.93	3.511	52291	31
603	0.644	0.602	19	30.9	21.32	105	10.64	14.32	6.94	3.51	52567	31
604	0.63	0.599	24.5	34.8	24.03	104	12.76	16.71	9.66	3.514	53229	31
605	0.639	0.598	19.5	33.2	24.21	105	12.76	16.76	9.84	3.515	53692	31
606	0.636	0.598	23	35.5	27.14	110	15.19	19.99	12.77	3.516	54316	31
607	0.636	0.594	18	33.2	26.92	106	14.9	19.69	12.55	3.521	54793	31
608	0.632	0.589	24	36.6	30.16	107	16.14	17.77	15.79	3.528	55868	31
609	0.638	0.589	19	34.8	30.19	108	16.15	17.84	15.82	3.528	56372	31
610	0.701	0.677	30	11.3	6.27	94	0.58	0.47	-8.1	3.411	57385	31
611	0.717	0.671	25	11.1	6.38	91	0.56	0.44	-7.99	3.419	57655	31
612	0.705	0.659	29	25.3	9.21	81	1.12	0.92	-5.17	3.436	58207	31
613	0.705	0.661	24	24.4	9.24	77	1.14	0.99	-5.14	3.433	58504	31
614	0.663	0.626	30	30.7	12.2	79	1.97	2	-2.18	3.48	58906	31
615	0.658	0.623	25	29.9	12.29	81	2	2.11	-2.09	3.483	59146	31
616	0.64	0.612	29	31.1	14.79	105	5.12	7.22	0.42	3.497	32667	32
617	0.642	0.612	24	30.3	15.19	104	5.42	7.84	0.83	3.497	32959	32
618	0.647	0.609	26	33.4	18.38	105	6.96	9.64	4.02	3.501	33703	32
619	0.646	0.608	21	32.1	18.52	106	7.02	9.81	4.16	3.503	33937	32
620	0.635	0.603	24	35.7	21.51	105	7.89	9.86	7.15	3.509	34539	32
621	0.634	0.606	19	33.8	21.53	106	7.89	9.9	7.17	3.506	34924	32
622	0.63	0.601	24	36.7	24.43	108	9.7	12.13	10.07	3.512	35378	32
623	0.631	0.6	19	35.8	25.42	106	10.37	13.07	11.06	3.513	35655	32
624	0.628	0.598	23	37.3	27.13	107	11.53	14.53	12.76	3.516	36591	32
625	0.627	0.598	18	35.4	27.14	106	11.48	14.62	12.78	3.516	36790	32
626	0.63	0.594	23	37.4	30.29	109	14.16	17.65	15.92	3.521	37256	32
627	0.638	0.592	18	35.2	30.42	111	14.2	17.81	16.05	3.523	37474	32
628	0.712	0.674	30	13.8	6.37	92	0.41	0.36	-8	3.416	39245	32
629	0.713	0.675	25	13	6.36	86	0.41	0.36	-8.01	3.414	39614	32
630	0.713	0.66	29.5	26.7	9.36	80	0.81	0.71	-5.01	3.434	40157	32
631	0.703	0.659	24.5	25.8	9.35	78	0.82	0.74	-5.01	3.435	40548	32

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
598	1996	0.365	76.74	73.2	69	75	64	731	851	90.2	0.12	29.33
599	1996	0.36	109.66	84.9	100	109	79	786	887	89.5	0.11	29.33
600	1996	0.397	94.48	85.1	366	379	195	976	1124	87.3	0.81	29.27
601	1996	0.422	89.32	85	365	379	194	1015	1163	87.2	0.84	29.27
602	1996	0.377	116.51	86.1	440	449	212	998	1154	85.8	1.16	29.26
603	1996	0.404	110.09	86.3	440	451	212	1039	1199	85.9	1.2	29.26
604	1996	0.359	138.43	87.2	498	513	229	988	1160	84.9	1.5	29.26
605	1996	0.376	134.1	86.9	504	514	233	1027	1203	84.8	1.59	29.26
606	1996	0.352	159.62	87.4	566	576	257	997	1189	83.8	1.99	29.26
607	1996	0.376	150.75	88.3	560	580	253	1047	1236	84	2.07	29.26
608	1996	0.341	187.52	89.6	643	660	242	1013	1185	82.6	2.63	29.26
609	1996	0.359	178.86	89.3	650	657	245	1061	1230	82.9	2.77	29.25
610	1996	1.109	9.68	64.2	85	89	76	879	1032	91.1	0.06	29.25
611	1996	1.129	10.01	64.7	85	89	74	881	1035	91	0.06	29.26
612	1996	0.493	37.96	74	145	152	75	912	1006	89.9	0.15	29.26
613	1996	0.511	37.01	74.1	145	153	73	932	1030	89.8	0.14	29.26
614	1996	0.407	62.57	80.3	205	218	83	935	1017	89	0.27	29.26
615	1996	0.417	61.13	80.9	207	220	84	953	1041	88.9	0.27	29.26
616	1996	0.402	74.08	83.7	255	264	151	923	1042	88.7	0.37	29.24
617	1996	0.413	74.36	83.8	263	270	158	939	1066	88.7	0.4	29.24
618	1996	0.374	102.7	86.1	332	337	176	946	1077	86.9	0.63	29.24
619	1996	0.39	99.53	86.5	334	340	178	976	1112	86.7	0.65	29.24
620	1996	0.35	130.62	89.4	402	410	175	976	1102	85.8	0.94	29.25
621	1996	0.369	124.22	90	405	412	176	1015	1145	85.7	0.98	29.25
622	1996	0.339	153.73	90.9	462	472	195	976	1115	84.9	1.27	29.25
623	1996	0.349	157.82	91.6	485	496	198	1002	1146	84.6	1.42	29.25
624	1996	0.334	173.2	91.1	516	525	216	985	1138	84.6	1.62	29.26
625	1996	0.352	166.04	91.9	517	529	215	1021	1177	84.4	1.68	29.25
626	1996	0.334	196.17	92.3	588	594	244	981	1153	83.3	2.05	29.25
627	1996	0.354	187.75	92.6	589	594	245	1021	1194	83.2	2.13	29.25
628	1996	0.906	12.02	63	75	77	78	813	987	90.5	0.04	29.26
629	1996	0.963	11.39	62.8	75	78	78	835	1007	90.3	0.03	29.26
630	1996	0.469	40.52	73.1	130	135	78	871	967	89.1	0.11	29.25
631	1996	0.484	39.23	73.9	134	137	80	884	985	89.1	0.11	29.25

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
598	30.03	0.318	16.35	0.8	70.5	817	772	800	800	754	744	79
599	30.24	0.315	16.35	0.75	76.1	812	780	800	799	760	745	85
600	25.12	0.304	16.39	0.64	74.4	1077	1023	1038	1026	1022	1019	179
601	25.23	0.305	16.39	0.64	74.4	1123	1063	1076	1065	1055	1051	174
602	25.36	0.306	16.39	0.64	82.1	1102	1060	1067	1063	1050	1043	171
603	25.37	0.306	16.39	0.64	81.2	1145	1101	1108	1106	1092	1083	174
604	24.6	0.307	16.39	0.64	81.6	1102	1070	1075	1072	1058	1052	177
605	24.99	0.307	16.39	0.64	81.6	1146	1112	1116	1115	1097	1088	179
606	24.97	0.307	16.38	0.64	80.4	1128	1102	1105	1104	1091	1077	185
607	25.48	0.307	16.38	0.64	80.6	1178	1149	1152	1152	1134	1117	183
608	25.17	0.307	16.38	0.64	80.7	1126	1104	1105	1106	1086	1073	182
609	25.14	0.309	16.38	0.64	80.7	1179	1154	1154	1149	1129	1114	175
610	28.06	0.324	16.38	0.69	60.7	1021	915	923	908	894	927	117
611	28.29	0.321	16.38	0.69	60.7	1038	926	923	906	902	933	116
612	28.4	0.312	16.39	0.68	69.4	993	918	939	922	904	918	135
613	28.02	0.31	16.39	0.68	69.8	1024	942	961	944	926	941	143
614	28.33	0.305	16.39	0.65	69.5	971	912	931	927	903	915	155
615	28.76	0.305	16.39	0.65	69.5	999	936	952	948	923	936	157
616	50.85	0.309	16.34	0.64	74.2	1003	945	960	950	935	940	163
617	51.13	0.309	16.34	0.64	75	1030	968	983	973	956	960	163
618	49.48	0.304	16.34	0.64	75	1017	977	990	985	965	964	168
619	48.03	0.304	16.34	0.64	75	1056	1010	1023	1020	996	993	170
620	49.25	0.299	16.41	0.64	76.2	1030	1000	1007	1014	994	979	175
621	49.07	0.301	16.41	0.64	76.2	1073	1038	1044	1058	1033	1011	175
622	50.5	0.301	16.41	0.64	80	1043	1019	1022	1030	1011	991	163
623	51.33	0.302	16.41	0.64	80	1074	1047	1050	1059	1039	1015	163
624	51.85	0.307	16.41	0.64	82	1070	1047	1048	1057	1036	1014	167
625	52.26	0.307	16.41	0.64	82	1112	1084	1086	1094	1070	1048	168
626	53.14	0.304	16.41	0.64	81	1087	1073	1068	1072	1054	1036	173
627	52.44	0.304	16.41	0.64	81	1136	1116	1113	1112	1093	1071	173
628	56.06	0.316	16.36	0.69	60.9	960	866	862	874	849	879	89
629	55.89	0.313	16.36	0.69	60.9	986	890	896	888	864	895	90
630	54	0.306	16.36	0.69	69.1	944	884	904	893	868	883	101
631	54.87	0.304	16.36	0.68	67.5	972	906	926	910	885	898	103

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
598	180	191	89	41	17.9	0.2793	0.61	668	255.9	9.27	2653.6	4.69
599	181	194	83	41	17.3	0.3971	0.9	633	225.1	8.69	4106.7	5.68
600	189	221	102	53	56.3	1.1728	5.06	1015	353.8	7.16	267.5	8.27
601	185	222	102	52	56.6	1.173	5.1	1005	362.8	7.16	120.7	8.27
602	185	223	102	56	55.8	1.3684	6.52	882	340.9	7.16	243.4	8.27
603	185	224	102	55	55.7	1.3801	6.53	861	344.2	7.16	123.6	8.27
604	188	227	101	53	54.1	1.534	7.8	755	329.6	7.16	360.3	8.27
605	189	228	102	56	53.9	1.5592	8.02	745	322.4	7.18	182.7	8.24
606	194	232	105	57	52	1.7388	9.6	636	319.2	7.18	383.8	8.24
607	192	231	102	52	52.5	1.7495	9.45	656	308.8	7.18	171.3	8.25
608	191	235	102	54	50.8	1.9796	11.57	671	314.5	7.15	580.3	8.28
609	187	232	103	59	52.2	1.9791	11.7	694	308.6	7.17	245.7	8.32
610	178	202	98	51	57.8	0.2792	0.91	1948	699.8	7.89	58.7	7.24
611	178	201	96	50	56.1	0.2877	0.91	1910	706.8	7.8	43	7.38
612	181	205	87	49	54.9	0.4999	1.62	1308	431.6	7.73	246.9	7.43
613	181	206	84	47	54.6	0.5083	1.65	1251	417.8	7.73	130.5	7.42
614	182	208	83	45	52.9	0.6897	2.46	1224	366.3	7.32	286.5	8.07
615	182	209	84	45	52.5	0.6921	2.49	1220	372.3	7.31	149.3	8.09
616	181	210	103	52	50.6	0.7989	3.22	1323	371.2	7.18	236.9	8.35
617	182	210	103	55	50.4	0.8211	3.36	1291	378	7.17	129.9	8.36
618	185	215	103	58	48.4	1.0466	4.51	1067	349.2	7.19	298	8.34
619	185	215	103	57	48.3	1.0546	4.58	1038	349.6	7.19	143.5	8.33
620	187	219	103	56	46.8	1.2637	5.83	933	338.3	7.18	380.2	8.34
621	187	219	103	57	47	1.2629	5.91	928	333.2	7.19	166.6	8.35
622	182	219	104	56	46.4	1.4359	7.1	929	333.4	7.17	487	8.37
623	182	218	102	55	46.5	1.5103	7.63	949	322.1	7.17	212.2	8.37
624	185	221	103	57	45.2	1.5643	8.31	943	323.1	7.17	452.7	8.37
625	186	221	102	55	45.1	1.5729	8.38	1020	313.2	7.16	199.6	8.39
626	187	224	104	59	44.2	1.7889	10.08	862	317.5	7.16	510.5	8.39
627	187	225	106	59	44	1.8123	10.07	1055	306.3	7.15	229.7	8.41
628	180	198	99	53	49.5	0.253	0.84	3096	694.5	7.63	43.2	7.67
629	180	198	95	53	49.6	0.2574	0.85	2080	712.2	7.79	33	7.43
630	181	201	87	53	47.8	0.4571	1.49	1391	427.8	7.71	260.1	7.45
631	181	201	85	56	47.8	0.4609	1.52	1371	427.7	7.69	130.1	7.49

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
632	95.48	2.14	0.26	0.16	1.54	0.43	854.63	88.3	0.003	35.03	1494	310.3
633	95.48	2.14	0.26	0.16	1.54	0.43	862.31	85.9	0.003	34.96	1492	302.5
634	95.25	2.24	0.29	0.17	1.62	0.43	1052.9	108.4	0.0029	40.92	1504	378.5
635	95.25	2.24	0.29	0.17	1.62	0.43	1082.2	107.6	0.0029	41.66	1502	376.4
636	95.25	2.24	0.29	0.17	1.62	0.43	1352.9	151.5	0.0028	53.06	1496	532
637	95.25	2.24	0.29	0.17	1.62	0.43	1361	145.8	0.0029	53.21	1496	511.9
638	95.13	2.32	0.33	0.19	1.6	0.43	1623.9	188	0.003	63.57	1499	658.5
639	95.13	2.32	0.33	0.19	1.6	0.43	1636.5	180.8	0.003	63.67	1498	633.9
640	95.13	2.32	0.33	0.19	1.6	0.43	2140.1	251.2	0.0031	80.71	1505	876.6
641	95.13	2.32	0.33	0.07	1.6	0.43	2130.6	241	0.0031	81.06	1506	840.4
642	94.85	2.56	0.36	0.21	1.61	0.41	2627.5	307.9	0.0031	100.7	1492	1083.7
643	94.85	2.56	0.36	0.21	1.61	0.41	2638.4	287.6	0.0031	100.89	1487	1015.7
644	94.85	2.56	0.36	0.21	1.61	0.41	262.31	12.8	0.0031	11.75	1250	53.6
645	94.85	2.56	0.36	0.21	1.61	0.41	257.85	12.7	0.0031	12.06	1239	53.7
646	94.85	2.56	0.36	0.21	1.61	0.41	887.44	97.6	0.003	35.86	1248	410.7
647	94.85	2.56	0.36	0.21	1.61	0.41	906.73	96.6	0.003	36.42	1249	406.4
648	94.85	2.56	0.36	0.21	1.61	0.41	1132.6	131.5	0.0031	44.87	1243	555.6
649	94.85	2.56	0.36	0.21	1.61	0.41	1148.4	127.2	0.0031	45.06	1260	530.3
650	94.91	2.53	0.36	0.2	1.56	0.45	230.55	18.8	0.003	12.97	1121	88.1
651	94.91	2.53	0.36	0.2	1.56	0.45	230.97	18.6	0.0029	13.08	1122	87.1
652	94.91	2.53	0.36	0.2	1.56	0.45	774.06	97.2	0.0031	34.24	1108	461
653	94.91	2.53	0.36	0.2	1.56	0.45	794.02	97.6	0.003	34.53	1109	461.9
654	94.91	2.53	0.36	0.2	1.56	0.45	210.82	16.2	0.003	9.89	999	85.2
655	94.91	2.53	0.36	0.2	1.56	0.45	211.23	15.9	0.003	9.86	991	84.3
656	94.91	2.53	0.36	0.2	1.56	0.45	707.96	91.6	0.003	33.62	1008	477.6
657	94.91	2.53	0.36	0.2	1.56	0.45	713.23	91.3	0.003	33.82	1007	476.4
658	94.86	2.53	0.36	0.2	1.53	0.52	149.9	12.7	0.003	7.66	799	83.2
659	94.86	2.53	0.36	0.2	1.53	0.52	149.32	12.6	0.003	7.64	797	83.3
660	94.86	2.53	0.36	0.2	1.53	0.52	280.42	34.9	0.0029	13.5	794	230.6
661	94.86	2.53	0.36	0.2	1.53	0.52	279.58	35.1	0.0029	13.55	796	231.7
662	94.86	2.53	0.36	0.2	1.53	0.52	424.94	55.7	0.003	20.45	800	365.7
663	94.86	2.53	0.36	0.2	1.53	0.52	429.01	55.9	0.003	20.51	800	366.8
664	94.84	2.52	0.39	0.22	1.45	0.58	581.5	75.7	0.003	27.93	799	498
665	94.84	2.52	0.39	0.22	1.45	0.58	588.22	74.9	0.003	28.39	798	492.9

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
632	0.671	0.627	29.5	31.5	12.3	83	1.44	1.52	-2.06	3.478	41024	32
633	0.663	0.626	24.5	30.7	12.36	85	1.48	1.61	-2.01	3.479	41254	32
634	0.635	0.613	28	33.2	14.8	105	3.93	5.86	0.44	3.496	41901	32
635	0.629	0.612	23	32.4	15.17	104	4.14	6.42	0.81	3.497	42167	32
636	0.64	0.61	26	35.8	18.26	103	4.9	6.9	3.9	3.5	42584	32
637	0.638	0.611	21	34.3	18.3	104	4.89	6.95	3.93	3.499	42791	32
638	0.639	0.61	24	37	21.33	105	6.34	9.14	6.99	3.5	47124	32
639	0.636	0.609	19	35.6	21.36	105	6.36	9.19	7.01	3.502	47661	32
640	0.616	0.601	23	39	27.27	108	9.86	14.36	12.92	3.513	48167	32
641	0.621	0.602	23	37.2	27.1	107	9.72	14.21	12.75	3.51	48517	32
642	0.626	0.595	20	38.3	33.42	110	14.32	20.56	19.08	3.52	49105	32
643	0.624	0.594	15	35.7	33.3	110	14.25	20.43	18.96	3.521	49255	32
644	0.731	0.671	29.5	13.6	6.31	100	0.3	0.25	-8.03	3.419	49771	32
645	0.763	0.681	24.5	13.2	6.33	100	0.3	0.24	-8.01	3.406	49969	32
646	0.66	0.615	26	34.1	15.07	102	3	4.22	0.74	3.493	50835	32
647	0.656	0.615	20.5	33.2	15.35	101	3.17	4.6	1.01	3.493	51003	32
648	0.647	0.616	24	36.7	18.26	101	4.5	6.69	3.92	3.492	51292	32
649	0.641	0.613	19	35.4	18.23	100	4.68	7.14	3.9	3.497	51604	32
650	0.919	0.772	29.5	18.2	6.32	97	0.24	0.19	-8.01	3.285	52562	32
651	0.926	0.77	24.5	17.8	6.3	94	0.24	0.19	-8.03	3.287	52832	32
652	0.723	0.679	24.5	35.6	15	103	2.52	3.68	0.66	3.41	53675	32
653	0.711	0.678	19.5	35.4	15.15	104	2.61	3.9	0.82	3.41	53960	32
654	0.767	0.736	29.5	20.5	6.44	95	0.19	0.17	-7.89	3.333	54519	32
655	0.763	0.737	24.5	20.2	6.46	93	0.19	0.16	-7.87	3.331	54814	32
656	0.776	0.7	23.5	34.1	15	97	2.15	3.18	0.67	3.381	55645	32
657	0.775	0.7	18.5	33.8	15.08	101	2.19	3.28	0.75	3.381	55908	32
658	0.834	0.782	29	20.7	6.31	97	0.12	0.13	-8.02	3.271	56633	32
659	0.835	0.787	24	20.7	6.29	93	0.12	0.13	-8.04	3.264	56946	32
660	0.786	0.788	26	32.4	9.27	81	0.23	0.16	-5.07	3.262	57939	32
661	0.792	0.785	21	32.4	9.27	79	0.23	0.17	-5.07	3.266	58195	32
662	0.786	0.735	24	34.1	12.24	77	0.48	0.35	-2.1	3.333	58656	32
663	0.781	0.736	19	34.1	12.24	77	0.49	0.37	-2.09	3.333	58942	32
664	0.785	0.702	16	33.9	15.05	90	1.56	2.12	0.72	3.379	59686	32
665	0.789	0.702	11	33	15.21	94	1.64	2.31	0.88	3.378	60009	32

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
632	1996	0.397	64.27	79.5	185	190	87	901	985	88.4	0.21	29.25
633	1996	0.407	62.66	80.1	186	192	88	919	1008	88.4	0.21	29.25
634	1996	0.377	78.41	83.8	228	234	140	899	1012	88.5	0.3	29.25
635	1996	0.387	77.98	84	237	241	147	921	1042	88.3	0.32	29.25
636	1996	0.35	110.2	87.5	294	301	147	926	1035	87.6	0.5	29.24
637	1996	0.365	106.04	88	293	303	145	957	1074	87.6	0.51	29.24
638	1996	0.338	136.4	90.1	353	361	168	943	1065	86.9	0.72	29.21
639	1996	0.352	131.3	90.7	359	364	171	978	1103	87	0.74	29.21
640	1996	0.321	181.59	92.8	465	476	215	949	1102	85.5	1.26	29.21
641	1996	0.336	174.09	92.7	466	474	214	987	1139	85.6	1.3	29.21
642	1996	0.327	224.48	94	576	585	267	955	1145	84	1.96	29.2
643	1996	0.351	210.4	95.1	579	587	265	1000	1190	84.1	2.06	29.2
644	1996	0.921	11.11	59	57	58	91	795	942	91.8	0.03	29.21
645	1996	0.951	11.13	58.4	56	57	86	775	944	91.6	0.03	29.2
646	1996	0.367	85.07	83.3	190	198	118	863	965	89.8	0.26	29.19
647	1996	0.377	84.18	83.4	194	202	121	877	990	89.8	0.27	29.19
648	1996	0.341	115.09	88	242	252	143	876	990	89.2	0.38	29.18
649	1996	0.354	109.85	87.8	246	256	150	904	1026	89.2	0.4	29.18
650	1996	0.69	18.25	58.4	50	51	79	743	915	91	0.02	29.18
651	1996	0.703	18.04	58.3	50	51	78	745	925	90.9	0.03	29.17
652	1996	0.352	95.49	83	167	172	113	871	972	88.7	0.19	29.18
653	1996	0.354	95.67	84.1	170	177	114	887	994	88.6	0.19	29.18
654	1996	0.61	17.64	57.8	45	47	79	717	883	91	0.02	29.18
655	1996	0.62	17.47	57.9	45	47	78	710	885	90.9	0.01	29.17
656	1996	0.367	98.93	82.9	152	158	107	859	962	88.7	0.15	29.19
657	1996	0.37	98.68	83.7	154	159	110	876	982	88.7	0.15	29.19
658	1996	0.605	17.24	52.9	33	33	83	642	801	91.2	0.01	29.19
659	1996	0.604	17.26	52.6	33	33	82	628	802	91.1	0.01	29.18
660	1996	0.387	47.77	65.6	62	62	77	718	830	89.8	0.04	29.19
661	1996	0.386	47.99	65.1	62	62	77	726	840	89.9	0.05	29.18
662	1996	0.367	75.75	74.2	93	95	77	775	874	89.1	0.13	29.18
663	1996	0.367	75.99	74.8	94	96	77	789	890	89.4	0.15	29.18
664	1996	0.369	103.16	84.7	128	129	100	839	931	88.8	0.21	29.17
665	1996	0.379	102.11	85.5	129	131	102	865	962	89	0.22	29.18

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
632	53.2	0.3	16.36	0.65	66.8	932	886	901	898	872	876	111
633	53.22	0.3	16.36	0.65	67	960	907	922	919	891	897	114
634	49.52	0.303	16.33	0.64	66.2	961	911	925	922	902	905	127
635	49.26	0.303	16.33	0.64	66.9	993	941	954	950	928	931	131
636	51.67	0.302	16.33	0.64	77.2	964	932	941	943	921	917	141
637	53.43	0.303	16.33	0.64	77.7	996	959	970	979	955	960	144
638	54.68	0.308	16.33	0.64	77.4	984	961	966	975	953	939	157
639	58.19	0.309	16.33	0.64	77.5	1021	996	1001	1013	987	970	159
640	59.51	0.309	16.33	0.64	80.6	1024	1009	1008	1018	997	974	164
641	59.8	0.312	16.33	0.64	80.6	1062	1045	1045	1055	1029	1007	165
642	61.68	0.313	16.33	0.64	82	1076	1066	1061	1064	1046	1020	169
643	61.43	0.314	16.33	0.64	82.4	1126	1116	1111	1108	1090	1057	165
644	60.34	0.332	16.33	0.69	65.3	926	852	863	869	837	856	103
645	58.34	0.329	16.33	0.69	65.6	936	848	873	856	825	855	92
646	56.08	0.315	16.33	0.64	71.4	911	866	881	878	853	852	109
647	56.51	0.314	16.33	0.64	72.4	942	892	908	905	877	875	109
648	57.93	0.31	16.33	0.64	79	920	891	898	902	876	867	118
649	57.78	0.31	16.33	0.64	79	956	925	933	938	910	901	127
650	56.33	0.314	16.34	0.8	75.6	901	818	852	841	810	834	84
651	57.4	0.313	16.34	0.8	75.6	915	823	859	845	811	839	83
652	60.93	0.304	16.34	0.7	80.7	909	865	886	882	852	848	107
653	59.16	0.303	16.34	0.7	80.7	932	885	905	901	873	869	109
654	57.86	0.311	16.34	0.75	77.5	872	785	805	810	777	807	83
655	57.23	0.31	16.34	0.75	77.5	878	781	811	802	770	805	80
656	56.68	0.303	16.34	0.72	81.7	896	853	874	872	842	836	105
657	58.51	0.302	16.34	0.72	81.7	919	874	892	890	861	854	109
658	53.53	0.31	16.33	0.8	69.6	802	734	744	771	733	746	79
659	50.68	0.31	16.33	0.8	69.6	816	733	765	770	733	742	74
660	47.6	0.305	16.33	0.8	68.9	826	761	785	775	746	776	78
661	48.06	0.305	16.33	0.8	68.9	842	773	799	787	759	788	79
662	49.01	0.302	16.33	0.75	72.6	833	787	811	804	765	764	83
663	47.27	0.302	16.33	0.75	72.6	849	800	825	818	779	776	87
664	46.81	0.3	16.35	0.72	76.1	857	826	846	838	809	796	94
665	46.56	0.301	16.35	0.72	76.1	888	853	872	868	836	816	96

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
632	181	203	87	54	45.9	0.62	2.21	1308	383.8	7.32	278.9	8.08
633	181	204	89	53	45.8	0.6191	2.22	1303	386.3	7.32	136.9	8.09
634	181	206	103	55	44.8	0.7185	2.84	1257	372.1	7.15	245.7	8.35
635	181	207	102	57	44.7	0.7309	2.96	1285	377.5	7.13	118.5	8.34
636	182	209	102	55	43	0.9331	3.9	1097	359.1	7.17	446	8.31
637	182	210	102	53	43	0.932	3.89	1152	352.1	7.16	181.4	8.31
638	183	213	102	55	41.8	1.0976	4.96	1026	351.9	7.18	509.7	8.33
639	184	213	102	57	41.7	1.0936	5.05	1089	339.4	7.17	222	8.33
640	185	217	104	54	40	1.3871	7.22	1136	331.8	7.13	584	8.4
641	185	218	103	56	39.9	1.3791	7.18	1196	317.7	7.12	256	8.42
642	186	221	105	57	38.2	1.712	9.77	1315	309.2	7.09	465.9	8.44
643	184	221	104	57	38.3	1.709	9.81	1339	289.1	7.1	192.4	8.45
644	177	202	109	57	39.5	0.1882	0.64	3448	670.4	7.5	42.4	7.78
645	177	197	109	56	40.3	0.1946	0.64	2492	685.3	7.73	35.4	7.42
646	181	202	101	50	36.8	0.6047	2.3	1236	367.6	7.17	293.4	8.31
647	181	202	101	51	36.7	0.6168	2.34	1276	362.9	7.17	130.7	8.3
648	181	203	100	50	35.5	0.7678	3.09	1162	363.5	7.18	558.9	8.27
649	181	205	100	50	35.8	0.7714	3.12	1228	350.5	7.14	213.8	8.34
650	177	193	109	52	36	0.2197	0.55	1462	580.6	9.02	417.4	5.23
651	177	192	107	52	36.3	0.2223	0.55	1361	560.7	9.03	223	5.21
652	181	201	102	52	31.5	0.5989	1.94	770	354.4	7.98	1734.3	6.92
653	181	203	102	50	31.3	0.6052	1.98	795	340.5	7.97	1003.8	6.95
654	177	195	108	51	30.8	0.1691	0.43	2312	581.2	8.53	172.6	6.13
655	177	191	107	51	31.1	0.1687	0.42	1849	569.1	8.61	110.1	5.99
656	181	200	98	52	28.3	0.5898	1.72	701	315.1	8.26	2547.9	6.43
657	181	202	101	53	28	0.5942	1.75	726	310.2	8.26	1637.6	6.47
658	177	192	117	55	23.6	0.1312	0.38	3163	568.2	8.99	313.1	5.3
659	177	189	116	56	23.9	0.131	0.35	1969	568.8	9.11	192.5	5.11
660	181	193	93	58	22.8	0.2351	0.53	1003	403.3	9.23	2313.2	4.71
661	181	193	92	58	22.7	0.2361	0.6	1042	393.1	9.24	1391.7	4.8
662	181	195	87	58	22.4	0.3601	0.71	779	345.2	8.67	2752.8	5.78
663	180	196	86	58	22.4	0.3607	0.73	789	337.8	8.67	1869.1	5.8
664	180	199	94	57	21.8	0.4948	1.34	745	304.9	8.27	2230.6	6.42
665	181	199	97	57	21.7	0.5017	1.42	803	289.6	8.27	1347.8	6.47

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
666	94.84	2.52	0.39	0.22	1.45	0.58	114.22	8.1	0.0028	6.49	654	65.1
667	94.84	2.52	0.39	0.22	1.45	0.58	122.54	8.4	0.0028	6.93	657	67.2
668	94.84	2.52	0.39	0.22	1.45	0.58	211.82	26.9	0.0027	10.8	642	220.2
669	94.84	2.52	0.39	0.22	1.45	0.58	212.75	25.8	0.0028	10.9	644	210.8
670	94.84	2.52	0.39	0.22	1.45	0.58	330.2	43.3	0.0029	15.61	650	350.2
671	94.84	2.52	0.39	0.22	1.45	0.58	335.26	42.7	0.0028	15.9	651	344
672	94.84	2.52	0.39	0.22	1.45	0.58	475.37	62.6	0.0029	22.28	647	508
673	94.84	2.52	0.39	0.22	1.45	0.58	481.44	62.4	0.0029	22.66	648	505.5
674	93.79	2.89	0.81	0.61	1.31	0.58	2880.3	350.1	0.0072	114.89	1490	1233.9
675	93.79	2.89	0.81	0.61	1.31	0.58	2909.2	331.4	0.0072	115.57	1503	1157.8
676	93.79	2.89	0.81	0.61	1.31	0.58	1579	192	0.0074	64.72	1254	804.2
677	93.79	2.89	0.81	0.61	1.31	0.58	1563.5	185.6	0.0074	64.08	1251	779.1
678	93.79	2.89	0.81	0.61	1.31	0.58	2005	247.4	0.0075	80.08	1237	1050.6
679	93.79	2.89	0.81	0.61	1.31	0.58	1988.9	237.8	0.0073	79.01	1252	997.7
680	93.58	3.16	0.86	0.65	1.15	0.6	2376.9	298.3	0.0073	94.11	1247	1255.9
681	93.58	3.16	0.86	0.65	1.15	0.6	2401.6	281.4	0.0072	95.04	1231	1200.2
682	93.58	3.16	0.86	0.65	1.15	0.6	382.31	42.4	0.0073	18.27	1093	203.5
683	93.58	3.16	0.86	0.65	1.15	0.6	381.01	41.9	0.007	18.66	1101	199.8
684	93.58	3.16	0.86	0.65	1.15	0.6	576.35	73.3	0.0069	27.1	1102	349.3
685	93.58	3.16	0.86	0.65	1.15	0.6	581.93	73.5	0.007	27.43	1103	350.1
686	93.58	3.16	0.86	0.65	1.15	0.6	1164.3	158.4	0.007	52.03	1099	756.7
687	93.58	3.16	0.86	0.65	1.15	0.6	1188.6	159	0.0071	53.02	1100	758.7
688	93.58	3.16	0.86	0.65	1.15	0.6	1549.4	210.3	0.0068	67.64	1091	1012.3
689	93.58	3.16	0.86	0.65	1.15	0.6	1556.9	209.9	0.0068	68.43	1100	1002
690	93.58	3.16	0.86	0.65	1.15	0.6	1862.1	269.2	0.0066	84.14	1103	1281.4
691	93.58	3.16	0.86	0.65	1.15	0.6	1925.3	275.8	0.0065	86.74	1102	1314
692	93.58	3.16	0.86	0.65	1.15	0.6	1936.4	269.3	0.0066	87.34	1093	1294.1
693	93.58	3.16	0.86	0.65	1.15	0.6	1071.7	147.1	0.0064	48.75	1004	769.8
694	93.58	3.16	0.86	0.65	1.15	0.6	1090.9	144.1	0.0063	49.48	994	761.4
695	93.58	3.16	0.86	0.65	1.15	0.6	1242.8	184.2	0.0062	61.64	1000	967.2
696	93.58	3.16	0.86	0.65	1.15	0.6	1248.4	176.7	0.0059	62.6	1001	927.2
697	93.58	3.16	0.86	0.65	1.15	0.6	726.13	104.8	0.0061	37.39	802	686.1
698	93.58	3.16	0.86	0.65	1.15	0.6	769.78	102.8	0.0061	38.19	801	673.4
699	94.74	2.53	0.6	0.35	1.04	0.74	1319.6	133	0.0023	54.8	1949	358.5

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
666	0.929	0.787	18	15.6	6.4	93	0.09	0.12	-7.93	3.264	60639	32
667	0.925	0.787	13	15.2	6.65	92	0.09	0.12	-7.68	3.264	60861	32
668	0.833	0.782	17.5	31.2	9.41	86	0.2	0.18	-4.93	3.27	61377	32
669	0.838	0.783	12.5	29.7	9.42	84	0.21	0.19	-4.92	3.27	61572	32
670	0.773	0.736	15	34.7	12.26	81	0.47	0.44	-2.09	3.332	61992	32
671	0.775	0.732	10	33.6	12.39	79	0.51	0.49	-1.95	3.338	62227	32
672	0.766	0.702	15	35.1	15.14	79	1.24	1.84	0.8	3.378	62468	32
673	0.769	0.704	10	34.4	15.25	82	1.3	1.98	0.91	3.376	62733	32
674	0.653	0.6	20	38	37.02	106	17.07	24.17	22.54	3.514	34745	37
675	0.651	0.599	15	35.8	37.03	107	17.02	24.29	22.55	3.514	35137	37
676	0.671	0.617	23	37	24.1	96	7.3	10.43	9.63	3.491	36008	37
677	0.671	0.618	18	36.2	23.99	96	7.2	10.29	9.51	3.489	36577	37
678	0.654	0.613	21	38.6	30.63	102	10.93	17.2	16.15	3.497	37259	37
679	0.651	0.612	16	37.6	30.06	99	10.54	16.62	15.59	3.497	37700	37
680	0.651	0.61	20	39.4	36	103	14.22	22.7	21.52	3.5	38414	37
681	0.65	0.609	15	36.8	35.94	104	14.09	22.63	21.46	3.502	38851	37
682	0.785	0.704	29	28.8	9.09	93	0.43	0.28	-5.39	3.376	39490	37
683	0.805	0.706	24	27.9	8.98	89	0.44	0.27	-5.49	3.373	39939	37
684	0.773	0.7	27	33.6	12.04	85	0.93	0.8	-2.44	3.381	40348	37
685	0.774	0.699	22	33.3	12.07	83	0.96	0.88	-2.41	3.382	40730	37
686	0.734	0.678	23	37.9	20.89	95	5.08	8.08	6.41	3.41	41445	37
687	0.733	0.679	18	37.3	21.13	95	5.23	8.37	6.66	3.409	42066	37
688	0.717	0.676	20	38.7	26.93	97	7.97	13.21	12.46	3.413	42812	37
689	0.722	0.676	15	38.1	27.14	98	8.07	13.4	12.68	3.414	43152	37
690	0.743	0.714	16	39.8	32.32	101	10.83	18.66	17.88	3.363	48626	37
691	0.74	0.713	14	39.5	33.24	102	11.37	19.61	18.81	3.363	49639	37
692	0.741	0.713	11	38.4	33.25	102	11.35	19.61	18.82	3.363	49928	37
693	0.747	0.7	15	37.5	20.95	96	4.61	7.32	6.52	3.381	50725	37
694	0.745	0.7	10	36.2	21.26	98	4.72	7.64	6.83	3.381	51589	37
695	0.815	0.763	11	37.2	24.12	96	6.08	10.28	9.69	3.296	52816	37
696	0.824	0.761	6	35.1	24.13	96	6.05	10.29	9.7	3.299	53049	37
697	0.846	0.755	10	34.9	18.17	93	2.59	3.91	3.75	3.307	53715	37
698	0.815	0.745	5	33.5	18.78	94	2.89	4.56	4.36	3.321	53945	37
699	0.684	6.544	30	30.2	15.1	108	6.36	9.28	0.67	0.018	51596	44

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
666	1996	0.801	13.49	48.7	25	25	86	625	781	91.3	0.02	29.18
667	1996	0.825	13.91	49.8	27	27	85	624	799	91.2	0.03	29.19
668	1996	0.401	45.62	61.2	46	47	79	670	783	90.5	0.08	29.18
669	1996	0.422	43.68	61.1	46	47	79	682	803	90.4	0.08	29.19
670	1996	0.36	72.54	71.2	71	74	77	734	840	89.4	0.11	29.2
671	1996	0.373	71.27	71.2	73	75	78	762	872	89.4	0.11	29.2
672	1996	0.356	105.24	83	103	106	92	781	873	88.9	0.11	29.19
673	1996	0.363	104.71	83.9	104	107	96	806	903	89	0.11	29.19
674	1996	0.328	255.61	93.3	630	641	285	958	1164	82.4	2.05	29.47
675	1996	0.349	239.84	93.5	634	648	285	1021	1221	82.3	2.19	29.47
676	1996	0.337	166.59	91.8	345	351	179	913	1038	88.3	0.63	29.47
677	1996	0.345	161.4	91.7	342	348	178	951	1073	88.2	0.64	29.48
678	1996	0.324	217.64	93.9	442	446	240	914	1080	86.3	0.98	29.48
679	1996	0.332	206.67	93.3	435	443	233	957	1117	86.2	0.98	29.48
680	1996	0.316	260.17	94	523	529	282	901	1100	84.4	1.35	29.48
681	1996	0.338	248.62	96.6	527	535	280	952	1147	84.4	1.4	29.48
682	1996	0.431	42.16	68.1	85	85	83	806	900	91	0.12	29.48
683	1996	0.446	41.38	67.7	84	85	78	795	899	90.8	0.12	29.47
684	1996	0.37	72.37	75.6	128	128	82	840	932	90	0.16	29.47
685	1996	0.373	72.52	75.7	128	130	82	862	954	89.9	0.16	29.47
686	1996	0.328	156.76	89.5	257	259	163	904	1025	88.2	0.33	29.47
687	1996	0.334	157.16	90.2	265	265	169	924	1050	87.7	0.35	29.46
688	1996	0.322	209.7	93.2	346	345	216	920	1071	86.4	0.56	29.45
689	1996	0.326	207.56	92.4	349	347	218	952	1105	86.3	0.59	29.45
690	1996	0.313	265.44	93.1	424	415	272	952	1137	85	0.83	29.4
691	1996	0.315	272.19	93.8	441	429	282	969	1159	84.8	0.9	29.39
692	1996	0.324	268.07	95.3	443	431	281	998	1187	84.7	0.92	29.39
693	1996	0.331	159.46	90.1	247	239	170	930	1053	89	0.32	29.38
694	1996	0.343	157.72	91.6	251	243	174	969	1095	88.9	0.33	29.38
695	1996	0.335	200.36	91.7	287	277	205	1000	1141	87.2	0.43	29.37
696	1996	0.354	192.07	91.9	288	278	203	1047	1190	87.1	0.45	29.37
697	1996	0.357	142.12	88.3	167	162	134	921	1033	89.5	0.25	29.37
698	1996	0.372	139.49	90.7	178	171	140	948	1068	89.1	0.26	29.37
699	1996	0.412	74.27	80.1	299	294	183	953	1088	88.2	0.42	29.38

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
666	47.58	0.308	16.35	0.8	61.5	783	701	725	742	707	709	77
667	49.17	0.308	16.35	0.8	62	803	714	742	744	711	716	75
668	51.19	0.307	16.35	0.8	66.1	788	730	765	751	716	710	75
669	52.06	0.307	16.35	0.8	66.1	820	756	794	776	741	731	76
670	55.39	0.305	16.35	0.75	70.6	815	768	798	784	742	730	80
671	54.64	0.304	16.35	0.75	70.6	843	792	824	811	767	754	81
672	55.19	0.303	16.35	0.72	76.8	802	776	794	787	747	733	83
673	56.47	0.303	16.35	0.72	76.8	826	800	819	814	773	757	86
674	66.97	0.311	16.38	0.65	90.5	1092	1087	1079	1085	1065	1034	168
675	67.17	0.309	16.38	0.65	90.5	1154	1151	1144	1139	1122	1082	167
676	67.77	0.322	16.38	0.65	83.5	952	946	937	950	927	900	143
677	66.11	0.32	16.38	0.65	83.5	987	976	969	981	958	926	140
678	64.4	0.314	16.38	0.65	84.6	996	993	980	996	975	939	153
679	61.39	0.314	16.38	0.65	84.6	1029	1029	1019	1029	1007	969	155
680	59.04	0.312	16.43	0.65	86.8	1023	1025	1015	1022	999	963	154
681	58.69	0.312	16.43	0.65	86.8	1069	1075	1063	1063	1041	1002	154
682	55.23	0.329	16.43	0.72	68.7	886	824	845	833	813	814	92
683	52.68	0.324	16.43	0.72	68.7	896	828	848	836	812	816	84
684	52.23	0.318	16.43	0.72	68.3	893	842	859	853	823	814	86
685	53.94	0.315	16.43	0.72	68.3	914	859	878	871	843	833	89
686	55.49	0.31	16.43	0.7	86.1	933	918	922	931	903	882	119
687	53.42	0.309	16.43	0.7	86.5	954	942	941	955	925	904	124
688	48.18	0.308	16.43	0.7	85.4	971	969	960	978	951	921	141
689	47.49	0.309	16.43	0.7	85.4	1002	1001	990	1012	983	949	142
690	39.65	0.306	16.43	0.74	85.6	1029	1039	1027	1046	1019	983	148
691	37.08	0.307	16.43	0.74	86	1050	1060	1049	1066	1041	1003	149
692	37.95	0.307	16.43	0.74	86	1072	1086	1074	1091	1065	1027	149
693	35.42	0.314	16.43	0.72	86	947	937	941	955	925	900	126
694	34.76	0.311	16.43	0.72	86.4	985	976	977	993	963	934	127
695	33.55	0.306	16.43	0.78	86.1	1019	1021	1016	1038	1007	973	145
696	32.46	0.306	16.43	0.78	86.1	1062	1066	1063	1083	1052	1012	145
697	33.03	0.312	16.43	0.77	89.9	904	896	911	925	896	875	112
698	32.85	0.31	16.43	0.77	89.4	942	936	947	959	932	902	110
699	14.24	0.303	16.47	0.66	71.2	1057	994	1008	993	984	990	155

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
666	177	192	122	57	18.7	0.112	0.28	2938	619.6	8.94	78.2	5.37
667	178	188	119	56	19.1	0.1196	0.34	2023	539.8	9.11	54.6	5.09
668	181	188	101	56	18.4	0.1869	0.54	1013	371	9.19	746.5	4.86
669	181	189	99	56	18.3	0.1887	0.5	959	326.3	9.2	298.1	4.86
670	180	191	90	54	18.2	0.2724	0.73	809	334.9	8.66	1047.6	5.83
671	181	192	89	54	18.1	0.2775	0.7	789	298.9	8.64	524.4	5.87
672	181	194	88	54	17.6	0.3911	1.02	774	305.1	8.27	2477.2	6.44
673	182	196	89	54	17.4	0.3975	1.05	783	286.2	8.27	1716.5	6.46
674	187	225	102	57	37.3	1.9651	11.05	1150	303.4	7.29	628.9	8.3
675	186	225	104	56	37.6	1.9844	11.1	1269	283.7	7.27	215.8	8.34
676	179	212	93	58	33.6	1.0684	4.73	1790	358.2	7.23	657.6	8.39
677	179	208	94	58	34.4	1.0635	4.74	1883	346.7	7.25	333	8.37
678	184	214	98	60	32.4	1.353	6.48	1839	329.2	7.23	686.3	8.41
679	184	215	96	58	32.5	1.3354	6.38	1952	317.1	7.23	317.2	8.36
680	183	220	99	59	31.1	1.6001	8.33	1615	309.9	7.23	789	8.35
681	183	218	100	58	31.4	1.616	8.31	1828	296.3	7.22	328.7	8.38
682	178	201	96	62	32.6	0.2954	0.95	1423	457.9	8.29	477.3	6.64
683	177	195	93	62	34	0.3057	0.93	1466	450.2	8.33	276.9	6.58
684	181	197	89	62	32.8	0.4526	1.46	974	400.5	8.31	1416	6.56
685	181	199	88	61	32.5	0.462	1.46	1021	384.6	8.29	766.2	6.61
686	182	207	94	61	29.5	0.8926	3.22	1170	277.2	8.05	2875.9	6.93
687	182	210	94	63	29.1	0.9104	3.33	1422	279.8	8.01	1906.8	7.05
688	183	214	95	64	27.8	1.1674	4.62	1782	226	7.95	2727.3	7.11
689	183	215	95	65	27.8	1.1757	4.78	1840	237	7.93	1662.8	7.17
690	183	220	98	69	26.8	1.4616	6.09	1846	143.1	8.39	1695	6.3
691	185	222	99	71	26.3	1.5021	6.42	1999	149.1	8.38	1490.2	6.33
692	185	223	99	70	26.3	1.5127	6.43	1999	170.9	8.38	1166.5	6.36
693	179	210	96	73	26.1	0.8248	3.05	1742	251.4	8.17	2255.3	6.71
694	181	208	97	72	26.4	0.8455	3.12	1680	242.5	8.19	1349.7	6.7
695	184	215	96	73	25.1	1.0702	3.69	1975	142.2	8.91	1684.1	5.35
696	184	215	95	74	25.1	1.0866	3.72	1988	164.3	8.9	1161.8	5.42
697	179	207	94	73	20.8	0.6371	1.86	1820	191.1	8.8	1435.4	5.56
698	179	205	94	73	20.9	0.6548	2.01	2094	196	8.64	2083.9	5.96
699	181	218	106	68	57.8	0.9599	3.84	1007	376.2	7.47	592.9	7.87

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
700	94.74	2.53	0.6	0.35	1.04	0.74	1329	133.5	0.0023	55.21	1949	359.6
701	94.74	2.53	0.6	0.35	1.04	0.74	1320.4	128.8	0.0023	54.86	1952	346.6
702	94.62	2.54	0.66	0.38	1	0.8	2486.4	298.5	0.0023	103.7	1952	803.3
703	94.62	2.54	0.66	0.38	1	0.8	2511.5	294.1	0.0023	103.76	1951	791.9
704	94.62	2.54	0.66	0.38	1	0.8	2478.4	283	0.0023	102.85	1953	761.1
705	94.62	2.54	0.66	0.38	1	0.8	651.42	51.8	0.0023	27.48	1708	159.3
706	94.62	2.54	0.66	0.38	1	0.8	657.07	50.4	0.0023	27.41	1705	155.1
707	94.78	2.49	0.61	0.35	0.99	0.78	656.65	48.7	0.0023	27.48	1698	150.7
708	94.78	2.49	0.61	0.35	0.99	0.78	938.16	90.1	0.0023	37.6	1702	277.9
709	94.78	2.49	0.61	0.35	0.99	0.78	941.98	88.2	0.0024	37.5	1704	271.8
710	94.78	2.49	0.61	0.35	0.99	0.78	944.97	86.4	0.0024	37.97	1703	266.6
711	94.78	2.49	0.61	0.35	0.99	0.78	664.43	86.8	0.0024	32.38	999	456.4
712	94.78	2.49	0.61	0.35	0.99	0.78	673.54	87.6	0.0024	32.63	998	460.7
713	94.8	2.53	0.6	0.34	1	0.73	672.26	86.5	0.0024	32.58	998	455.1
714	95.43	2.02	0.39	0.25	1.21	0.69	581.34	47.9	0.0056	24.27	1506	167.2
715	95.43	2.02	0.39	0.25	1.21	0.69	577.07	47.1	0.0056	24.37	1499	165.1
716	95.43	2.02	0.39	0.25	1.21	0.69	579.92	45.5	0.0058	24.58	1509	158.3
717	95.43	2.02	0.39	0.25	1.21	0.69	821.03	78.1	0.0059	33.1	1501	273.2
718	95.43	2.02	0.39	0.25	1.21	0.69	822.11	77	0.0059	33.32	1503	269.2
719	95.43	2.02	0.39	0.25	1.21	0.69	828.57	74.2	0.006	33.38	1501	259.7
720	95.64	2.08	0.32	0.22	1.13	0.61	1016	113.7	0.0059	42.65	1496	399.1
721	95.64	2.08	0.32	0.22	1.13	0.61	1046.4	114.7	0.0059	43.26	1506	400.2
722	95.64	2.08	0.32	0.22	1.13	0.61	1010.9	107.1	0.0059	42.08	1497	375.8
723	95.64	2.08	0.32	0.22	1.13	0.61	1289.4	149.9	0.0059	53.67	1506	523
724	95.64	2.08	0.32	0.22	1.13	0.61	1307.9	149.8	0.0057	54.7	1501	524.2
725	95.64	2.08	0.32	0.22	1.13	0.61	1306.8	145.3	0.0056	54.62	1501	508.3
726	95.64	2.08	0.32	0.22	1.13	0.61	1574.9	192	0.0058	65.78	1495	674.3
727	95.64	2.08	0.32	0.22	1.13	0.61	1579.2	187.8	0.0056	65.49	1496	659.3
728	95.64	2.08	0.32	0.22	1.13	0.61	1583.1	184.1	0.0057	66.19	1495	646.6
729	94.92	2.32	0.52	0.33	1.12	0.78	1825.8	218.9	0.0056	74.28	1497	768.1
730	94.92	2.32	0.52	0.33	1.12	0.78	1823.8	214.6	0.0054	74.44	1493	755
731	94.92	2.32	0.52	0.33	1.12	0.78	1835.7	208.2	0.0056	74.52	1494	731.8
732	95.37	2.22	0.4	0.23	1.08	0.7	1838.2	225.9	0.005	75.55	1495	793.8
733	95.37	2.22	0.4	0.23	1.08	0.7	1845.6	223	0.005	75.65	1495	783.3

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
700	0.684	6.51	27	30	15.25	110	6.49	9.6	0.83	0.027	52013	44
701	0.684	6.479	24	29.2	15.12	112	6.47	9.68	0.7	0.035	52232	44
702	0.687	6.447	24	35.7	26.89	121	14.12	19.89	12.46	0.044	53341	44
703	0.68	6.513	21	35.2	26.87	120	14.08	19.82	12.45	0.026	53624	44
704	0.683	6.472	18	34.2	26.29	104	13.72	19.14	11.87	0.037	54049	44
705	0.695	6.487	30	23.4	9.18	95	1.18	0.89	-5.23	0.033	55590	44
706	0.687	6.494	27	22.8	9.2	93	1.19	0.93	-5.22	0.031	55901	44
707	0.69	6.52	24	22	9.23	93	1.2	0.95	-5.19	0.024	56270	44
708	0.66	6.493	32	29.7	12.25	100	2.13	1.84	-2.17	0.031	57171	44
709	0.656	6.496	29	29.2	12.29	102	2.16	1.9	-2.13	0.031	57621	44
710	0.662	6.438	26	28.3	12.35	102	2.2	1.99	-2.06	0.046	58001	44
711	0.803	6.487	24	33.3	14.99	105	2	2.88	0.58	0.033	59188	44
712	0.798	6.498	21	33.3	15.06	105	2.05	2.98	0.65	0.03	59494	44
713	0.799	6.508	18	32.9	15.01	104	2.06	3.05	0.61	0.028	59941	44
714	0.686	6.482	29.5	24.6	9.16	88	0.91	0.68	-5.2	0.034	34635	45
715	0.694	6.492	26.5	24.1	9.18	88	0.91	0.7	-5.17	0.032	34881	45
716	0.696	6.485	23.5	23	9.16	89	0.92	0.73	-5.2	0.034	35390	45
717	0.662	6.48	31	29.4	12.13	99	1.66	1.41	-2.23	0.035	36431	45
718	0.666	6.479	28	28.8	12.16	99	1.69	1.46	-2.2	0.035	36694	45
719	0.662	6.452	25	27.7	12.2	99	1.71	1.52	-2.15	0.042	36999	45
720	0.692	6.52	26.5	33.1	15.01	108	3.77	6.01	0.66	0.025	38045	45
721	0.682	6.471	23.5	32.9	15.22	109	3.92	6.38	0.88	0.037	38508	45
722	0.686	6.435	20.5	31.6	14.87	108	3.8	6.21	0.53	0.047	39040	45
723	0.686	6.439	24	34.7	17.97	109	4.59	6.91	3.63	0.046	39569	45
724	0.69	6.491	21	34	18.12	103	4.6	6.97	3.77	0.032	39891	45
725	0.689	6.523	18	33	18.13	107	4.58	6.99	3.78	0.024	40205	45
726	0.689	6.484	22	36.2	21.18	100	6.07	9.16	6.84	0.034	40803	45
727	0.684	6.484	19	35.6	21.2	104	6.07	9.21	6.86	0.034	41101	45
728	0.689	6.486	16	34.5	21.23	105	6.07	9.22	6.89	0.033	41382	45
729	0.668	6.446	23	36.7	24.12	103	7.74	11.62	9.79	0.044	42060	45
730	0.671	6.448	20	35.9	24.06	101	7.65	11.51	9.73	0.043	42437	45
731	0.667	6.5	17	34.8	24.06	102	7.61	11.59	9.72	0.03	42650	45
732	0.677	6.434	22	37.1	24.15	103	7.83	11.69	9.85	0.047	49818	45
733	0.676	6.449	19	36.6	24.15	102	7.81	11.69	9.85	0.043	50107	45

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
700	1996	0.414	74.49	80.2	301	296	189	966	1106	88.1	0.43	29.37
701	1996	0.426	71.79	80.4	299	294	187	979	1119	88	0.43	29.37
702	1996	0.347	166.41	86.6	564	553	270	1002	1196	82.9	1.56	29.37
703	1996	0.353	164.05	87.3	570	559	270	1024	1219	82.9	1.59	29.37
704	1996	0.363	157.66	85.6	563	552	264	1048	1239	82.9	1.61	29.36
705	1996	0.53	33	72.6	148	145	90	899	991	89.8	0.11	29.36
706	1996	0.544	32.14	72.9	150	146	91	912	1004	89.8	0.12	29.35
707	1996	0.564	31.21	72.9	150	146	92	927	1021	89.6	0.11	29.35
708	1996	0.417	57.57	79.1	213	209	100	916	997	89	0.21	29.35
709	1996	0.425	56.3	79.3	215	210	102	931	1012	89	0.22	29.35
710	1996	0.439	55.24	79.3	215	210	103	947	1030	89.1	0.22	29.34
711	1996	0.373	94.54	79.8	151	148	115	842	943	89.5	0.11	29.34
712	1996	0.373	95.43	80.5	153	150	117	852	954	89.6	0.11	29.34
713	1996	0.377	94.28	80.5	153	150	118	866	969	89.5	0.11	29.33
714	1996	0.506	34.63	73.1	132	129	88	864	957	89.7	0.09	29.23
715	1996	0.517	34.2	72.8	131	128	88	874	967	89.7	0.1	29.23
716	1996	0.54	32.79	73	132	129	90	893	988	89.7	0.1	29.23
717	1996	0.424	56.6	79.7	187	183	97	887	969	89.1	0.17	29.22
718	1996	0.433	55.76	79.4	187	183	98	902	986	89.2	0.17	29.22
719	1996	0.45	53.8	79.8	189	184	99	920	1005	89.2	0.18	29.22
720	1996	0.375	82.67	81.4	234	226	154	913	1030	88.4	0.25	29.22
721	1996	0.377	82.9	82.1	240	233	158	929	1050	87.7	0.26	29.22
722	1996	0.393	77.85	81.6	233	225	160	950	1073	88	0.25	29.21
723	1996	0.358	108.33	85.8	299	287	164	942	1058	86.9	0.4	29.21
724	1996	0.365	108.58	85.8	302	291	163	966	1080	86.9	0.42	29.21
725	1996	0.376	105.3	86.2	303	291	165	989	1104	86.9	0.42	29.21
726	1996	0.343	139.67	88.2	366	351	187	971	1097	85.9	0.6	29.2
727	1996	0.349	136.58	88.8	367	352	187	990	1118	85.8	0.61	29.2
728	1996	0.36	133.95	89.2	368	352	187	1014	1146	85.8	0.63	29.2
729	1996	0.339	159.11	89.8	429	406	211	956	1096	85.1	0.79	29.19
730	1996	0.347	156.39	90	419	406	202	975	1114	85	0.81	29.19
731	1996	0.358	151.6	90.6	421	409	202	1001	1145	85.2	0.83	29.19
732	1996	0.334	164.44	90.6	435	409	217	970	1115	84.8	0.8	29.12
733	1996	0.339	162.26	90.8	437	411	218	988	1134	84.9	0.81	29.11

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
700	14.15	0.303	16.47	0.66	71.2	1076	1012	1025	1009	1000	1003	156
701	14.23	0.302	16.47	0.66	71.2	1090	1024	1038	1020	1013	1017	156
702	14	0.294	16.47	0.66	80.6	1129	1104	1108	1111	1094	1076	161
703	13.94	0.296	16.47	0.66	80.6	1153	1126	1130	1132	1113	1096	161
704	13.9	0.297	16.47	0.66	80.6	1171	1145	1148	1153	1133	1113	161
705	14.02	0.306	16.47	0.65	69.5	986	910	926	909	890	902	112
706	13.95	0.305	16.47	0.65	69.5	1004	927	944	922	901	917	111
707	13.92	0.302	16.48	0.65	69.5	1026	943	954	938	915	933	110
708	13.95	0.299	16.48	0.63	70.1	957	897	915	909	885	893	120
709	13.94	0.299	16.48	0.63	70.1	976	913	931	925	898	904	119
710	13.93	0.299	16.48	0.63	70.1	993	931	947	940	911	918	120
711	14.25	0.301	16.48	0.7	81.9	884	841	852	854	825	810	97
712	14.32	0.301	16.48	0.7	81.9	900	851	865	865	836	820	96
713	14.42	0.3	16.49	0.7	81.9	914	865	882	879	850	833	98
714	47.53	0.3	16.43	0.66	67.3	947	884	901	885	861	871	101
715	47.46	0.299	16.43	0.65	67.3	955	896	913	895	870	878	102
716	45.98	0.298	16.43	0.65	67.3	984	920	934	915	886	897	102
717	43.71	0.295	16.43	0.63	6.8	920	876	893	887	861	856	113
718	43.8	0.295	16.43	0.63	66.8	939	892	907	903	873	870	113
719	42.75	0.295	16.43	0.63	66.8	960	911	924	920	887	884	112
720	40.99	0.292	16.49	0.66	66.8	976	928	941	939	916	915	133
721	39.56	0.291	16.49	0.66	67.1	994	946	959	957	935	933	136
722	38.75	0.293	16.49	0.66	67.1	1021	969	980	978	952	951	135
723	36.95	0.29	16.49	0.66	76.1	988	953	962	965	943	930	140
724	35.64	0.29	16.49	0.66	77.1	1008	974	983	988	961	947	143
725	35.72	0.29	16.49	0.66	77.1	1032	999	1005	1012	983	967	146
726	35.22	0.289	16.49	0.66	77.6	1017	994	996	1007	985	958	157
727	34.13	0.29	16.49	0.66	77.6	1033	1010	1012	1027	1005	976	158
728	33.79	0.291	16.49	0.66	77.6	1057	1036	1038	1054	1029	996	159
729	33.47	0.293	16.43	0.64	81.2	1014	998	995	1008	988	956	160
730	32.49	0.293	16.43	0.64	81.2	1032	1017	1011	1026	1002	971	159
731	33.34	0.294	16.43	0.64	81.2	1060	1040	1034	1057	1032	993	159
732	23.91	0.288	16.48	0.66	81	1029	1012	1009	1025	1004	975	159
733	24.12	0.288	16.48	0.66	81	1046	1032	1028	1046	1023	991	159

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
700	182	218	108	68	57.8	0.9694	3.89	970	369.5	7.48	436.3	7.86
701	182	218	107	69	57.9	0.9649	3.89	983	365.7	7.49	277.6	7.86
702	184	230	115	69	52.3	1.8731	9.06	453	313.4	7.64	1353.8	7.59
703	185	230	114	69	52.4	1.8631	9.23	462	312.3	7.63	853.8	7.62
704	184	229	101	69	53	1.8402	9.03	484	301.9	7.62	477.9	7.64
705	179	204	100	70	54.8	0.4766	1.71	1678	486.5	7.32	100.3	8.14
706	179	203	98	70	54.8	0.478	1.73	1738	494.8	7.3	70.5	8.15
707	180	204	97	71	54.6	0.483	1.73	1749	512.6	7.27	48.6	8.19
708	181	208	102	69	52.5	0.6688	2.59	1480	409.4	7	197.7	8.6
709	181	207	103	70	52.7	0.6669	2.61	1565	424.6	6.98	122.3	8.61
710	181	207	104	70	52.8	0.6746	2.61	1598	434.4	6.98	85.1	8.6
711	179	201	105	70	28.1	0.5726	1.76					
712	179	201	106	70	28.1	0.5766	1.78	857	342.3	8	1416.2	6.91
713	180	201	105	70	28.1	0.5762	1.77	849	338	8	972.7	6.92
714	179	200	94	66	48.5	0.4299	1.47	1814	497.7	7.33	75.8	8.08
715	180	200	94	66	48.3	0.4325	1.46	1880	508	7.32	57.2	8.1
716	180	201	95	68	48.6	0.4379	1.49	1892	503.3	7.37	44.7	8.02
717	180	204	102	68	47	0.5957	2.2	1720	458.9	6.91	107	8.73
718	180	204	102	68	47.2	0.5993	2.21	1812	477.4	6.9	69.2	8.73
719	180	203	102	69	47.3	0.6005	2.23	1892	504.5	6.88	47.6	8.75
720	182	209	108	71	44.3	0.7749	2.88	980	348.9	7.98	1851.7	6.95
721	182	209	108	70	44.7	0.7888	2.98	1138	362.8	7.51	310.6	7.78
722	181	208	107	71	45.1	0.7634	2.84	1133	354.6	7.5	166.2	7.77
723	183	211	108	73	43.7	0.9827	3.86	1011	363.5	7.43	527.4	7.88
724	183	211	104	72	43.5	1.0009	3.91	904	321.3	7.54	321.6	7.68
725	183	211	106	73	43.6	1	3.93	950	338	7.44	207.6	7.87
726	184	215	101	74	41.5	1.2095	4.95	915	347.1	7.54	762.4	7.67
727	184	215	103	73	41.5	1.1995	4.98	928	336.6	7.53	484.3	7.71
728	184	215	104	73	41.7	1.2099	5.02	1049	434.3	7.79	1735.7	7.36
729	184	216	101	77	40.8	1.3463	6.12	1140	460.5	7.76	1115	7.43
730	184	216	99	70	40.9	1.3477	6	1251	430.2	7.76	627.3	7.45
731	184	215	100	69	41	1.3462	6.08	1249	423.2	8.07	540.9	6.98
732	185	218	102	78	40.2	1.3955	6.16	1349	423.1	7.79	1981	7.38
733	185	218	102	78	40.1	1.3953	6.2	1336	447.3	7.76	1387.8	7.46

Recorded Data

Run Number	Methane (%)	Ethane (%)	Propane (%)	Butane (%)	CO2 (%)	N2 (%)	Air Flow (lb/hr)	Power (bhp)	Humidity (lb H20/Air)	NG Flow (lb/hr)	Speed (rpm)	Torque (ft-lb)
734	95.37	2.22	0.4	0.23	1.08	0.7	1845.5	220.1	0.0051	76.6	1497	772.2
735	95.37	2.22	0.4	0.23	1.08	0.7	2320.4	282.8	0.0051	93.78	1497	992.1
736	95.37	2.22	0.4	0.23	1.08	0.7	2336	278.2	0.005	94.16	1500	973.9
737	95.37	2.22	0.4	0.23	1.08	0.7	2360.9	271.8	0.0049	94.96	1504	949.2
738	96.2	2.12	0.17	0.09	0.96	0.45	2319.7	291.6	0.005	95.46	1494	1025.1
739	96.2	2.12	0.17	0.09	0.96	0.45	2312	291.4	0.0047	94.54	1497	1022.3
740	96.2	2.12	0.17	0.09	0.96	0.45	2278.6	279.3	0.0046	93.23	1493	982.6
741	96.37	2.14	0.12	0.05	0.92	0.41	2347.8	280.6	0.0046	96.81	1503	980.6
742	96.37	2.14	0.12	0.05	0.92	0.41	847.91	101	0.0045	35.97	1251	423.8
743	96.37	2.14	0.12	0.05	0.92	0.41	862.35	101.1	0.0045	36.65	1250	424.8
744	96.37	2.14	0.12	0.05	0.92	0.41	877.47	100.6	0.0045	36.86	1250	422.5
745	96.37	2.14	0.12	0.05	0.92	0.41	1102.6	137	0.0045	46.65	1257	572.4
746	96.37	2.14	0.12	0.05	0.92	0.41	1134.4	139.4	0.0044	47.62	1255	583.6
747	96.37	2.14	0.12	0.05	0.92	0.41	1115.8	134.4	0.0045	47.02	1252	563.9
748	96.45	2.14	0.11	0.03	0.88	0.41	1766.9	216.1	0.0044	69.81	1253	906.3
749	96.45	2.14	0.11	0.03	0.88	0.41	1775.4	212.4	0.0044	70.25	1247	894.4
750	96.45	2.14	0.11	0.03	0.88	0.41	1776.5	207.9	0.0045	70.6	1253	871.3
751	96.45	2.14	0.11	0.03	0.88	0.41	1956.4	232.9	0.0044	75.6	1238	988.2
752	96.45	2.14	0.11	0.03	0.88	0.41	1957.8	235.1	0.0044	76.49	1246	990.9
753	96.45	2.14	0.11	0.03	0.88	0.41	1981.6	231.7	0.0044	77.93	1248	974.8
754	96.45	2.14	0.11	0.03	0.88	0.41	2213.3	260.3	0.0044	83.84	1250	1094.1
755	96.45	2.14	0.11	0.03	0.88	0.41	2184.8	251.9	0.0044	82.51	1245	1063
756	96.45	2.14	0.11	0.03	0.88	0.41	2179.8	241.7	0.0044	83.19	1233	1029.9
757	96.45	2.14	0.11	0.03	0.88	0.41	2160.9	266.6	0.0044	84.69	1245	1124.1
758	96.46	2.14	0.1	0.03	0.88	0.4	2159.8	259.3	0.0044	84.64	1232	1105.1
759	96.46	2.14	0.1	0.03	0.88	0.4	2158.8	255.5	0.0044	84.63	1244	1078.5

Recorded Data

Run Number	Eq Ra	Equiv O2	Ign Tim (deg)	BTE (%)	MAP (psia)	Boost AF IC (deg F)	Pre-Turbine (psig)	Comp Out (psig)	MAP (psig)	O2 (volts)	Time (sec)	Date (julian)
734	0.684	6.527	16	35.7	24.32	102	7.93	11.89	10.02	0.023	50377	45
735	0.666	6.523	22.5	37.4	30.31	107	11.9	17.67	16.02	0.024	51213	45
736	0.664	6.469	19.5	36.7	30.41	108	11.98	17.72	16.11	0.038	51541	45
737	0.663	6.472	16.5	35.5	30.44	108	12.03	17.81	16.14	0.037	51812	45
738	0.684	6.509	21	37.6	30.24	106	11.85	17.53	15.95	0.027	52927	45
739	0.679	6.5	21	38	30.03	104	11.83	17.35	15.75	0.03	55613	45
740	0.68	6.463	18	36.9	29.71	105	11.59	16.9	15.43	0.039	55963	45
741	0.687	6.466	15	35.6	30.54	107	12.23	17.95	16.26	0.039	56314	45
742	0.706	6.528	25.5	34.5	15.05	98	2.98	4.06	0.77	0.022	57248	45
743	0.708	6.44	22.5	33.9	15.19	99	3.1	4.29	0.92	0.045	57651	45
744	0.7	6.483	19.5	33.5	15.38	98	3.23	4.54	1.1	0.034	57960	45
745	0.705	6.509	23.5	36.1	18.19	98	4.52	6.76	3.91	0.027	58527	45
746	0.699	6.495	20.5	36	18.54	95	4.71	7.19	4.26	0.031	58811	45
747	0.702	6.455	17.5	35.1	18.35	97	4.66	7.2	4.07	0.041	59178	45
748	0.659	6.457	23	38	27.25	101	8.86	14.16	12.98	0.041	60165	45
749	0.66	6.476	20	37.1	27.26	101	8.89	14.16	12.99	0.036	60474	45
750	0.663	6.498	17	36.1	27.2	100	8.82	14.08	12.93	0.03	60769	45
751	0.644	6.487	22	37.8	29.96	103	10.51	16.83	15.69	0.033	61338	45
752	0.651	6.496	19	37.7	29.86	102	10.4	16.75	15.58	0.031	61585	45
753	0.656	6.454	16	36.5	30.2	103	10.61	17.07	15.92	0.042	61925	45
754	0.631	6.49	23	38.1	33.45	106	12.78	20.34	19.18	0.032	62380	45
755	0.63	6.541	20	37.5	33.08	103	12.48	19.96	18.8	0.019	62586	45
756	0.636	6.485	17	35.7	33.15	105	12.49	20.05	18.88	0.034	62786	45
757	0.653	6.514	22	38.6	33.13	104	12.45	19.97	18.86	0.026	63033	45
758	0.653	6.484	19	37.6	33.05	104	12.34	19.97	18.77	0.034	63237	45
759	0.654	6.538	16	37.1	32.97	104	12.24	19.88	18.69	0.02	63438	45

Recorded Data

Run Number	Year	BSFC (#/bhp-hr)	BMEP (psi)	Vol Eff (%)	Intake Air (acfm)	Intake Air (scfm)	Boost B4 IC (deg F)	Stack (deg F)	Pre-Turbine (deg F)	Fuel Press (psig)	EBP ("Hg)	Baro ("Hg)
734	1996	0.348	159.96	90	437	411	218	1013	1162	84.7	0.85	29.11
735	1996	0.332	205.52	91.5	549	517	265	946	1125	83.4	1.29	29.1
736	1996	0.338	201.75	91.7	551	520	264	968	1148	83.4	1.34	29.1
737	1996	0.349	196.63	92.4	559	526	267	996	1175	83.4	1.39	29.1
738	1996	0.327	212.35	91.8	551	516	266	968	1149	83	1.33	29.09
739	1996	0.324	211.77	91.6	551	515	265	964	1143	83.3	1.3	29.08
740	1996	0.334	203.54	91.6	544	507	263	985	1161	83.4	1.29	29.08
741	1996	0.345	203.13	91.7	561	523	270	1020	1203	83	1.44	29.07
742	1996	0.356	87.79	79.6	202	189	140	871	977	89	0.23	29.07
743	1996	0.362	88	80.3	206	192	143	885	994	88.9	0.24	29.07
744	1996	0.366	87.53	80.5	210	195	146	900	1014	88.8	0.24	29.07
745	1996	0.341	118.57	85.1	263	245	171	896	1019	88.2	0.33	29.07
746	1996	0.342	120.89	85.6	271	253	177	908	1034	88.2	0.35	29.07
747	1996	0.35	116.8	85.6	267	248	178	925	1053	88.2	0.35	29.06
748	1996	0.323	187.73	91.4	422	393	242	891	1048	85.3	0.76	29.06
749	1996	0.331	185.28	92.3	424	395	242	910	1068	85.3	0.78	29.06
750	1996	0.34	180.49	92	425	395	242	935	1092	85.5	0.8	29.06
751	1996	0.325	204.7	93.5	467	436	264	890	1062	85.2	0.92	29.06
752	1996	0.325	205.27	93.1	467	436	264	910	1083	84.9	0.93	29.06
753	1996	0.336	201.94	93.3	473	441	267	940	1113	84.8	0.98	29.06
754	1996	0.322	226.65	94.2	530	493	293	870	1063	84.1	1.14	29.06
755	1996	0.327	220.2	93.9	524	486	292	890	1082	84.3	1.14	29.06
756	1996	0.344	213.34	94.7	523	485	291	919	1108	84.2	1.17	29.06
757	1996	0.318	232.86	93.1	518	481	292	888	1079	84.1	1.12	29.06
758	1996	0.326	228.92	94.2	517	481	290	905	1097	84.1	1.13	29.06
759	1996	0.331	223.42	93.5	515	481	289	933	1122	84.2	1.15	29.06

Recorded Data

Run Number	RH (%)	Density	Stioch A/F	GEM Eq Ra	GEM Vol Eff (%)	Exh #1 (deg F)	Exh #2 (deg F)	Exh #3 (deg F)	Exh #4 (deg F)	Exh #5 (deg F)	Exh #6 (deg F)	Water In (deg F)
734	23.92	0.288	16.48	0.66	81	1072	1057	1053	1072	1048	1013	158
735	23.03	0.287	16.48	0.64	82.6	1047	1040	1032	1043	1021	989	155
736	22.45	0.288	16.48	0.64	82.6	1074	1063	1054	1066	1043	1007	155
737	22.31	0.289	16.48	0.64	82.6	1104	1090	1083	1093	1068	1030	156
738	21.85	0.284	16.62	0.66	82.6	1066	1060	1051	1067	1045	1011	157
739	19.68	0.284	16.62	0.66	82.6	1063	1056	1050	1060	1038	1007	156
740	18.83	0.284	16.62	0.66	82.6	1081	1072	1062	1076	1053	1020	156
741	18.77	0.282	16.65	0.66	82.6	1121	1112	1102	1118	1093	1056	157
742	18.53	0.293	16.65	0.66	71.8	922	877	890	892	866	864	115
743	18.44	0.291	16.65	0.66	71.8	940	893	907	908	880	874	114
744	18.14	0.29	16.65	0.66	71.8	960	909	924	923	896	891	114
745	18.33	0.287	16.65	0.66	78.9	944	916	923	928	903	890	124
746	18.07	0.287	16.65	0.66	78.9	958	930	936	943	918	902	126
747	18.14	0.287	16.65	0.66	78.9	978	948	954	960	935	918	128
748	18.16	0.283	16.67	0.63	82.8	966	956	948	965	941	910	139
749	18.07	0.283	16.67	0.63	82.8	984	974	968	983	958	924	140
750	18.13	0.283	16.67	0.63	82.8	1008	999	986	1008	980	945	141
751	18.11	0.284	16.67	0.63	84.4	981	975	965	979	955	921	144
752	18.22	0.284	16.67	0.63	84.4	1001	997	985	1000	976	937	146
753	18.19	0.284	16.67	0.63	84.4	1028	1024	1016	1029	1005	963	147
754	18.25	0.282	16.67	0.61	85.7	991	989	978	986	962	928	150
755	18.22	0.283	16.67	0.61	85.7	1010	1007	998	1003	979	942	151
756	17.97	0.282	16.67	0.61	85.7	1039	1034	1024	1028	1005	963	151
757	17.99	0.282	16.67	0.63	85.7	999	1001	990	1000	977	942	152
758	18.03	0.282	16.67	0.63	85.7	1019	1017	1006	1016	994	956	153
759	18.12	0.283	16.67	0.63	85.7	1042	1041	1031	1039	1017	974	153

Recorded Data

Run Number	Water Out (deg F)	Oil Sump (deg F)	Oil Gallery (deg F)	Intake @ LFE (deg F)	Oil Press (psig)	Fuel Flow (@ RT Meter)	Inlet Rest ("H2O)	HC (ppm)	CO (ppm)	CO2 (%)	NOx (ppm)	O2 (%)
734	184	218	101	79	40.5	1.4121	6.28	1283	434.1	7.78	716.8	7.45
735	183	220	105	78	39.2	1.7346	8.62	1206	417.4	8.27	641.9	6.65
736	183	220	105	77	39.4	1.7356	8.74	1837	397.3	7.7	1671.6	7.54
737	183	220	105	78	39.7	1.747	8.78	1647	418.8	7.72	1321.7	7.51
738	185	223	103	79	38.5	1.7869	8.55	1234	404	8	1259.4	7.05
739	182	221	102	80	39.1	1.767	8.56	1095	384.9	8.39	872.8	6.44
740	183	220	102	81	39	1.7413	8.54	2236	374.5	7.64	1620	7.6
741	183	220	104	81	39.5	1.8223	8.79	1945	352.2	7.97	1984.1	7.08
742	179	205	100	81	36.5	0.6513	2.45	1293	333.6	8.33	2205.2	6.48
743	179	204	101	81	36.7	0.6692	2.48	991	342.9	8.64	1148.8	6
744	180	203	100	81	36.9	0.6763	2.52	2264	203.6	8.53	3227.7	6.11
745	182	207	99	81	35.4	0.8638	3.32	1850	194.9	8.73	3231.7	5.79
746	182	208	98	81	35.1	0.882	3.41	832	226.1	8.84	2627.8	5.59
747	182	208	99	82	35.2	0.87	3.38	650	258.6	9.21	1175	5.02
748	182	213	100	81	33.1	1.3107	5.88	2466	140.7	8.74	3875.9	5.7
749	182	214	100	81	33.2	1.3193	5.96	1715	149.4	8.9	3542.8	5.45
750	183	213	100	81	33.3	1.3239	6.02	665	188.8	9.21	2559.8	4.93
751	181	215	102	80	32.5	1.4123	6.86	603	226	9.62	1254.2	4.3
752	182	215	100	80	32.5	1.4306	6.81	693	183.1	9.46	3343.1	4.54
753	183	215	102	80	32.5	1.4597	7.01	713	213.3	9.66	2112.5	4.23
754	184	216	104	81	32.2	1.5795	8.11	692	229.6	9.98	1003.9	3.63
755	184	217	103	82	31.8	1.5503	7.98	730	249.9	10.22	418.9	3.2
756	184	217	103	82	32	1.5654	7.99	1130	538.8	8.76	656.4	5.85
757	185	218	103	81	31.7	1.5946	7.82	1055	475.1	8.68	446.6	5.97
758	185	218	103	81	31.5	1.5932	7.9	1016	399.9	8.66	408.3	6
759	185	219	103	80	31.4	1.5893	7.9	789	367	8.99	256.3	5.43

APPENDIX C

FINAL CALIBRATION

325 bhp

GEM Lean Burn Control System - Drive-By-Wire Parameters

Speed	0	rpm	RPMdt	0	rpm/s	StartTPS	2.00	Volts
MAP 10.0	14.4	psia	RPMdt_dz	150	rpm/s	StartRPMOffst	75	rpm
ECT	128	°F	RPMdt_max	0	rpm/s	StartRPMDecay	10	rpm/s
FPPn	0.51	Volts	RPMdt_dcy	156	rpm/s/s			
TPSc	1.99	Volts						
RunTime	00:00:00		FPPmin/max	0.41 3.51 V		1.022		
GovControl	MIN-MAX		FPPactual	0.41 V				

Min Governor:	Idle	Fast		Max Governor:	
RPM_target	675		rpm	Droop	
RPM_targ_def	600	1200	rpm	RPM	TPS
RPM_enable	300	400	rpm	1975	4.50
RPM_dz	75	10	rpm	2005	3.50
Kp	0.001	0.003	V/rpm	2050	2.90
Ki	0.002	0.006	V/rpm/s	2200	2.60
Kd	0.0001	0.0002	V/rpm*s	2300	2.10
K_I_init	0.10	0.00	V/100rpm/s	2330	1.55
I_init	0.00		Volts	2350	1.20
Min_TPSc	0.00		Volts	2400	0.50
				Max_TPSc 4.50	Volts

GEM Lean Burn Control System - ECT Based Modification Tables

ECT (°F)	Idle Offset (rpm)	Adv Offset (CAD BTDC)	Max Boost (psia)	Phi Cold (%)
-40	50	+5.0	30.0	100
-20	50	+5.0	30.0	100
0	50	+5.0	30.0	100
32	50	+5.0	30.0	100
50	50	+5.0	30.0	75
70	50	+3.0	30.0	75
90	50	+0.0	30.0	60
110	50	+0.0	32.1	50
130	50	+0.0	35.1	30
155	0	+0.0	35.1	30
160	0	+0.0	45.0	0
190	0	+0.0	45.0	0
200	0	+0.0	45.0	0
210	0	+0.0	45.0	0
220	0	+0.0	45.0	0
230	0	+0.0	45.0	0

ECT	128	°F
Speed	0	rpm
Idle	675	rpm
Idle_def	600	rpm
IgnAdv	5.0	°BTDC
IgnOffst	+0.0	°BTDC
MAP	14.4	psia
Max_boost	15.1	psia
Max_boost_s	15.1	psia
PhiECT	32	%

GEM Lean Burn Control System - Miscellaneous Calibrations

UEGO Calibration

Volts	UEGO_Phis
0.647	1.100
1.000	1.000
1.627	0.912
1.902	0.872
2.196	0.828
2.431	0.800
2.647	0.770
2.863	0.743
3.098	0.710
3.235	0.691
3.412	0.671
3.549	0.650
3.725	0.630
3.882	0.609
4.020	0.588
4.274	0.537
UEGO	0.922 Volts
UEGO_Phis	1.022
UEGO_Phi	1.022

GEM Lean Burn Control System - Closed Loop Activation Map

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
600	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
800	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1000	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1100	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1250	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1500	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1700	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1950	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
2000	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0

Closed Loop Selection (1=ClosedLoop, 0=OpenLoop)

Speed	0	rpm	CL_select	0	(0-1)	ControlMode	OPEN LOOP
MAP	14.4	psia	Phi	1.000		CL_Mult	+0.00 %
FSO_on	1150	rpm	UEGO_Phi	1.022		Adpt_Mult	+0.00 %
FSO_off	850	rpm	FSO_TPS_min	4.51	V	Block_Mult	100.0 %

GEM Lean Burn Control System - Manifold Filling Calibration

TPS (Volts)	Acceleration Multiplier (psi/V)	Acceleration Decay (ms)	Deceleration Multiplier (psi/V)	Deceleration Decay (ms)
0.0	0.98	3	0.00	5
0.5	0.98	3	0.00	5
1.0	0.98	3	0.00	5
1.5	0.00	5	0.00	5
2.0	0.00	5	0.00	5
3.5	0.00	5	0.00	5
3.0	0.00	5	0.00	5
3.5	0.00	5	0.00	5
4.0	0.00	5	0.00	5
4.5	0.00	5	0.00	5

ControlMode	OPEN LOOP	FSO_on	1150	rpm	Speed	0	rpm
Phi	1.000	FSO_off	850	rpm	MAP	14.4	psia
Phi_delay	1.000	FSO_TPS_min	4.51	V	PTP	14.2	psia
UEGO_Phi	1.022	FSO_TPS_off	1000	rpm	PTP_dt	+0.0	psi/s
Fuel_In	129.8 mg/inj	EvsTemp_C	0.251	%	TPS	0.41	Volts
PW	24.1 ms	Tau_idle	40.0	sec	TPS_dt	+0.0	V/sec
					TPS_dtTrig	12.0	V/sec
					TPSdt->MAPdt	0.00	psi/V
					MAP_dtPrdct	+0.0	psi/s
					MAP_dt_f	+0.0	psi/s
					MAP_dtTrig_f	70.1	psi/s
					MAP_dt_s	+0.0	psi/s
					MAP_dtTrig_s	8.8	psi/s
					MAP_dt_mg	0.0	mg/inj
					CPM_mg	0.0	mg/inj
					EvsTempCF	+2.3	%
					CL_Mult	+0.00	%
					Adpt_Mult	+0.00	%
					Block_Mult	100.0	%

GEM Lean Burn Control System - Turbo Lag Compensation Screen

RPM	TPSc (volts) 2.00	2.51	2.75	3.00	3.39	3.80	4.06	4.29
650	15.1	15.9	15.9	16.5	17.0	17.0	17.0	17.0
900	15.1	15.9	17.0	18.1	18.9	20.0	22.1	25.1
1100	15.1	17.0	20.0	22.1	24.0	25.1	26.1	27.0
1200	15.1	18.1	22.1	25.1	28.0	31.0	34.5	32.1
1250	15.1	17.0	20.0	23.0	25.9	28.0	30.8	34.4
1500	15.1	15.9	17.5	20.0	24.0	26.5	29.6	33.1
1700	15.1	15.9	17.5	18.9	23.0	25.9	27.5	32.4
1950	15.1	15.9	17.0	18.9	22.1	25.1	28.0	32.4
1970	15.1	15.9	17.0	18.9	22.1	24.0	25.9	28.9
2150	15.1	15.1	15.1	15.1	15.1	15.4	15.9	16.3
2200	15.1	15.9	15.1	15.1	15.1	15.1	15.1	15.1
2700	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1

Maximum Desired Boost (psia)

K_enrich	2.20	%/psi
K_retard	1.50	°ATDC/psi
TLC_enrich	0	%
TLC_retard	0.0	°ATDC
TLC_enable	0	%
TLC_MAP_dz	3.0	psi
TLC_On	4000	ms
TLC_Reset	3000	ms
TLC_Slew	500	ms
TLC_TPS	0.51	+/- volts
TLC_enr_max	13	%
TLC_ret_max	8.0	°ATDC
TLC_range	1050	1700 rpm

Speed	0	rpm	Phi	1.000		MAP	14.4	psia
PTP	14.2	psia	UEGO_Phi	1.022		Max_boost	15.1	psia
MAT	122	°F	IgnAdv	5.0	°BTDC	Max_boost_s	15.1	psia
TPS	0.41	volts	IgnOffset	+0.0	°BTDC	Min_boost	26.6	psia
TPSc	1.99	volts				Boost_PWM	0.0	%

GEM Lean Burn Control System - BASE Boost Control Calibration Screen

RPM	TPS (volts) 2.00	2.51	2.75	3.00	3.39	3.80	4.06	4.29
650	15.1	15.9	15.9	16.5	17.0	17.0	17.0	17.0
900	15.1	15.9	17.0	18.1	18.9	20.0	22.1	25.1
1100	15.1	17.0	20.0	22.1	24.0	25.1	26.1	27.0
1200	15.1	18.1	22.1	25.1	28.0	31.0	34.5	32.1
1250	15.1	17.0	20.0	23.0	25.9	28.0	30.8	34.4
1500	15.1	15.9	17.5	20.0	24.0	26.5	29.6	33.1
1700	15.1	15.9	17.5	18.9	23.0	25.9	27.5	32.4
1950	15.1	15.9	17.0	18.9	22.1	25.1	28.0	32.4
1970	15.1	15.9	17.0	18.9	22.1	24.0	25.9	28.9
2150	15.1	15.1	15.1	15.1	15.1	15.4	15.9	16.3
2200	15.1	15.9	15.1	15.1	15.1	15.1	15.1	15.1
2700	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1

BASE Maximum Desired Boost (psia)

Boost (psia)	MaxInt (%)	Speed (rpm)	Kd_PTP (%s/p)
15.1	80.0	1250	0.0
18.1	80.0	1700	0.0
20.0	80.0	1800	2.0
22.1	80.0	2000	2.0
25.9	80.0	BP	Derate
28.9	80.0	10.0	5.0
31.0	80.0	11.5	0.0
35.1	80.0	0.0	%Derate

MAP	14.4	psia
Max_boost	15.1	psia
Max_boost_s	15.1	psia
Min_boost	26.6	psia
PhiMAP_C	0.8	dPhi/dMAP
Kp_MAP	12.00	%/psi
Ki_MAP	6.00	%/psi/sec
Kd_MAP	2.00	%/psi*sec
Kd_PTP	0.00	%/psi*sec
Boost_PWM	0.0	%

Speed	0	rpm	Phi	1.000	
PTP	14.2	psia	UEGO_Phi	1.022	
MAT	122	°F	IgnAdv	5.0	°BTDC
FPPn	0.51	volts	IgnOffset	+0.0	°BTDC
TPSc	1.99	volts	EBP	14.41	psia

GEM Lean Burn Control System - COLD Phi Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
400	95	95	95	95	95	90	83	83	83	83	83	83	83	83	83	80
600	95	95	95	95	95	90	80	79	78	78	78	78	78	78	78	70
800	95	95	95	95	95	90	80	79	78	78	73	73	71	71	71	68
1000	95	95	95	95	90	85	80	80	80	77	71	71	71	71	71	64
1100	93	82	82	80	80	80	80	80	80	80	80	77	73	69	69	64
1250	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1500	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1700	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1950	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
2000	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64

COLD Equivalence Ratio (Phi*100)

Speed	0	rpm	Phi	1.000		ControlMode	OPEN LOOP	
MAP	14.4	psia	UEGO_Phi	1.006		CL_Mult	+0.00	%
IgnAdv	5.0	°BTDC	PhiECT	32	%	Adpt_Mult	+0.00	%
IgnOffset	+0.0	BTDC	PhiMAP_C	0.8	dP/dMAP	Block_Mult	100.0	%

GEM Lean Burn Control System - BASE Phi Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
400	91	86	83	83	83	81	81	81	81	81	81	81	81	81	81	81
600	91	86	83	83	81	77	77	77	76	76	76	76	76	76	76	71
800	91	86	83	83	81	77	77	77	76	76	71	71	69	69	69	69
1000	91	81	77	74	74	74	78	78	78	75	69	69	69	69	69	69
1100	91	80	77	74	74	74	74	78	78	78	78	75	71	67	67	66
1250	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1500	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1700	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1950	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
2000	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65

BASE Equivalence Ratio (Phi*100)

Speed	0	rpm	Phi	1.000		ControlMode	OPEN LOOP	
MAP	14.4	psia	UEGO_Phi	1.022		CL_Mult	+0.00	%
IgnAdv	5.0	°BTDC	PhiECT	32	%	Adpt_Mult	+0.00	%
IgnOffset	+0.0	BTDC	PhiMAP_C	0.8	dP/dMAP	Block_Mult	100.0	%

GEM Lean Burn Control System - Ignition Advance Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.93	38.03	42.06	45.04
270	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
300	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
400	13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	5
600	13	13	13	13	13	13	12	11	10	10	10	10	10	10	10	5
800	16	16	16	15	16	15	15	13	12	12	12	10	10	10	10	5
1000	26	26	26	20	20	18	14	14	13	13	13	12	10	10	10	5
1100	27	27	27	24	21	18	16	15	14	13	13	13	10	10	10	5
1250	26	26	26	24	21	18	17	17	16	14	14	13	13	13	10	5
1500	26	26	26	24	21	18	17	17	17	16	16	16	16	14	10	5
1700	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5
1950	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5
2100	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5

Ignition Advance (°BTDC)

Speed	0	rpm	IgnAdv	5.0	°BTDC	ControlMode	OPEN LOOP	
MAP	14.4	psia	IgnOffset	+0.0	°BTDC	CL_Mult	+0.00	%
PTP	14.2	psia	TLC_retard	0.0	°ATDC	Adpt_Mult	+0.00	%
UEGO_Phi	1.022		Phi	1.000		Block_Mult	100.0	%

GEM Lean Burn Control System - VE Calibration Screen

MAP (psia)

RPM	0.00	2.80	4.56	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.93	39.08	42.06
200	40	40	55	60	65	70	80	85	88	88	88	88	88	88	88	88
400	40	40	55	60	65	70	80	85	88	88	88	88	88	88	88	88
600	50	50	55	60	65	70	80	85	88	88	88	88	88	88	88	88
775	50	50	55	60	65	71	80	90	90	90	90	90	90	90	90	90
950	50	50	60	63	65	72	77	87	90	90	90	90	90	90	89	89
1100	50	50	60	63	68	74	80	84	88	90	91	91	91	91	90	90
1300	50	50	60	63	67	69	78	82	86	87	89	91	91	91	90	90
1500	50	50	60	63	66	68	77	81	85	86	87	88	88	91	90	90
1700	50	50	60	63	66	68	77	79	81	83	85	86	87	88	88	87
1900	45	45	60	63	66	68	74	77	80	82	84	84	85	86	86	86
2100	45	45	60	63	66	68	74	77	80	82	82	82	82	82	82	82
3000	45	45	60	63	66	68	74	77	80	82	82	82	82	82	82	82

Volumetric Efficiency (%)

Speed	0 rpm	VE_std	78.7 %	ControlMode	OPEN LOOP
MAP	14.4 psia	VE_mod	100.3 %	CL_Mult	+0.00 %
PTP	14.2 psia	VE_act	80.8 %	Adpt_Mult	+0.00 %
UEGO_Phi	1.017	Phi	1.000	Block_Mult	100.0 %

GEM Lean Burn Control System - Adaptive Parameter Table

Speed	0	rpm					MAP (psia)					
MAP	14.4	psia			4.56	6.13	9.99	15.07	19.98	25.06	31.02	38.03
PTP	14.2	psia		560	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
TPS	0.41	Volts	R	900	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
MAT	122	°F	P	1200	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
ECT	128	°F	M	1600	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
NGP	58.8	psia		2000	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
NGT	106	°F					Adaptive Parameters (%)					
PW	30.3	ms										

PWtiming	0.0	°ATDC	Adpt_Mult	+0.00	%	RunMode	STOPPED	
IgnAdv	5.0	°BTDC	K_Adapt	5	%	ControlMode	OPEN LOOP	
IgnOffst	+0.0	°BTDC	Adpt_step	2.00	%	RunTime	00:00:00	
			Adpt_dzone	1.00	%	EBP	14.41	psia
CL_Mult	+0.00	%	Adpt_max	+35.00	%	EBP_est	14.71	psia
K_CL	20	%	Adpt_min	-30.00	%	BP	14.71	psia
CL_step	5.00	%	Adpt_valid	3.00	%	VE_act	78.7	%
CL_switch	0		T_delay	4096	ms	Fuel_In	164.5	mg/inj
CL_max	+40.00	%	UEGO_Phi	1.017		MAPdt_mg	0.0	mg/inj
CL_min	-35.00	%	Phi	1.000				
BlockMult	100.0	%	Phi_delay	1.000				

GEM Lean Burn Control System Faults PROM ID: 2570-008- 09/11/98

Voltage	HIGH	LOW
EBP	17:OK	18:OK
FPP	21:OK	22:OK
TPS	54:OK	56:OK
MAT	23:OK	25:OK
MAP	33:OK	34:OK
PTP	37:OK	48:OK
ECT	26:OK	27:OK
NGT	14:OK	15:OK
NGP	38:OK	39:OK
NGTT	64:OK	65:OK
NGTP	66:OK	67:OK
UEGOP	63:OK	62:OK
UEGOH	58:OK	59:OK
UEGOR	68:OK	69:OK
Batt	53:OK	52:OK

Function	HIGH	LOW
EBP Exp	19:OK	29:OK
TPS Exp	57:OK	81:OK
NGP Exp	41:OK	43:OK
BP Exp	35:OK	36:OK
BoostExp	71:OK	72:OK
CL Limit	44:OK	45:OK
AL Limit	46:OK	47:OK

Function	
ECT High Exp	28:OK
MAT High Exp	24:OK
NGTP High Exp	83:OK
PTP Active	49:OK
OverBoost	73:OK
UEGOS Fail	13:OK
Oil Pressure	74:OK
Inj DutyCycle	75:OK

Miscellaneous	
Trigger	42:OK
TPS Cal	82:OK
J1708 Rx	83:OK
J1708 Tx	84:OK

ECU Internal	
COP	55:OK
Interrupt	55:OK
Analog	55:OK
Execution	55:OK
Clocks	55:OK
Stack	55:OK
RAM	51:OK

GEM Lean Burn Control System Diagnostics

Fault	High	Low	Miscellaneous Faults		Engine Parameters			
FPP	21:OK	22:OK	UEGOS Fail	13:OK	Speed	0	rpm	
TPS	16:OK	17:OK	Spark Input	42:OK	MAP	14.4	psia	15.1 Des
TPSExp	18:OK	19:OK	TPS_Cal	29:OK	PTP	14.2	psia	1.63 V
MAT	23:OK	25:OK	MAT_HiExp	24:OK	MAT	122	°F	1.37 V
MAP	33:OK	34:OK	OverBoost	73:OK	ECT	128	°F	1.43 V
PTP	35:OK	36:OK	PTP_Active	37:OK	NGP	93.1	psia	2.37 V
ECT	26:OK	27:OK	ECT_HiExp	28:OK	NGT	106	°F	1.96 V
NGT	14:OK	15:OK	Oil_Press	74:OK	FPP	0.41	V	0.41 Min
NGP	38:OK	39:OK	Inj_DutyCyc	75:OK	TPS	1.99	VCmd	0.02 FB
NGPExp	41:OK	43:OK	EBP_Hi	:OK	EBP	14.41	psia	2.41 V
BPExp	35:OK	34:OK	EBP_Lo	:OK	Phi	1.022	Act	1.000 Des
NGTT	64:OK	65:OK	EBP_HiExp	:OK	NGTP	0	psig	0.02 V
NGTP	66:OK	67:OK	EBP_LoExp	:OK	NGTT	-50	°F	5.00 V
UEGOP	63:OK	62:OK	Interrupts	55:OK	Batt	14.2	V	
UEGOH	58:OK	59:OK	COP	55:OK	IgnAdv	5.0	°BTDC	
UEGOR	68:OK	69:OK	Execution	55:OK	PW	19.5	ms	
Volts	53:OK	52:OK	Clocks	55:OK	CL_Mult	+0.00	%	
Boost	71:OK	72:OK	Stack	55:OK	AL_Mult	+0.00	%	
ALlim	46:OK	47:OK	Analog	55:OK	Control	OPEN LOOP		
CLlim	44:OK	45:OK	RAM	51:OK	RunTime	00:00:00		

APPENDIX D

FINAL REPORT FOR

TASK 2 – 1000-HOUR SUPER THERMAL CYCLE TEST

SwRI PROJECT NO. 03-7501-002

400-HOUR VALVE PERFORMANCE, 1500-HOUR DURABILITY, AND BREAK-IN AND PERFORMANCE MAPPING OF MACK E-7 NATURAL GAS ENGINES

FINAL REPORT
TASK 2 - 1000-HOUR SUPER THERMAL CYCLE TEST

SwRI Project No. 03-7501-002

Prepared for:

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Prepared by:

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November 1996

Approved:

James H. Garrett, Director
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EXECUTIVE SUMMARY

The original goal of this task was to perform two 1500-hour durability tests. Due to budget constraints, the two 1500-hour durability tests were replaced with one 1000-hour super thermal cycle durability test. The super thermal cycle consisted of two minutes at idle (unloaded stage) and 10 minutes at high speed and load (loaded stage). The engine was thermally "shocked" with 38°C (100°F) coolant at the unloaded stage and 94°C (200°F) coolant at the loaded stage to produce a 56°C (100°F) temperature difference between the stages.

The 1000-hour super thermal cycle durability test was completed. Basic engine performance data were recorded every hour during the test, and more detailed performance data were recorded every 25 hours. Oil consumption was recorded every 50 hours. Valve stem heights, valve lash, spark plug gaps, cylinder compression, and cylinder leak down were recorded every 250 hours.

Oil consumption was consistent for the first 750 hours. During the last 250 hours the engine had high oil consumption in part due to a failed blowby filter, which allowed oil to enter the engine directly through the intake system. Platinum-nickel tipped spark plugs showed a gap life of approximately 410 hours, whereas platinum-iridium tipped spark plugs showed a gap life of approximately 540 hours, although some of the platinum-iridium spark plugs appeared to be failing at the crimp before 540 hours. Cylinder pressure checks showed no loss of compression during the test, and valve recession was low.

Major problems encountered during the tests were spark plug failures, the blowby filter failure, and, as reported by Mack Trucks, piston cracking. Further work should include an investigation of the spark plug failure, a redesign of the blowby filter for a longer life, a redesign of the piston to prevent the cracking, and another 1000-hour test to verify the durability of the pistons.

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1.0 BACKGROUND

The goal of this project was to aid Mack Trucks, Inc. in expediting the development of a natural gas-fueled Mack E-7 engine. The project was originally broken down into three individual tasks. The purpose of the first task, "Four 100-Hour Valve Wear Tests," was to verify a valve seat/valve combination that exhibits the greatest resistance to wear. The purpose of the second task, "Two 1500-Hour Durability Tests," was to verify the durability of the recommended valve seat/valve combination and other natural gas-related hardware, including the engine control system. The purpose of the final task, "Ten Engine Break-In and Performance Mapping," was to verify through break-in procedures and performance mapping that fresh preproduction engines are assembled properly and that control system components function as required. A fourth task was added to the project for unscheduled maintenance, to account for changes in the original scope of work as directed by Mack Trucks, Inc.

The second task, "Two 1500-Hour Durability Tests," was replaced with, "One 1000-Hour Durability Test," using the super thermal cycle (STC) as provided by Mack Trucks. This durability test was completed and is reported herein.

Funding for this task was provided by this project and by the "Mack LNG Vehicle Development" project conducted by SwRI for Mack Trucks.

2.0 TECHNICAL DISCUSSION

A 1000-hour super thermal cycle (STC) durability test was conducted. The STC test cycle (as provided by Mack Trucks) consisted of two minutes at idle (unloaded stage) and ten minutes at high speed and load (loaded stage) with a coolant out temperature difference of 56°C (100°F) between the loaded and unloaded stages. The following sections describe the test schedule, engine and stand preparations, and test results.

2.1 Test Schedule

The test schedule for the durability test engine is shown in Table 1. The engine was rebuilt for this test schedule as described in the next section. Total engine hours, as described in this report, refers to the hours on the engine since the rebuild. STC test hours refers to the hours of actual test time on the STC cycle.

TABLE 1. TEST SCHEDULE

Test	Time (hours)	Engine Speed (rpm)	Power (kW)
Break-In	12	1950	121
Break-In	12	1950	242
Valve Recession	100	1950	266
Emissions	As needed	13 Mode Points	13 Mode Points
STC	500	STC Cycle	STC Cycle
Emissions	As needed	13 Mode Points	13 Mode Points
STC	500	STC Cycle	STC Cycle

The cycle for the STC test is shown in Table 2. The unloaded stage is at idle speed with minimum load. The loaded stage was selected by Mack Trucks as 1700 rpm and 110% load based on a power curve as provided by Renualt V.I. for an engine rated at 261 kW (350 hp) at 1900 rpm to reach 290 kW at 1700 rpm. At the loaded stage, the equivalence ratio was increased from 0.65 to 0.67 and the ignition timing was set to MBT. Due to the high ambient temperature in San Antonio at the time of the year this test was performed, the specified coolant out temperature for the unloaded stage (idle) of 32°C (90°F) could not be obtained. Therefore, a coolant out temperature of 38°C (100°F) was specified for the unloaded stage and 94°C (200°F) for the loaded stage. These temperatures maintain the 56°C (100°F) differential between the loaded and unloaded stages.

The schedule for data recording and maintenance during the 1000-hour durability test is shown in Table 3. Shutdowns were scheduled every 25 hours.

TABLE 2. SUPER THERMAL CYCLE

Parameter	Unloaded	Loaded
Engine Speed (rpm)	650	1700
Power (kW)	4	290
Time (minutes)	2	10
Coolant Out Temperature (°C at end of cycle)	38	94

TABLE 3. SCHEDULED DATA RECORDING AND MAINTENANCE

Description	Schedule
Oil Sample	At one hour after oil change
HP Hourly Data	Every hour
HP Snapshot Data	Every 25 hours
GEM Transient Data	Every 25 hours
GEM NGP Data	Every 25 hours
Oil Level Check (fill as needed)	Every 25 hours
Oil Sample	Every 50 hours
Oil Fill (record oil consumption)	Every 50 hours
Drain Blowby Filter Housing	Every 50 hours
Drain Gas Filter Housings	Every 50 hours
Add Adsorption Filter to Gas Line	At 250 hours
Replace Adsorption Filter Element	Every 250 hours
Measure Valve Stem Heights	Every 250 hours
Measure Valve Lash	Every 250 hours
Measure Spark Plug Gaps	Every 250 hours
Measure Cylinder Compression	Every 250 hours
Measure Cylinder Leak Down	Every 250 hours
Remove Catalyst	At 500 hours
Change Oil and Filters	At 500 hours
Replace Coalescing Fuel Filters	Every 500 hours
Measure Coolant Flow	Every 500 hours

2.2 Engine and Stand Preparations

The engine (S/N 9E-0002) used for the Task 1 valve wear tests was rebuilt for the 1000-hour durability test. There were a total of 653.4 hours on the engine block at the time of the rebuild which included 415.5 hours for the valve tests and 237.9 hours of miscellaneous time.

The engine was assembled with new spark plugs, pistons, piston rings, liners, and cylinder heads (provided by Mack Trucks). The pistons were modified by Mack Trucks to include a groove for the oil control ring groove which is closer to the piston top. The second rings were also modified to a Napier style ring. Engine specifications are shown in Table 4. The compression ring gaps were measured, and the results are shown in Table 5. Valve lash was set to 0.41mm (0.016") for intake valves and 0.71 mm (0.028") for exhaust valves, and spark plug gaps were set to 0.25mm (0.010").

TABLE 4. ENGINE SPECIFICATION

Engine Model	E7G-325
Engine Serial Number	9E0002
Engine Displacement (L)	12
Bore and Stroke (mm)	123.8 x 165.1
Piston	Modified Zolliner Aluminum H Ring
First Ring	1st Design
Second Ring	Modified to a Napier Style
Oil Ring	2nd Design
Camshaft Timing	8.57°CA Advanced
Ignition System Controller Supplier	MESA
Ignition System Coil Supplier	Nippondenso
Ignition System Type	Inductive
Ignition System Timing Sensor	Electro, K Coil
Spark Plug Supplier	Champion
Mixer Type	Fabricated Annular with One 90° Bend
Number of Holes in Mixing Ring	9
Fuel Metering System Supplier	MESA
Fuel Injector Type	Servojet SP021S1
Number of Injectors	8
Throttle Supplier	Woodward
Throttle Model	FLOWTECH, 68mm
Throttle Type	Electronic, Digital
UEGO Sensor	NGK Universal

TABLE 5. PISTON RING GAPS

Cylinder	1st Ring Gap (mm)	1st Ring Gap (in.)	2nd Ring Gap (mm)	2nd Ring Gap (in)
1	0.56	0.022	0.71	0.028
2	0.53	0.021	0.69	0.027
3	0.56	0.022	0.69	0.027
4	0.53	0.021	0.69	0.027
5	0.56	0.022	0.71	0.028
6	0.56	0.022	0.69	0.027

After the break-in, 100-hour valve recession test, and emissions tests were performed, the test stand was modified to thermally "shock" the engine for the durability test. Two coolant tanks were installed in the test cell to provide either hot coolant to the engine during the loaded stage, or cold coolant during the unloaded stage. The hot tank was maintained at approximately 93°C (200°F) at the beginning of the loaded stage and the cold tank was maintained at approximately 38°C (100°F) at the beginning of the unloaded stage. A schematic of the coolant system for the test is shown in Figure 1. A mixture of Nalcool™ 2000 and demineralized water at a ratio of 489 ml (16 ounces) of Nalcool™ to 15.2 l (4 gallons) of water was added to the cooling system. The test stand was also equipped with an external electric motor to operate the water pump on the engine at a constant speed that was equivalent to the speed of the water pump at 2000 rpm when the engine is in its normal configuration.

The oil and filters were changed. A catalyst was installed for Renault V.I. at the beginning of the STC test for aging. At the request of Renault V.I., it was removed at 500 test hours and will be returned to Mack Trucks. A closed crankcase ventilation system was installed, which included a blowby filter and canister provided by Mack Trucks and an in line blowby flow meter. The blowby was routed to the filter, the inline flow meter, and then to the inlet air for the engine between the laminar flow element and the turbocharger. New coalescing natural gas filters were installed. New style fuel injectors (part number SP-021S1) designed for LNG use were received from BKM Inc. and installed. An adsorption filter was added to the natural gas fuel line at 250 test hours on the STC. The first 250 hours were conducted without the adsorption filter in the fuel line. Figure 2 shows the schematic of the fuel filtering system with the adsorption filter installed.

2.3 Test Results

There were a total of 1147.6 hours on the engine since the rebuild for the durability test. A runtime history is shown in Table 6. The valve recession test was performed for Task 1 of this project, and therefore the results are not reported herein. Results of the HP data, GEM data, oil consumption, valve measurements, spark plug maintenance, cylinder compression and leak down measurements, coolant flow measurements, unscheduled shutdowns, and emissions tests are presented in the following sections.

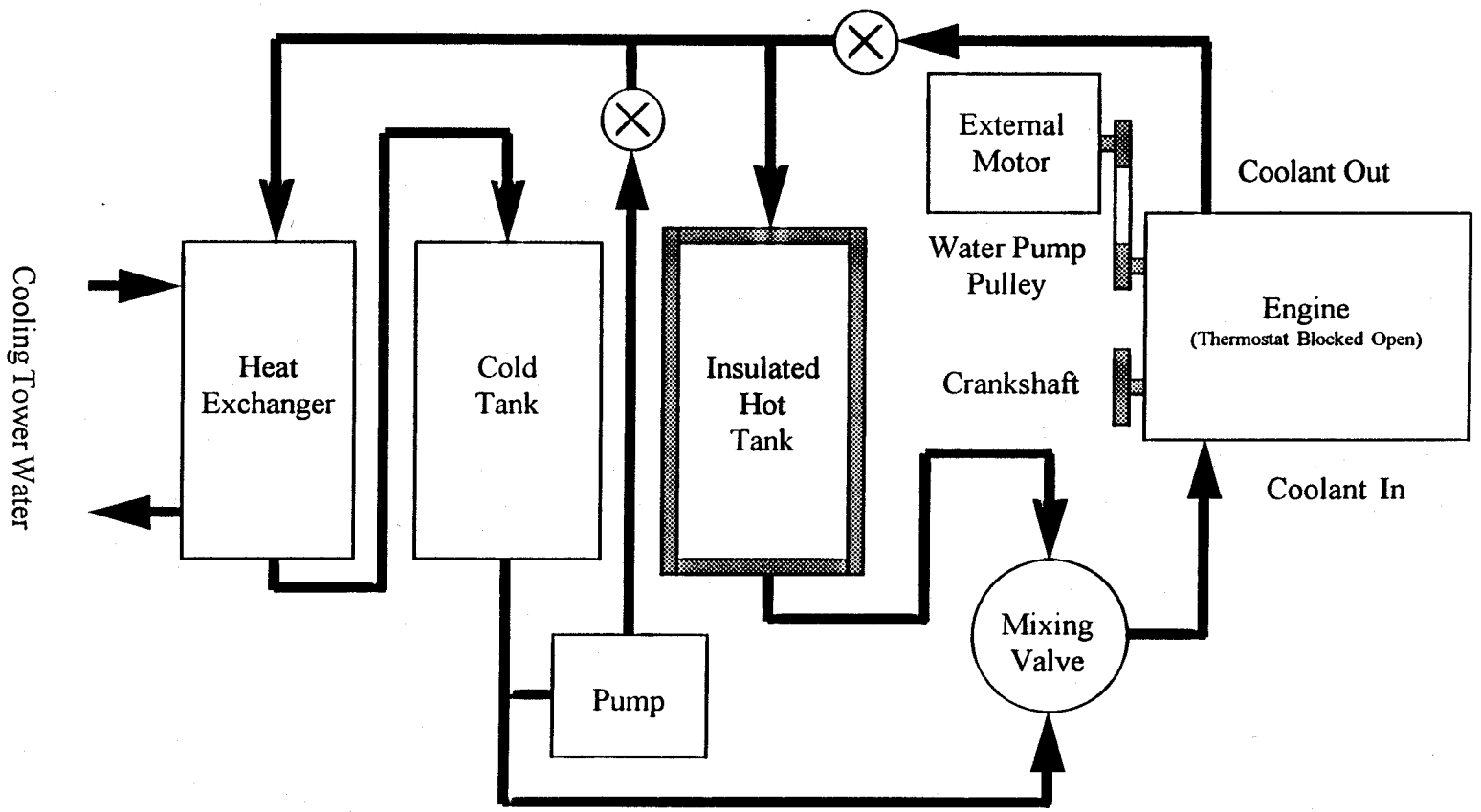


FIGURE 1. SUPER THREMAL CYCLE TEST STAND CONFIGURATION

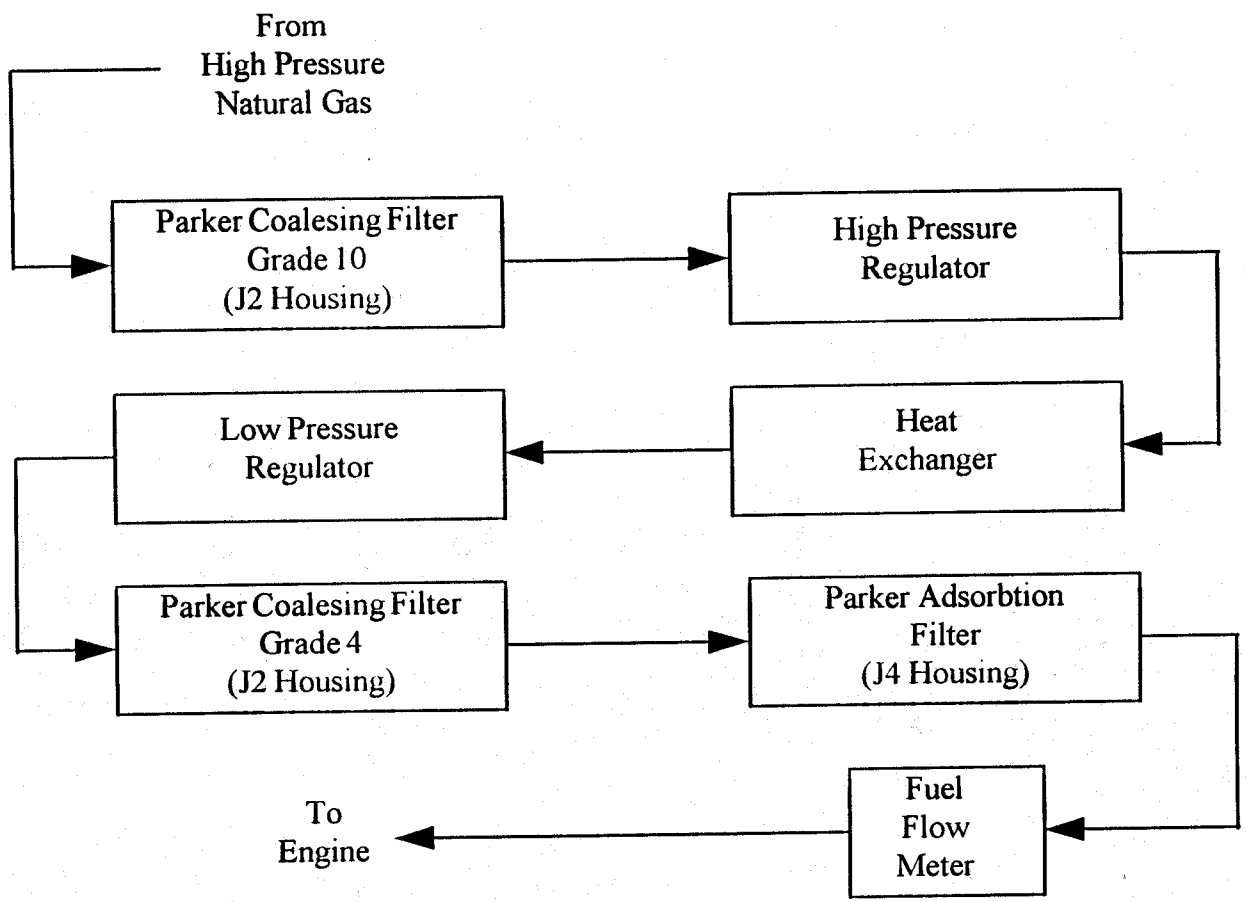


FIGURE 2. FUEL FILTER SIZE AND LOCATION FOR THE STC TEST

TABLE 6. RUNTIME HISTORY OF ENGINE SINCE THE REBUILD

Test Type	Test Type Time (Hours)	Miscellaneous Time (Hours)	Total Engine Time (Hours)
Break-In*	24.0	0.8	24.8
Valve Recession	100.0	4.5	129.3
STC	250.0	7.6**	386.9
STC	500.0	3.7	640.6
STC	750.0	4.9**	895.5
STC	1000.0	2.1	1147.6

* Includes Both 12-Hour Break-In Tests
** Includes Emissions Tests

2.3.1 HP Data

Hourly and snapshot data were recorded by the HP data acquisition system during the test. Hourly data were recorded by an average of two points within one minute of the end of each stage. Snapshot data were recorded for one full cycle in approximately 15 second intervals as a snapshot. There were a total of 1974 hourly readings and 2295 snapshot readings during the 1000-hour STC test. The hourly readings were not recorded correctly at 290 test hours due to unknown reasons, at 752 test hours due to an unscheduled shutdown during the data recording, at 836 test hours due to unknown reasons, and at 914 test hours due to an unscheduled shutdown during the data recording. A listing of all run numbers recorded during the STC test with corresponding test hours and data type is included in Appendix A.

2.3.2 GEM Data

Data from the gas engine management (GEM) system were recorded every 25 hours. Transient data were recorded for one full cycle in one second intervals for engine speed, manifold air pressure (MAP), volumetric efficiency (VE), and engine coolant temperature (ECT). Figure 3 shows the average readings from 1 to 1000 hours from the transient data. There were 40 sets of data recorded. Data at 275 and 300 were not recorded correctly due to operator error, and additional data at 309 hours were recorded. Figures 4-7 show the average for each parameter along with a band of one standard deviation. Figures for individual reading are included in Appendix B.

Data from the GEM system for injector block leak down were recorded every 25 hours. Data were recorded for two minutes at one second intervals by starting the data acquisition with the ignition key turned off, then turning the ignition key on (without starting the engine) within five seconds after starting the data acquisition. Turning the key on energizes the solenoid in the injector block to allow fuel to pressurize the injector block. When the GEM system does not receive a signal

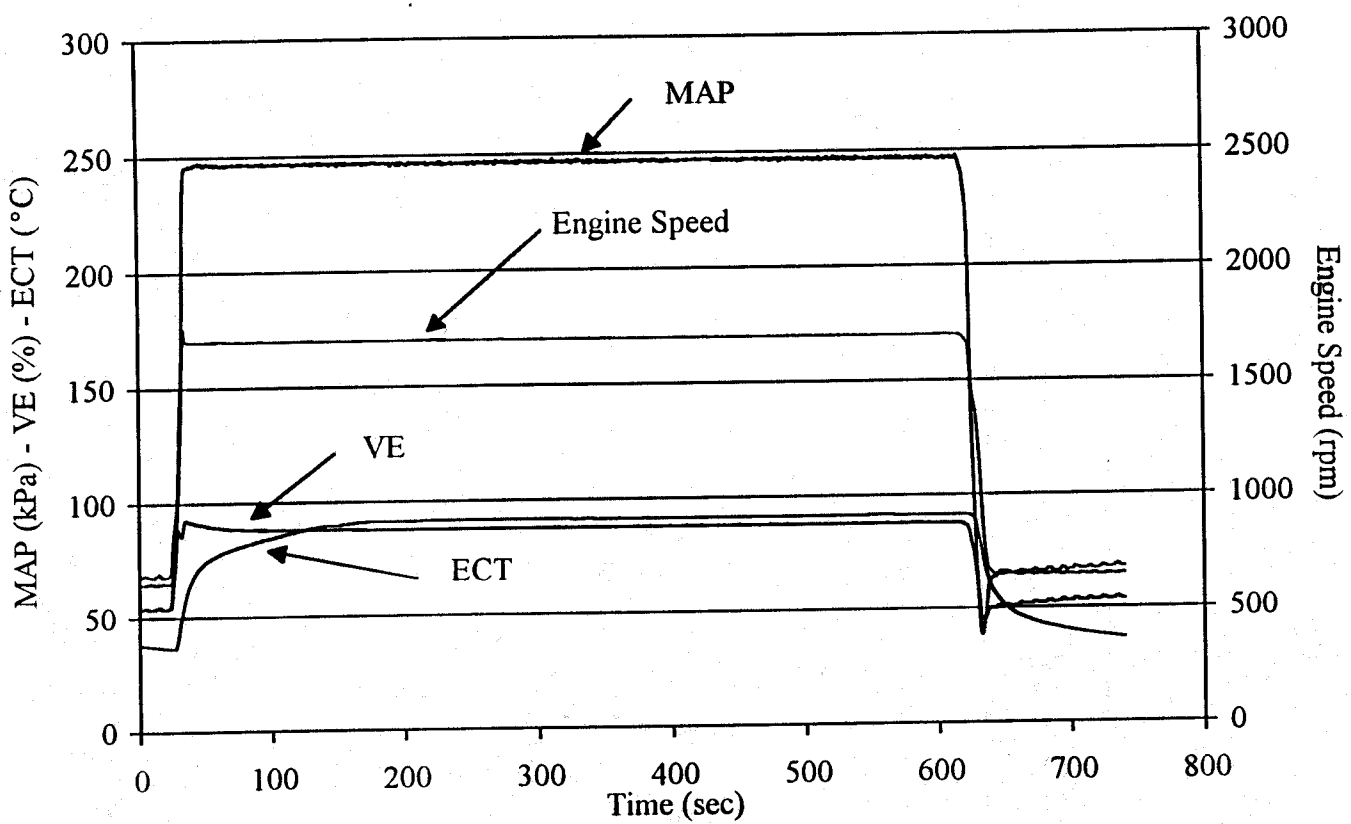


FIGURE 3. AVERAGE OF 40 READINGS RECORDED BETWEEN 1 AND 1000 HOURS FROM THE GEM SYSTEM DURING THE STC TEST.

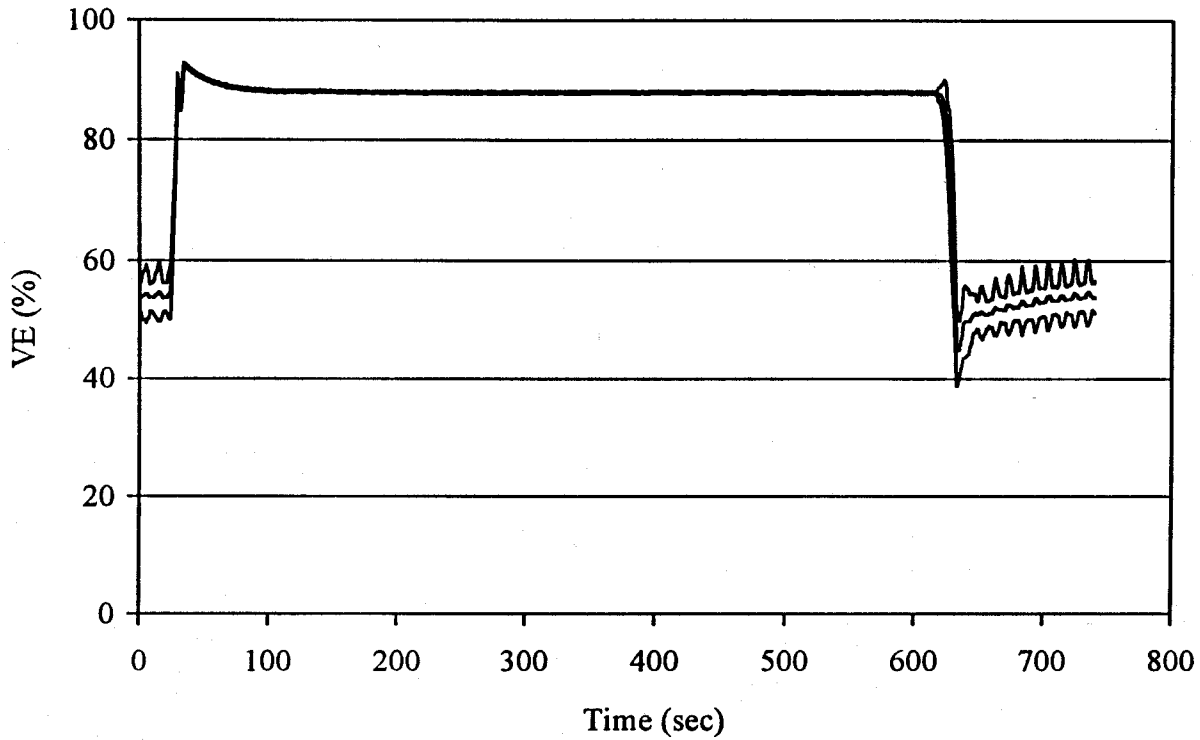


FIGURE 4. AVERAGE OF 40 READINGS AND ± ONE STANDARD DEVIATION FOR VE RECORDED BETWEEN 1 AND 1000 HOURS FROM THE GEM SYSTEM DURING THE STC TEST.

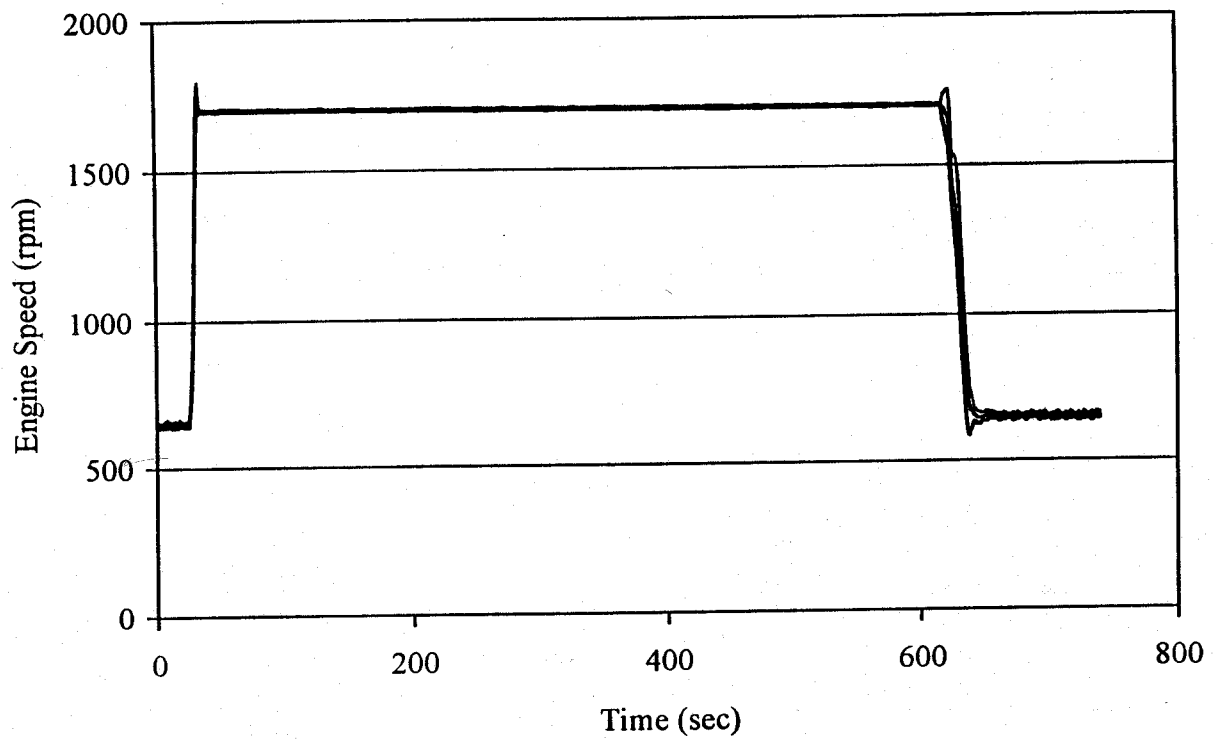


FIGURE 5. AVERAGE OF 40 READINGS AND ± ONE STANDARD DEVIATION FOR ENGINE SPEED RECORDED BETWEEN 1 AND 1000 HOURS FROM THE GEM SYSTEM DURING THE STC TEST.

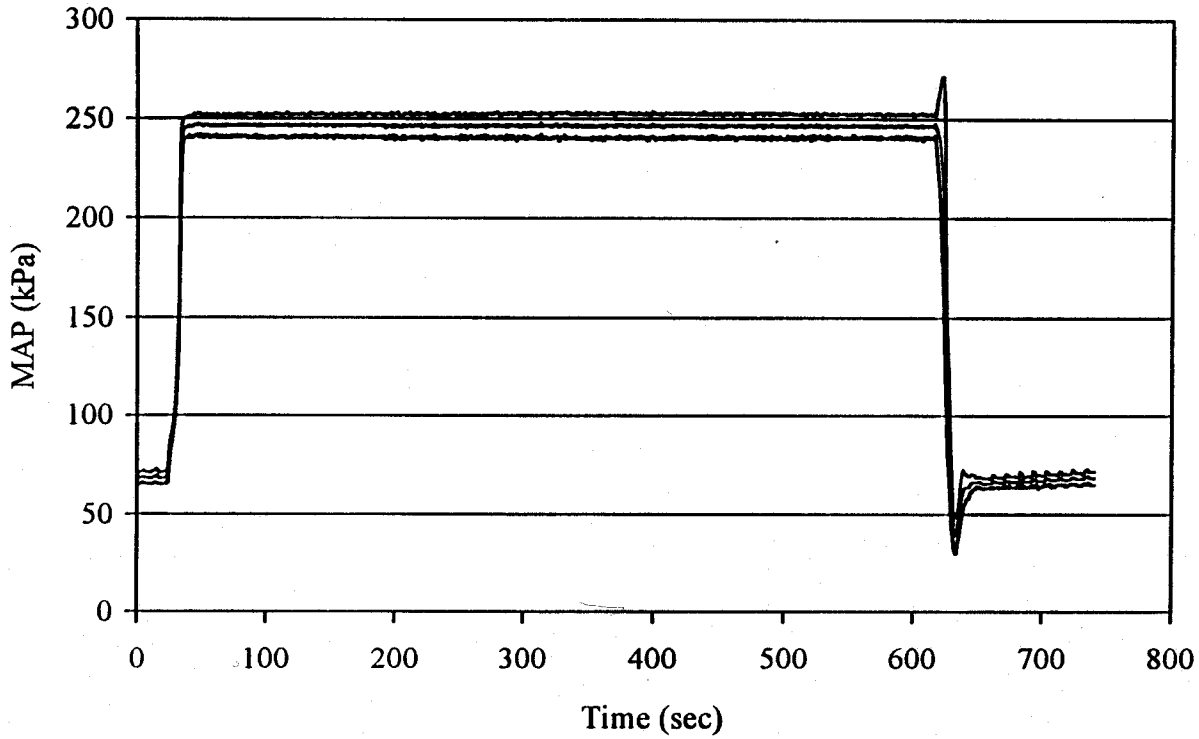


FIGURE 6. AVERAGE OF 40 READINGS AND ± ONE STANDARD DEVIATION FOR MAP RECORDED BETWEEN 1 AND 1000 HOURS FROM THE GEM SYSTEM DURING THE STC TEST.

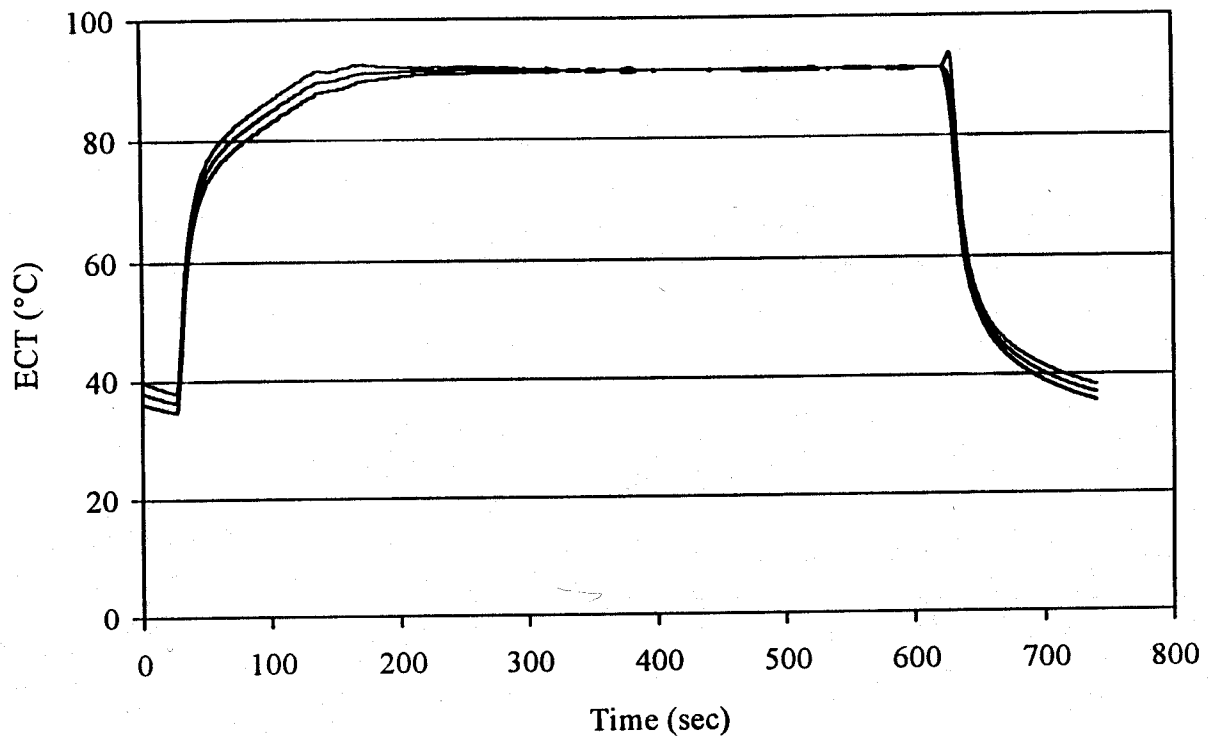


FIGURE 7. AVERAGE OF 40 READINGS AND ± ONE STANDARD DEVIATION FOR ECT RECORDED BETWEEN 1 AND 1000 HOURS FROM THE GEM SYSTEM DURING THE STC TEST.

that the engine has started, it de-energizes the solenoid, and the GEM system records the pressure in the injector block as it leaks down. Figures 8 and 9 show the data from the injector block leak down at the beginning and end of the test, respectively. All other data from the injector block leak down showed similar results. The static pressure to the injector block (setting of the low pressure regulator) is set to maintain at least 620 kPa (90 psia) when the engine is in the loaded stage. The regulator was reset at 250 hours to account for the pressure loss associated with the addition of the adsorption filter, therefore the static pressure in the injector block at the end of the test was greater than at the beginning. Figure 10 shows the leak down rate during the STC test. Each of the injectors operated for approximately 68 million cycles at the end of the test.

2.3.3 Oil Consumption

Dryden Experimental natural gas oil was used for the durability test. Oil samples were taken and sent to Dryden Oil for analysis. Results of the analysis were sent to Mack Trucks.

Oil was added and oil consumption was recorded every 50 hours during the STC test. In addition, the level was checked at 25 hours after each oil add, and oil was added as needed. The procedure used for recording oil consumption was as follows:

(1) While engine is idling, take a small discard sample from the engine and record weight.
(2) After taking discard sample, take oil sample from engine and record weight.
(3) After engine is stopped, drain oil from blowby filter housing and record weight.
(4) After engine is stopped, record weight of oil leakage.
(5) After the engine has soaked for 10 minutes, fill with oil until level is at the full mark on the dip stick and record weight.
(6) Calculate oil consumption from the amount of oil added in step 5 plus the amount of oil added at the 25 hour oil level check (if any), minus the amount of oil drained in steps 1-4 minus any other oil drains during the 50 hours.

The estimated accuracy of the oil adds is approximately ± 100 grams. Oil adds and drains are shown in Table 7, and oil consumption is shown in Table 8 along with average blowby for each stage. At 150 hours, the drain from the blowby filter was not recorded correctly, therefore the oil consumption calculation at 150 hours in Table 8 includes the oil drained from the blowby filter housing.

2.3.4 Valve Measurements

Valve lash and valve stem heights were measured before, during, and after the STC test. Results of the intake and exhaust valve stem height measurements are shown in Figures 11 and 12, respectively. Data for the valve stem height measurements are included in Appendix C. Valve lash measurements are shown in Table 9.

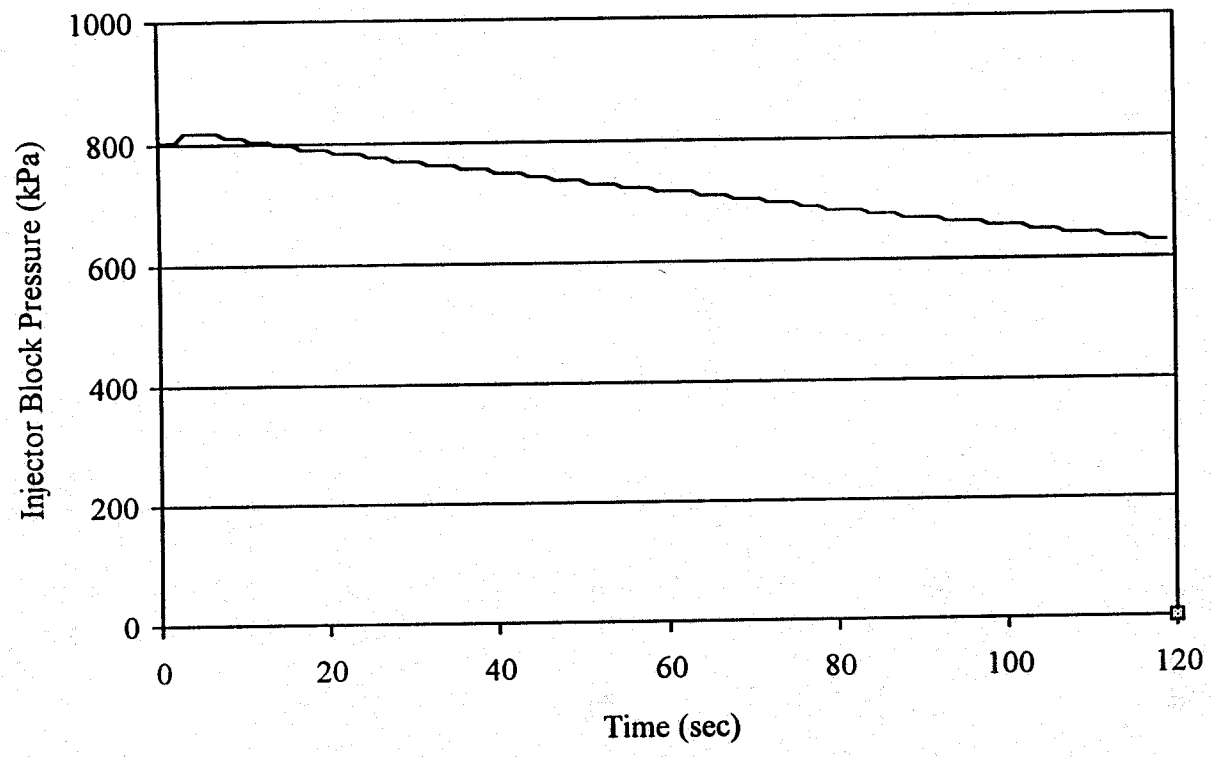


FIGURE 8. DATA FROM THE INJECTOR BLOCK LEAK DOWN BEFORE THE START OF STC TEST.

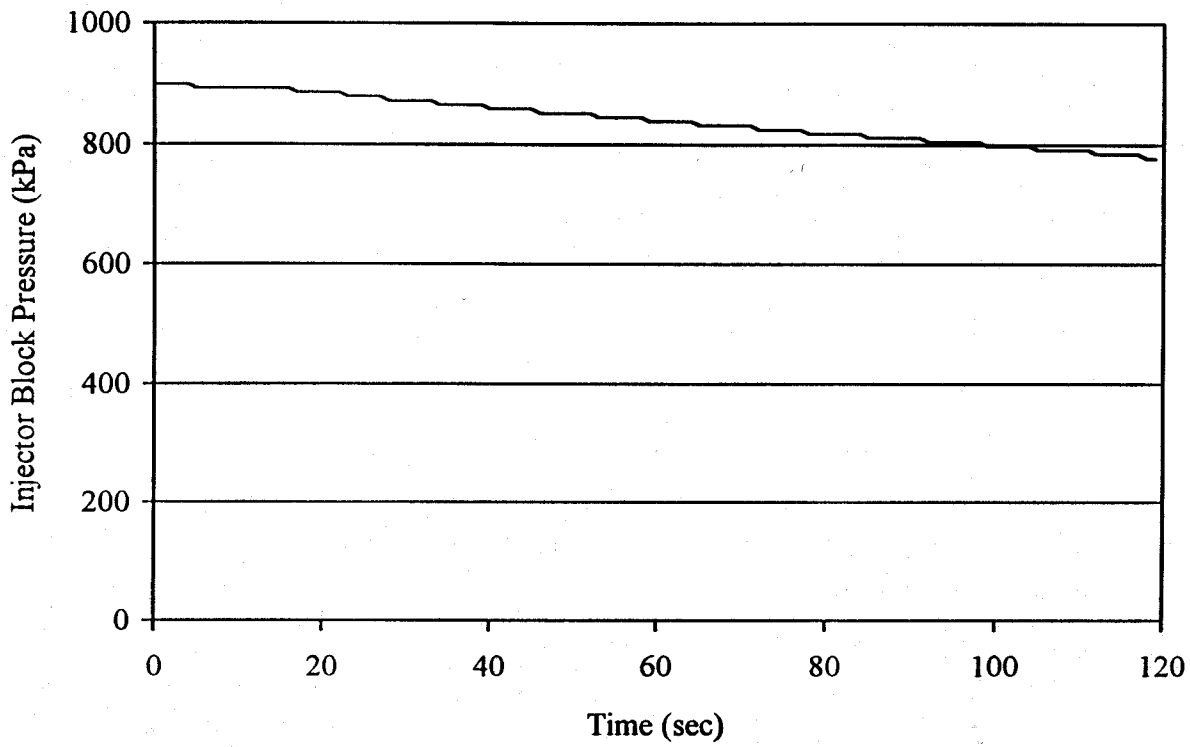


FIGURE 9. DATA FROM THE INJECTOR BLOCK LEAK DOWN AT THE END OF STC TEST.

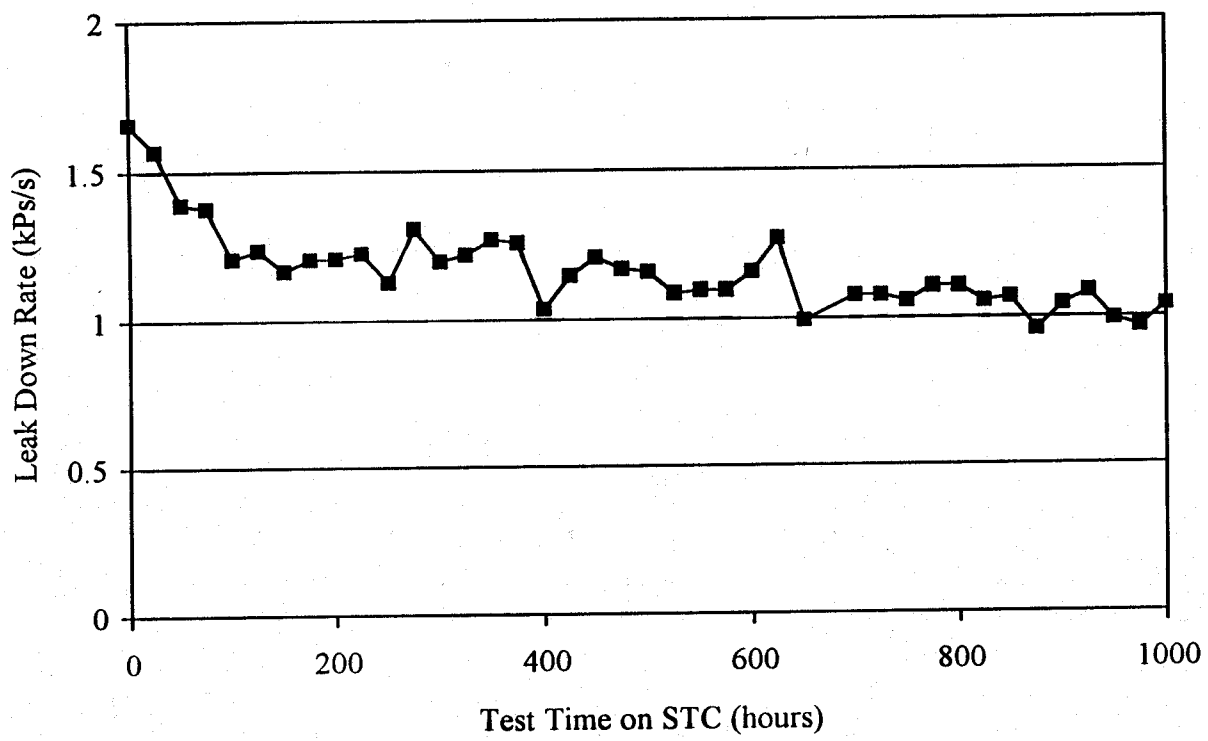


FIGURE 10. INJECTOR BLOCK LEAK DOWN RATE DURING THE STC TEST

TABLE 7. OIL ADDS AND DRAINS

Test Hour	Oil Add (grams)	Oil Drained for Discard (grams)	Oil Drained for Sample (grams)	Oil Drained from Leakage (grams)	Oil Drained from Blowby (grams)
1		28	150		
50	2433	25	148	7	8
100	1788	33	121	14	17
150	1287	28	137	9	
200	1956	28	138	6	33
250	2827	24	144	7	39
300	1949	40	148	25	57
350	2345	24	141	28	28
400	2440	18	134	21	77
450	3047	12	136	18	114
500	3168	23	151	21	111
501		19	144		
550	2145	28	145	3	149
600	3022	24	138	1	131
650	2801	18	143	2	110
700	2900	5	144	14	118
750	2641	15	145	1	137
775	2359				
800	1841	40	131	4	145
850	3978	24	146	33	154
870	1870				
900	3159	26	128	49	37
925	1617				
950	3208	22	144	130	12
975	1632				
1000	3181	28	131	127	30

TABLE 8. OIL CONSUMPTION

Test Hour	Oil Consumption (grams)	Oil Consumption (g/kw-hr)	Average Blowby for 650 rpm Operation (l/min)	Average Blowby for 1700 rpm Operation (l/min)
0-50	2,067	0.174	7.5	106.5
50-100	1,593	0.133	6.6	108.2
100-150	1,113	0.094	7.0	109.6
150-200	1,751	0.148	7.6	111.6
200-250	2,613	0.221	8.0	114.0
250-300	1,679	0.143	9.0	119.4
300-350	2,124	0.182	9.3	123.0
350-400	2,190	0.185	9.1	124.9
400-450	2,767	0.229	10.5	130.9
450-500	2,862	0.239	10.3	131.4
500-550	1,647	0.137	10.1	134.6
550-600	2,728	0.229	10.3	129.7
600-650	2,528	0.209	9.6	126.7
650-700	2,619	0.219	9.4	133.2
700-750	2,343	0.196	9.7	136.3
750-800	3,880	0.328	9.8	137.5
800-850	3,621	0.307	10.1	141.8
850-900	4,789	0.406	10.4	150.3
900-950	4,517	0.380	10.6	146.3
950-1000	4,497	0.371	10.6	148.6
0-1000	53,928	0.227	9.3	128.2

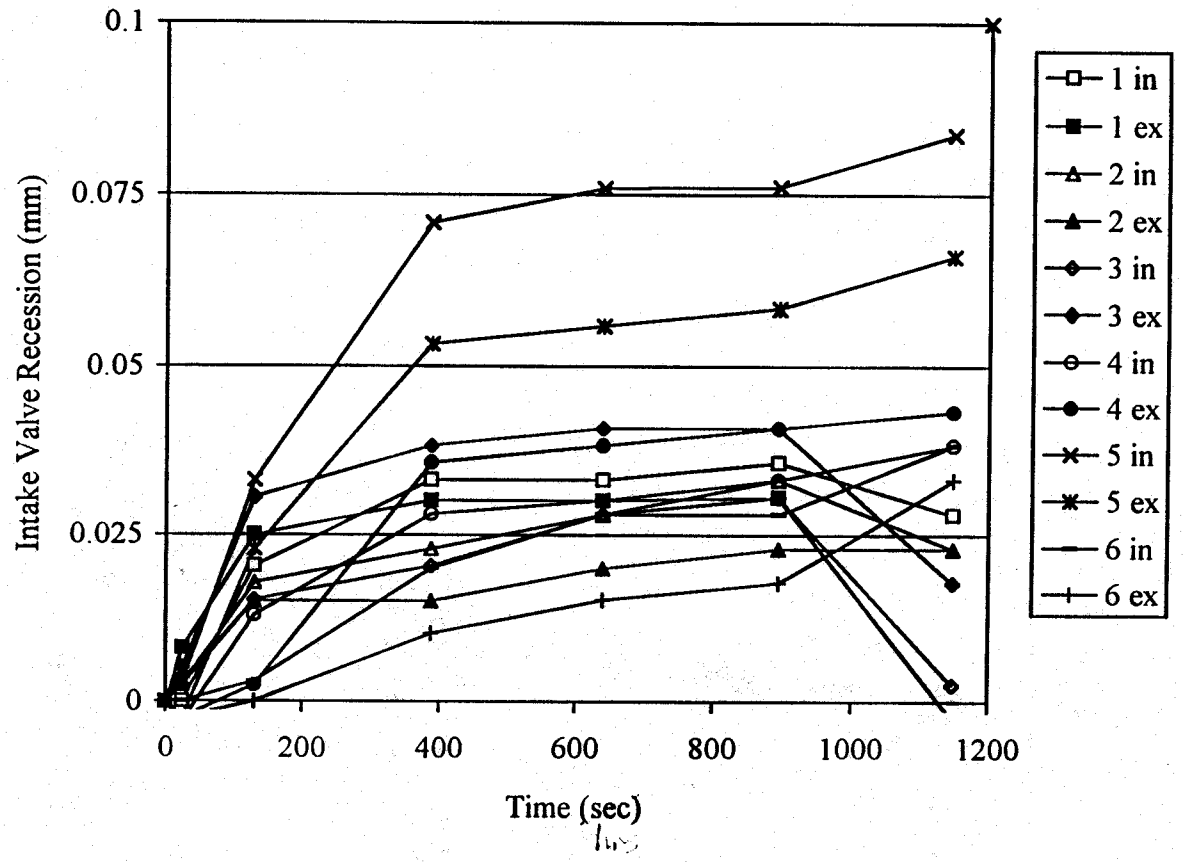


FIGURE 11. INTAKE VALVE RECESSION

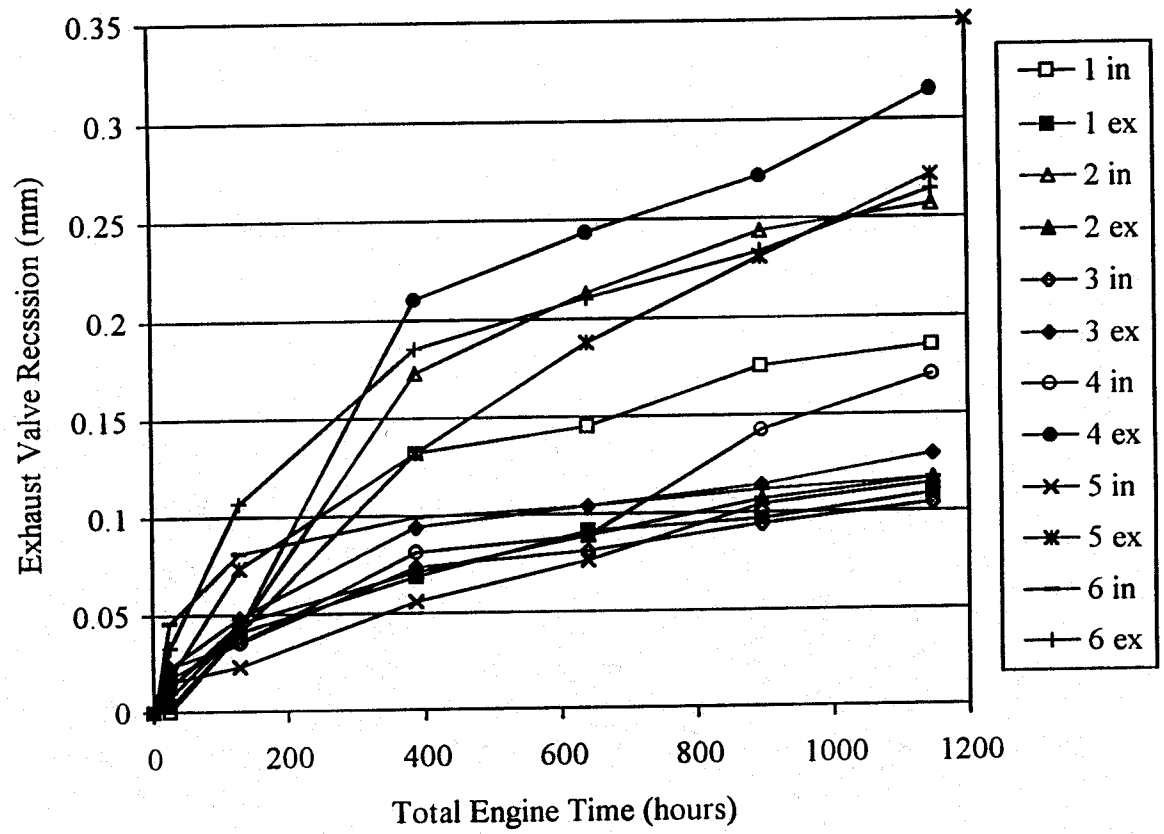


FIGURE 12. EXHAUST VALVE RECESSION

TABLE 9. VALVE LASH MEASUREMENTS

Cylinder	Valve	Lash (mm) @ Total Engine Hour						
		0.0	24.8	129.3	386.9	640.6	895.5	1147.8
1	in.	0.41	0.33	0.30	0.28	0.28	0.28	0.28
2	in.	0.41	0.36	0.30	0.28	0.25	0.25	0.25
3	in.	0.41	0.36	0.33	0.30	0.28	0.28	0.30
4	in.	0.41	0.38	0.33	0.28	0.28	0.25	0.28
5	in.	0.41	0.38	0.36	0.36	0.30	0.30	0.30
6	in.	0.41	0.38	0.33	0.30	0.28	0.28	0.25
1	ex.	0.71	0.66	0.61	0.53	0.51	0.51	0.46
2	ex.	0.71	0.69	0.61	0.56	0.51	0.51	0.48
3	ex.	0.71	0.66	0.61	0.53	0.56	0.56	0.56
4	ex.	0.71	0.66	0.64	0.56	0.53	0.51	0.46
5	ex.	0.71	0.66	0.61	0.53	0.51	0.51	0.51
6	ex.	0.71	0.69	0.64	0.58	0.53	0.53	0.53

2.3.5 Spark Plugs Maintenance

Champion spark plugs were used for the durability test. New spark plugs were installed in the engine before the break-in. All new spark plugs installed in the engine were initially gapped to 0.25 mm (0.010"). The history of spark plug maintenance is shown in Table 10.

The initial set of RX501PYP/1E5 spark plugs were platinum-nickel tipped. At 410.6 total engine hours, the No. 4 cylinder started misfiring due to a large gap and the spark plug was replaced. At 416.8 total engine hours, the No. 5 cylinder started misfiring due to a large gap and the spark plug was replaced. At 427.5 total engine hours, spark plug Nos. 1,2,3, & 6 were replaced. All replacements were with RX501PYP/1E5 spark plugs (platinum-nickel tipped). All six of the original spark plugs were sent to Champion for inspection.

At 565.1 total engine hours, the RX501PYP/1E5 spark plugs (platinum-nickel tipped) were replaced with RC550PYP/4F6 spark plugs (platinum-iridium tipped) for short-term use until the platinum-iridium tipped RX501PYP spark plugs were available. Since these spark plugs have a 19mm reach (0.75") and the engine requires a 13mm (0.50") reach, they were modified to fit this engine by adding a thick copper washer.

TABLE 10. SPARK PLUG HISTORY

Total Engine Hours	Test Hours on the STC	Description
0.0	---	Installed new Champion RX501PYP/1E5 (platinum-nickel) spark plugs, gapped to 0.25 mm (0.010").
129.3	0.0	Checked gaps, start of STC test.
386.9	250.0	Checked gaps.
410.6	273.5	Misfire on cylinder No. 4, replaced with new Champion RX501PYP/1E5, gapped to 0.25 mm (0.010").
416.8	278.9	Misfire on cylinder No. 5, replaced with new Champion RX501PYP/1E5, gapped to 0.25 mm (0.010").
427.5	289.5	Replaced spark plugs in cylinders Nos. 1,2,3, and 6 with new Champion RX501PYP/1E5, gapped to 0.25 mm (0.010").
565.1	425.0	Replaced spark plugs in all cylinders with new Champion RC550PYP/4F6 (platinum-iridium) spark plugs, gapped to 0.25 mm (0.010"). (Spark plugs were modified with additional copper gasket to provide the correct depth)
640.6	500.0	Replaced spark plugs in all cylinders with new Champion RX501PYP/2H6 (platinum-iridium) spark plugs, gapped to 0.25 mm (0.010").
895.5	750.0	Checked Gaps.
897.8	752.0	Spark plug in the No. 2 cylinder failed (ceramic insulator broke into small pieces), replaced with new Champion RX501PYP/2H6 gapped to 0.25mm (0.010"). Also replace spark plug boot.
1060.8	914.1	Spark plug in the No. 4 cylinder failed (ceramic insulator separated from metal shell), replaced with new Champion RX501PYP/1E5 gapped to 0.25mm (0.010"). Also replaced spark plug boot.
1060.8	914.1	Spark Plug in the No. 1 cylinder showed possible signs of leakage between the ceramic insulator and the metal shell, replaced with new Champion RX501PYP/2H6, gapped to 0.25 mm (0.010").
1060.8	914.1	Checked gaps while engine was down.
1079.8	932.7	Misfire on cylinder No. 6, replaced with new Champion RX501PYP/1E5, gapped to 0.25 mm (0.010").
1147.6	1000.0	Checked gaps.

At 640.6 total engine hours, the RC550PYP/4F6 spark plugs (platinum-iridium tipped) were replaced with RX501PYP/2H6 spark plugs (platinum-iridium tipped). The gaps on these spark plugs were checked at 895.5 total engine hours (254.9 hours on the spark plugs), as scheduled. At 897.7 total engine hours (257.1 hours on the spark plug), the spark plug in the No. 2 cylinder broke apart and was replaced with a RX501PYP/2H6 spark plug (platinum-iridium tipped). At 1060.8 total engine hours (420.2 hours on the spark plug), the spark plug in the No. 4 cylinder broke apart and was replaced with a RX501PYP/1E5 spark plug (platinum-nickel tipped), and the spark plug in the No. 1 cylinder showed signs of leakage and was replaced with a RX501PYP/2H6 spark plug (platinum-iridium tipped). These three spark plugs were sent to Champion for inspection. At 1079.8 total engine hours (439.2 hours on the spark plug), the No. 6 cylinder started misfiring due to a large gap, and the spark plug was replaced with a RX501PYP/1E5 spark plug (platinum-nickel tipped).

Copies of the letters sent to Champion Spark Plugs concerning this test are included in Appendix D. The letters included a detailed discussion of the failure of the platinum-iridium spark plugs. According to Champion Spark Plugs, the failure was a result of over-torquing the spark plugs during installation. However, further experiments conducted by SwRI indicate that the spark plugs were not over-torqued. Figure 13 shows the spark plug gap growth and Table 11 shows the data.

2.3.6 Cylinder Compression and Leak Down Measurements

Cylinder compression and leak down measurements were recorded every 250 test hours on the STC cycle. The results are shown in Tables 12 and 13 respectively. Cylinder leak down was performed by regulating air upstream of a 1.02 mm (0.040") orifice at 690 kPa_{gage} (100 psig), and measuring pressure downstream of the orifice (cylinder pressure). The percent leak down is the difference between the upstream and downstream pressure normalized by the upstream pressure.

2.3.7 Coolant Flow Measurements

Coolant flow was measured every 500 hours on the STC cycle. A turbine flow meter was installed in the coolant line between the outlet of the engine and the gate valve for these tests. Coolant flow was measured at a typical valve position during the unloaded and loaded stages. The results are shown in Table 14.

2.3.8 Unscheduled Shutdowns

Shutdowns for the engine are scheduled for every 25 hours. Unscheduled shutdowns are shown in Table 15.

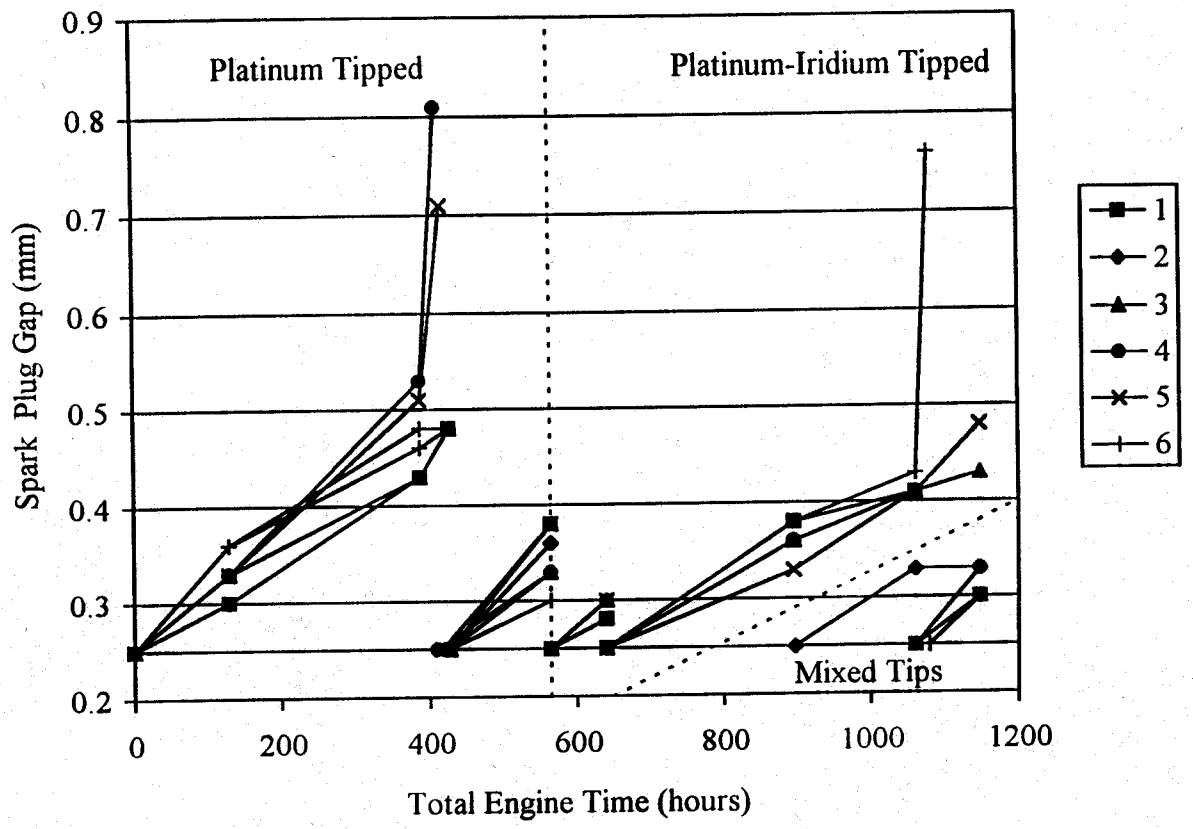


FIGURE 13. SPARK PLUG GAP GROWTH

TABLE 11. SPARK PLUG GAPS

Total Engine Hours	STC Test Hours	Gap for Cylinder (mm)					
		1	2	3	4	5	6
0.0	0.0	0.25	0.25	0.25	0.25	0.25	0.25
129.3	0.0	0.30	0.30	0.33	0.33	0.33	0.36
386.9	250.0	0.43	0.43	0.43	0.53	0.51	0.46
410.6	273.5				0.81		
					Replaced		
					0.25		
416.8	278.9					0.71	
						Replaced	
						0.25	
427.5	289.5	0.48	0.48	0.48			0.48
		Replaced					Replaced
		0.25	0.25	0.25			0.25
565.1	425.0	0.38	0.36	0.33	0.33	0.38	0.30
		Replaced					
		0.25	0.25	0.25	0.25	0.25	0.25
640.6	500.0	0.28	0.30	0.25	0.28	0.30	0.30
		Replaced					
		0.25	0.25	0.25	0.25	0.25	0.25
895.5	750.0	0.38	0.38	0.36	0.36	0.33	0.38
897.8	752.0		Replaced				
			0.25				
1060.8	914.1	0.41	0.33	0.41	Replaced	0.41	0.43
		Replaced			0.25		
		0.25					
1079.8	932.7						0.76
							Replaced
							0.25
1147.6	1000.0	0.30	0.33	0.43	0.33	0.48	0.30

TABLE 12. CYLINDER PRESSURES

Compression @ ~200 rpm (KPa_{gage})					
Total Engine Hours	**129.3**	**386.9**	**640.6**	**895.5**	**1147.6**
Hours on STC Cycle	**0.0**	**250.0**	**500.0**	**750.0**	**1000.0**
Cylinder No. 1	1469	1517	1586	1660	1590
Cylinder No. 2	1276	1448	1517	1520	1480
Cylinder No. 3	1531	1689	1724	1690	1690
Cylinder No. 4	1531	1620	1586	1660	1620
Cylinder No. 5	1572	1565	1586	1720	1690
Cylinder No. 6	1538	1517	1655	1690	1690

TABLE 13. CYLINDER PRESSURE LEAK DOWN

Leak Down (%)					
Total Engine Hours	**129.3**	**386.9**	**640.6**	**895.5**	**1147.6**
Hours on STC Cycle	**0.0**	**250.0**	**500.0**	**750.0**	**1000.0**
Cylinder No. 1	78	80	80	76	74
Cylinder No. 2	80	88	87	88	82
Cylinder No. 3	36	36	41	48	50
Cylinder No. 4	74	47	78	56	75
Cylinder No. 5	49	43	47	57	52
Cylinder No. 6	18	30	17	21	22

TABLE 14. COOLANT FLOW MEASUREMENTS

Hours on STC Cycle	Coolant Flow at Unloaded Stage (l/m)	Coolant Flow at Loaded Stage (l/m)
0.0	232	314
500.0	303	336
1000.0	295	329

TABLE 15. UNSCHEDULED SHUTDOWNS ON THE STC TEST

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
8/1/96	160.4	26.1	"ALlim" high fault on GEM. Adjusted VE table, set K-Adapt to 0%. Stopped engine and restarted.
8/1/96	165.8	32.1	"CLlim" low fault on GEM. Stopped engine and restarted.
8/2/96	176.0	42.0	Air in cooling system. Stopped engine. Pressurized coolant system with regulated shop air. Restarted engine.
8/2/96	184.1	50.0	Engine would not start. Provided more fuel to start. Restarted engine.
8/3/96	205.3	71.1	Low water pressure to building. Stopped engine. Water pressure to building restored. Restarted engine.
8/5/96	236.2	100.4	Engine would not start. Modified VE table to provide more fuel at idle. Restarted engine.
8/7/96	294.9	158.9	"UEGOS fail" fault on GEM. Stopped engine and restarted.
8/7/96	297.0	160.9	"UEGOS fail" fault on GEM. Stopped engine. Replaced UEGO sensor. Restarted engine.
8/10/96	350.4	213.8	"UEGOS fail" fault on GEM. Stopped engine and restarted.
8/10/96	351.1	214.4	"UEGOS fail" fault on GEM. Stopped and restarted engine.
8/13/96	410.6	273.5	Cylinder No. 4 misfiring. Stopped engine. Replaced spark plug. Restarted engine.
8/13/96	412.6	275.2	"CLlim" low fault on GEM. Stopped engine and restarted.
8/13/96	416.8	278.9	Cylinder No. 5 misfiring. Stopped engine. Replaced spark plug. Restarted engine.
8/14/96	427.6	289.5	Stopped engine. Replaced spark plugs in cylinders Nos. 1,2,3, and 6. Restarted engine.
8/15/96	445.4	307.0	Engine mounting bolt broke. Stopped engine. Replaced bolt. Restarted engine.
8/17/96	505.2	366.3	"UEGOS fail" fault on GEM. Stopped and restarted engine.
8/19/96	548.7	409.3	Lab power failure. Engine stopped. Restarted engine.

TABLE 15. UNSCHEDULED SHUTDOWNS ON THE STC TEST (CONT'D)

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
8/19/96	522.2	412.3	Lost fuel pressure. Engine stopped. Fuel supply restored. Restarted engine.
8/28/96	658.5	515.3	Loose driveshaft coupling flange . Stopped engine. Replaced flange and coupling. Restarted engine.
9/3/96	821.0	577.0	Gas compressor failure. Engine stopped. Gas compressor restarted. Restarted engine.
9/8/96	845.2	700.3	Coolant leak at inlet ot turbocharger. Coolant line on engine was supplied by SwRI. Stopped engine. Replaced coolant line. Restarted engine.
9/9/96	851.1	705.8	Engine mounting bolt broke. Stopped engine. Replaced bolt. Restarted engine.
9/11/96	895.0	749.6	Boost hose at turbocharger outlet came loose. Stopped engine. Tightened clamps on boost hose. Restarted engine.
9/12/96	897.8	752.0	Spark plug in the No. 2 cylinder failed. Stopped engine. Replaced spark plug and spark plug boot. Also replaced exhaust stack thermocouple Restarted engine.
9/20/96	1060.8	914.1	Spark plug in the No. 4 cylinder failed. Stopped engine. Measured gap on all spark plugs. Replaced spark plug and spark plug boot on No. 4 cylinder, replaced spark plug on No. 1 cylinder. Restarted engine.
9/21/96	1079.8	932.7	Cylinder No. 6 misfiring. Stopped engine. Replaced spark plug. Restarted engine.

2.3.9 Emissions Tests

Exhaust emissions for the European emissions test (ECE R49, December 1993), both before and after the catalyst, were recorded at 0 and 500 test hours on the STC test. The engine was returned to its original cooling sytem configuration for these tests, and the calibration from the "Mack LNG Engine Development for Long-Haul Truck" project for Renault V.I. (RVI) conducted at SwRI was used. The test stand used for the "Mack LNG Engine Development for a Long Haul Truck" (cell 04) was different from the one used for the emissions tests at 0 and 500 hours reported here (cell 05). Due to the differences in the test stands, the exhaust system was lengthened by 41 cm (16") between the engine and the catalyst.

Results of the 13 mode tests at 0 test hours are shown in Table 16. Additional tests were conducted with the exhaust pipe insulated between the turbocharger and the catalyst for Mode 6. Low speed data (run numbers 890-891, 894-915) are included in Appendix E. Further details of the emissions results are included in Appendix F.

TABLE 16. RESULTS OF THE 13-MODE EUROPEAN EMISSIONS TEST AT 0 HOURS ON THE STC TEST

Mode	Catalyst THC Eff	BSTHC		$BSNO_x$ (corrected)		BSCO	
		(g/kw-hr)	g/bhp-hr)	(g/kw-hr)	g/bhp-hr)	(g/kw-hr)	g/bhp-hr)
1,7,13	15%	13.87	10.37	0.71	0.53	0.00	0.00
2	1%	11.75	8.78	0.72	0.54	0.00	0.00
3	32%	3.18	2.38	1.54	1.15	0.00	0.00
4	70%	.092	0.69	3.23	2.41	0.00	0.00
5	72%	1.50	1.12	3.78	2.83	0.00	0.00
6	78%	1.43	1.07	2.60	1.95	0.00	0.00
8	83%	0.40	0.30	2.22	1.66	0.00	0.00
9	91%	0.31	0.20	1.76	1.32	0.00	0.00
10	96%	0.32	0.20	1.01	0.75	0.00	0.00
11	88%	1.20	0.89	0.93	0.69	0.00	0.00
12	84%	3.40	2.54	0.91	0.68	0.00	0.00
13 -mode	---	1.66	1.24	2.48	1.85	0.00	0.00
6*	77%	1.41	1.06	3.18	2.37	0.00	0.00
13-mode*	---	1.65	1.23	2.71	2.02	0.00	0.00

* Exhaust pipe insulated on mode 6.

Results of the 13 mode tests at 500 test hours are shown in Table 17. Additional tests were conducted with the exhaust pipe insulated between the turbocharger and the catalyst for Mode 6. Low speed data (run numbers 3269-3292) are included in Appendix G. Further details of the emissions results are included in Appendix H.

TABLE 17. RESULTS OF THE 13-MODE EUROPEAN EMISSIONS TEST AT 500 HOURS ON THE STC TEST

Mode	Catalyst THC Eff.	BSTHC		$BSNO_x$ (corrected)		BSCO	
		(g/kw-hr)	g/bhp-hr)	(g/kw-hr)	g/bhp-hr)	(g/kw-hr)	g/bhp-hr)
1,7,13	1%	18.06	13.47	0.64	0.48	0.00	0.00
2	8%	18.18	13.56	0.54	0.40	0.00	0.00
3	14%	5.03	3.75	0.90	0.67	0.00	0.00
4	25%	2.14	1.60	1.77	1.32	0.00	0.00
5	24%	4.04	3.01	1.87	1.40	0.00	0.00
6	27%	4.40	3.28	1.57	1.17	0.00	0.00
8	33%	7.41	5.53	0.98	0.73	0.00	0.00
9	28%	5.87	4.38	0.96	0.72	0.00	0.00
10	44%	8.62	6.43	0.64	0.48	0.00	0.00
11	24%	12.34	9.20	0.70	0.52	0.00	0.00
12	24%	27.49	20.50	0.74	0.56	0.00	0.00
13 -mode	26%	5.86	4.37	1.35	1.01	0.00	0.00
6*	63%	2.06	1.53	1.70	1.27	0.00	0.00
13-mode*	36%	4.91	3.66	1.41	1.05	0.00	0.00

* Exhaust pipe insulated on mode 6.

At 500 hours on the STC test, the catalyst was removed from the exhaust system at the request of RVI. Table 18 shows a summary of all the emissions results using the final calibration from the Mack LNG Engine Development for a Long Haul Truck. A total runtime history of the catalyst is shown in Table 19.

TABLE 18. EMISSIONS SUMMARY WITH THE FINAL RVI CALIBRATION

Test	Catalyst THC Eff.	BSHC (g/kw-hr)	$BSNO_x$ (g/kw-hr)	BSCO (g/kw-hr)
Original	80%	0.84	3.25	0.00
Before STC Test	65%	1.66	2.53	0.00
Before STC Test *	68%	1.65	2.71	0.00
At 500 hours on the STC Test	26%	5.86	1.35	0.00
At 500 hours on the STC Test *	36%	4.91	1.41	0.00
Target	---	1.0	3.5	3.0
Euro II	---	1.1	7.0	4.0
* Exhuast pipe insulated on mode 6.				

TABLE 19. CATALYST RUNTIME HISTORY

Purpose	Hours	Total Hours
Break-In	21.9	21.9
Emissions Tests	47.3	69.2
Reat Rejection Tests	2.4	71.6
Demonstration to RVI	4.7	76.3
Emissions Tests	2.8	79.1
STC Test	511.3	590.4
Emissions Tests	2.6	593.0

3.0 CONCLUSIONS & RECOMMENDATIONS

A 1000-hour durability test was successfully completed. Several conclusions regarding the technical content of the program were made.

(1) Oil consumption increased significantly during the last 250 hours of the STC test. The high oil consumption can be attributed in part to a failed blowby filter, which allowed oil to directly enter the engine through the intake system. The filter had broken apart and had plugged the drain on the blowby canister as shown by the low blowby drains during the last 250 hours on the STC cycle. Heavy oil deposits were observed on the inlet to the turbocharger.

(2) The valve/valve seat materials selected for this test showed low recession. As reported by Mack Trucks, half of the valves had rotators installed, and the other half did not. The rotators did not appear to affect the valve recession significantly.

(3) The platinum-iridium tipped spark plugs showed a lower gap growth than the platinum-nickel tipped spark plugs.

(4) After the test, the engine was shipped to Mack Trucks for disassembly. Mack Trucks reported that one of the pistons had a crack in it, and that the valves with rotators installed showed wear from the rotation of the valves.

(5) The catalyst showed significant loss in hydrocarbon conversion efficiency when aged for 500 hours.

Recommendations for future work include:

(1) Improved design of the blowby filter for longer life;

(2) Further research into the cause of the platinum-iridium tipped spark plug failures, which did not occur with the platinum-nickel tipped spark plugs;

(3) Use of platinum-iridium tipped spark plugs with a recommended regap maintenance interval to extend the life of the spark plugs (Note: Due to the high BMEP during this test, spark plug regap maintenance interval may be extended to a period longer than shown here);

(4) Redesign of the piston and another 1000-hour STC test to verify the durability of the new piston design.

APPENDIX A

LISTING OF RUN NUMBERS

STC Test Runs

Run # From	Run # To	Test Hours From	Test Hours To	Hourly	Snapshot	Comments
978	979	0	0	x		
980	1035	0	0		x	
1036	1083	1	24	x		
1084	1139	25	25		x	
1140	1141	25	25	x		
1142	1189	26	49	x		
1190	1245	50	50		x	
1258	1258	50	50	x		650 rpm reading
1298	1298	50	50	x		1700 rpm reading
1302	1349	51	74	x		
1350	1405	75	75		x	
1406	1407	75	75	x		
1408	1455	76	99	x		
1456	1511	100	100		x	
1512	1513	100	100	x		
1514	1561	101	124	x		
1562	1617	125	125		x	
1618	1619	125	125	x		
1620	1623	126	127	x		
1626	1669	128	149	x		
1726	1727	150	150	x		
1728	1783	150	150		x	
1784	1831	151	174	x		
1832	1887	175	175		x	
1888	1889	175	175	x		
1890	1937	176	199	x		
1938	1993	200	200		x	
1994	1995	200	200	x		
1996	2043	201	224	x		
2044	2099	225	225		x	
2100	2101	225	225	x		
2102	2149	226	249	x		
2150	2205	250	250		x	
2206	2207	250	250	x		
2208	2255	251	274	x		
2256	2311	275	275		x	
2312	2313	275	275	x		
2314	2341	276	289	x		
		290	290	x		Missed Reading
2344	2361	291	299	x		
2362	2417	300	300		x	
2418	2419	300	300	x		
2420	2431	301	306	x		
2433	2468	307	324	x		
2469	2523	325	325		x	
2524	2525	325	325	x		
2526	2573	326	349	x		
2574	2629	350	350		x	
2630	2631	350	350	x		

STC Test Runs

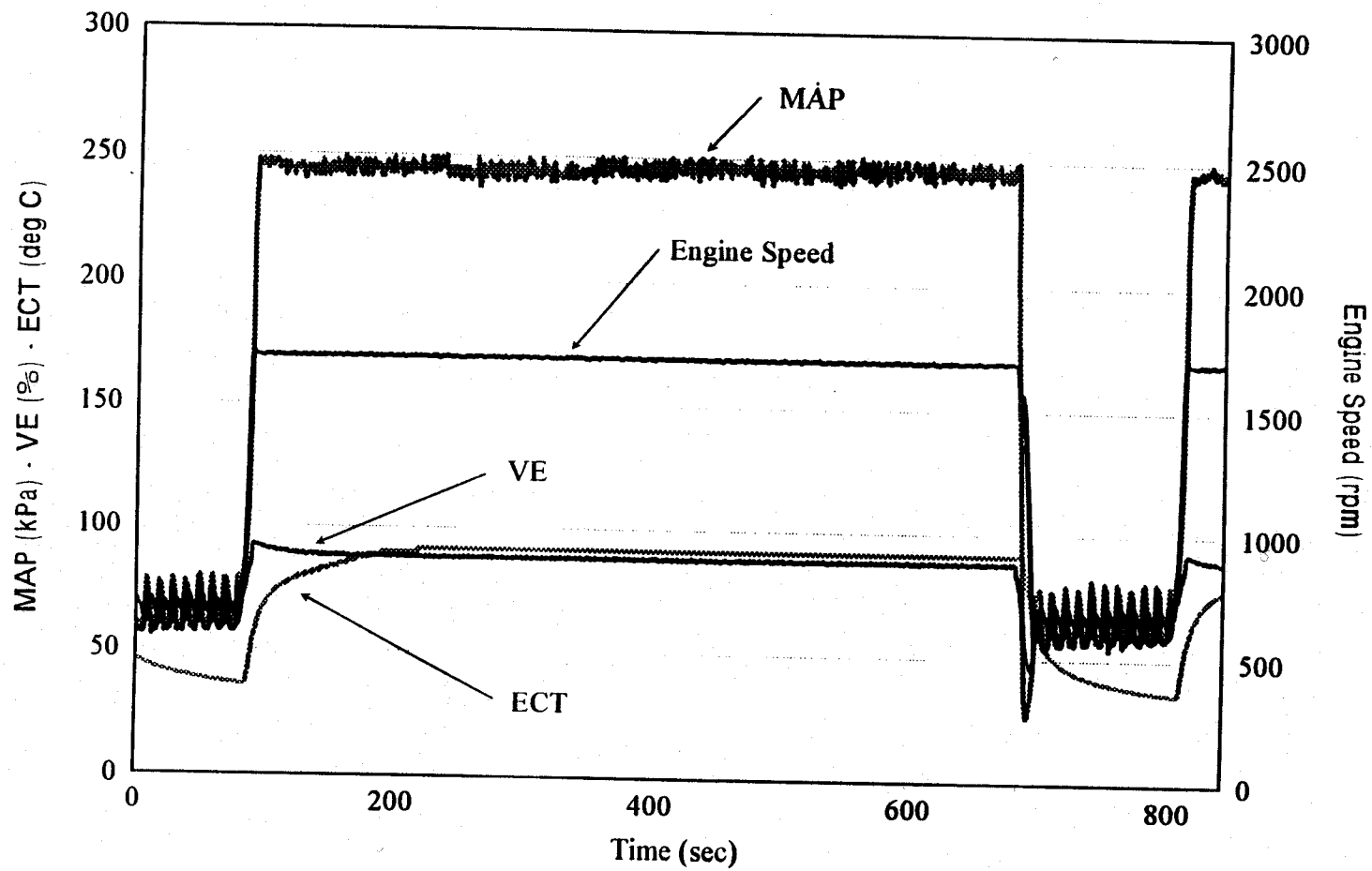
Run # From	Run # To	Test Hours From	Test Hours To	Hourly	Snapshot	Comments
2632	2679	351	374	x		
2680	2735	375	375		x	
2736	2737	375	375	x		
2738	2785	376	399	x		
2786	2841	400	400		x	
2842	2843	400	400	x		
2844	2891	401	424	x		
2892	2947	425	425		x	
2948	2949	425	425	x		
2950	2997	426	449	x		
2998	3053	450	450		x	
3054	3055	450	450	x		
3056	3099	451	472	x		
3101	3104	473	474	x		
3105	3160	475	475		x	
3161	3162	475	475	x		
3163	3210	476	499	x		
3211	3266	500	500		x	
3267	3268	500	500	x		
3293	3340	501	524	x		
3341	3396	525	525		x	
3397	3398	525	525	x		
3399	3446	526	549	x		
3447	3502	550	550		x	
3503	3504	550	550	x		
3505	3552	551	574	x		
3553	3608	575	575		x	
3609	3610	575	575	x		
3611	3658	576	599	x		
3659	3714	600	600		x	
3715	3716	600	600	x		
3717	3764	601	624	x		
3765	3820	625	625		x	
3821	3822	625	625	x		
3823	3870	626	649	x		
3871	3926	650	650		x	
3927	3928	650	650	x		
3929	3976	651	674	x		
3977	4032	675	675		x	
4033	4034	675	675	x		
4035	4082	676	699	x		
4083	4138	700	700		x	
4139	4140	700	700	x		
4141	4190	701	725	x		
4191	4246	725	725		x	
4247	4294	726	749	x		
4295	4350	750	750		x	
4351	4352	750	750	x		

STC Test Runs

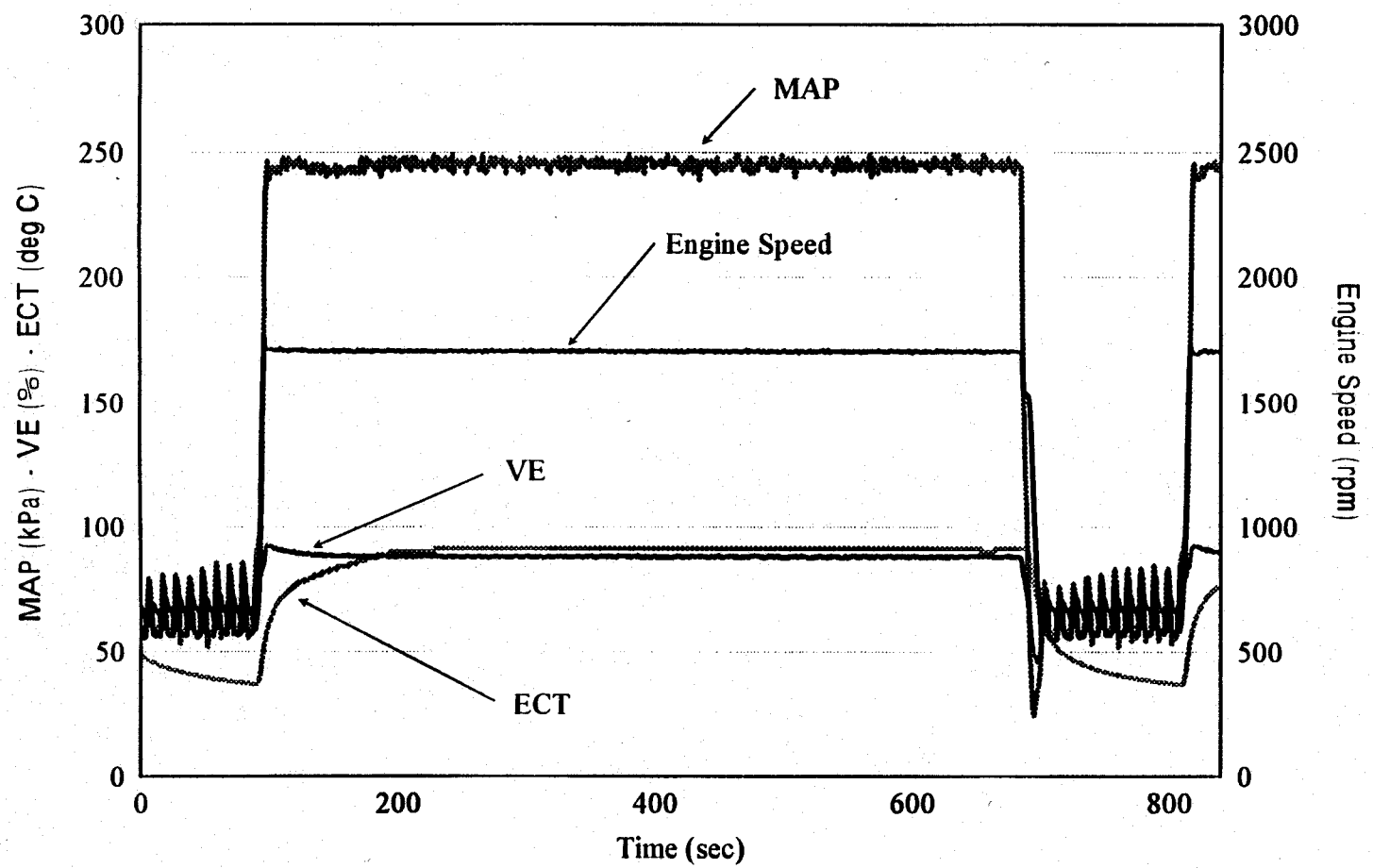
Run # From	Run # To	Test Hours From	Test Hours To	Hourly	Snapshot	Comments
4353	4354	751	751	x		
		752	752	x		Missed Reading
4356	4399	753	774	x		
4400	4455	775	775		x	
4456	4457	775	775	x		
4458	4505	776	799	x		
4506	4561	800	800		x	
4562	4563	800	800	x		
4564	4611	801	824	x		
4612	4667	825	825		x	
4668	4669	825	825	x		
4670	4689	826	835	x		
		836	836			Missed reading
4690	4715	837	849	x		
4716	4771	850	850		x	
4772	4773	850	850	x		
4774	4821	851	874	x		
4822	4877	875	875		x	
4878	4879	875	875	x		
4880	4927	876	899	x		
4928	4983	900	900		x	
4984	4985	900	900	x		
4986	5011	901	913	x		
		914	914			Missed Reading
5013	5032	915	924	x		
5033	5088	925	925		x	
5089	5090	925	925	x		
5091	5102	926	931	x		
5105	5140	932	949	x		
5141	5196	950	950		x	
5197	5198	950	950	x		
5199	5246	951	974	x		
5247	5302	975	975		x	
5303	5304	975	975	x		
5305	5352	976	999	x		
5353	5408	1000	1000		x	
5409	5410	1000	1000	x		

APPENDIX B

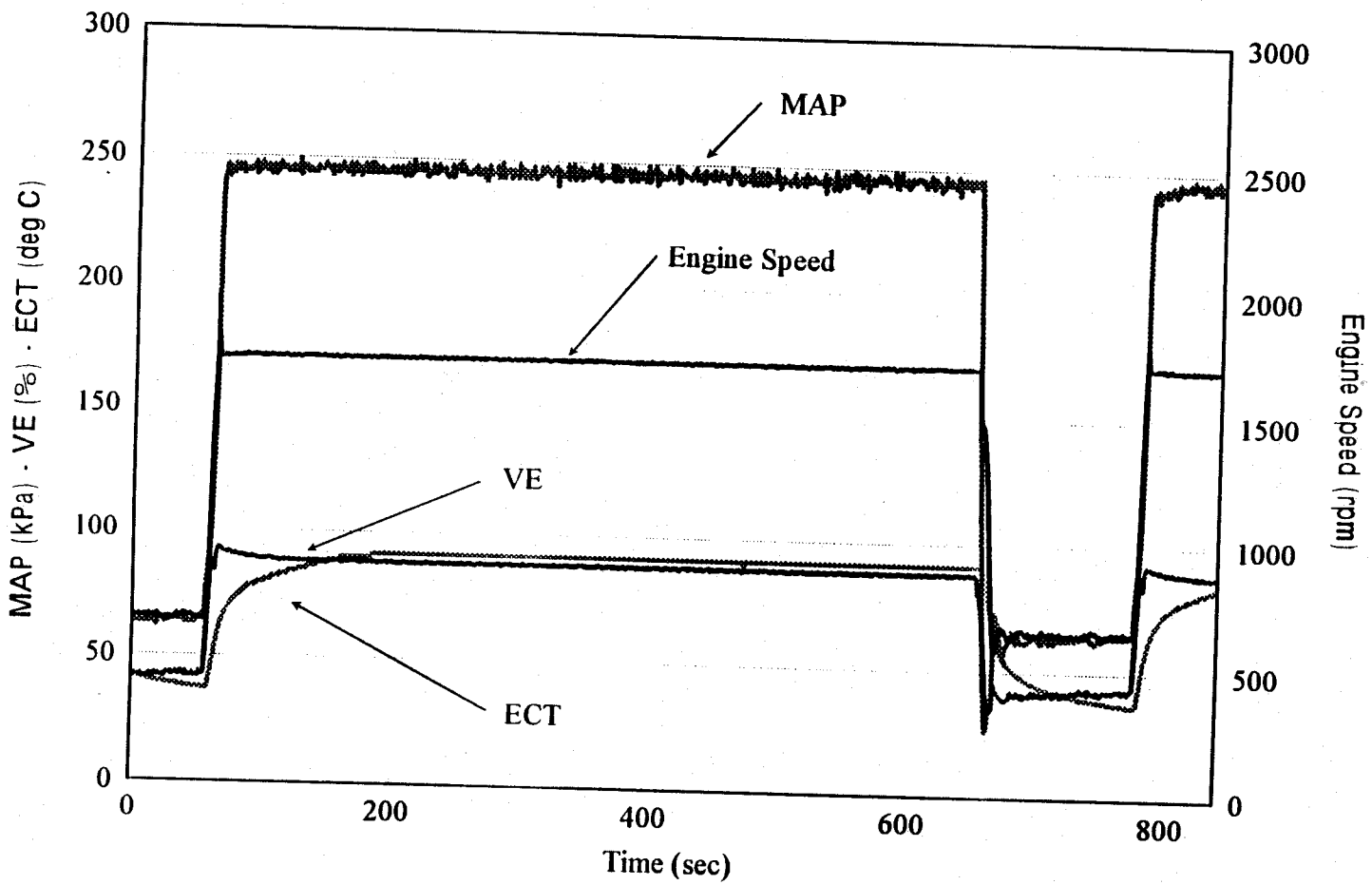
GEM TRANSIENT DATA



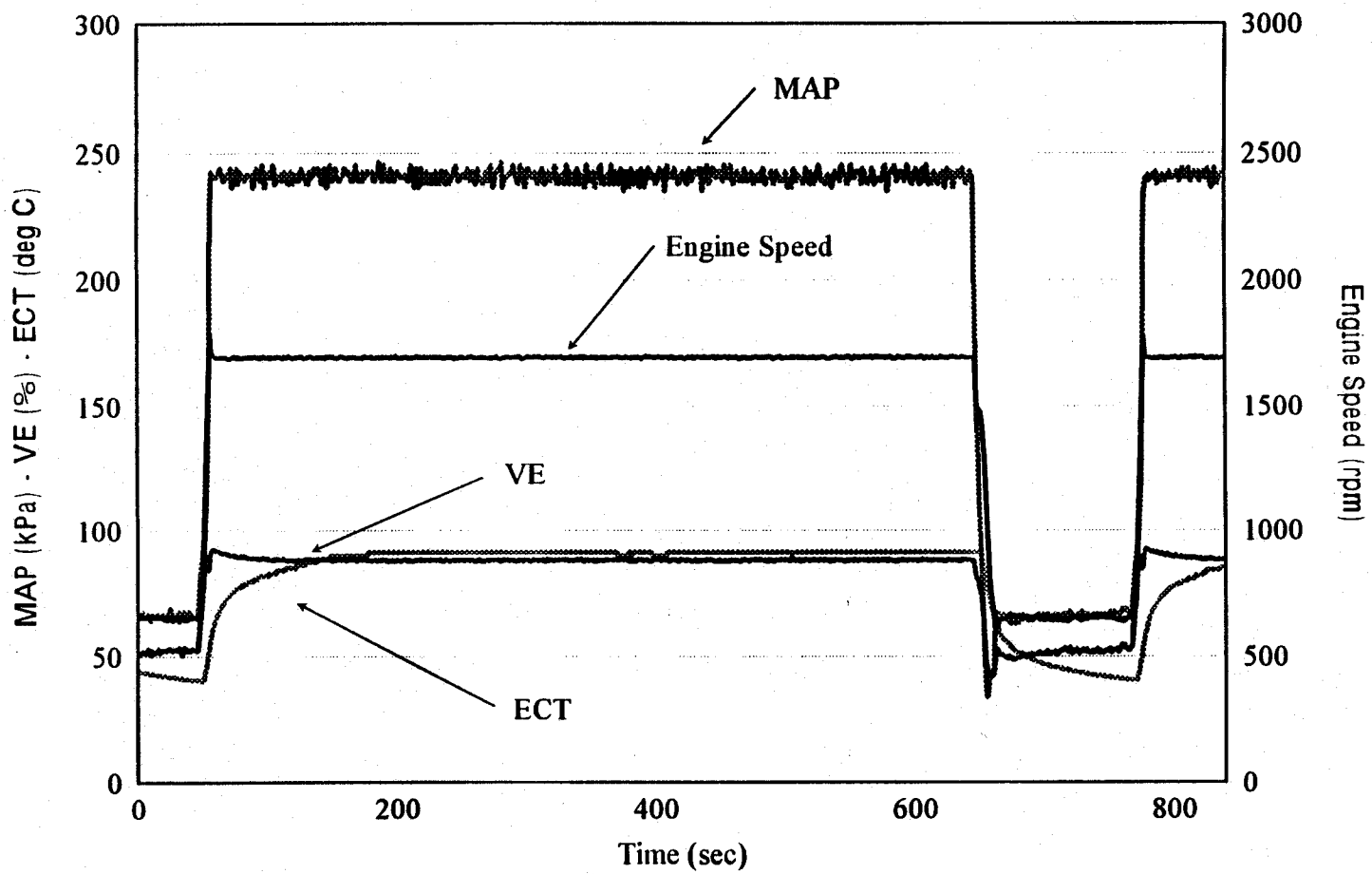
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 1 HOUR



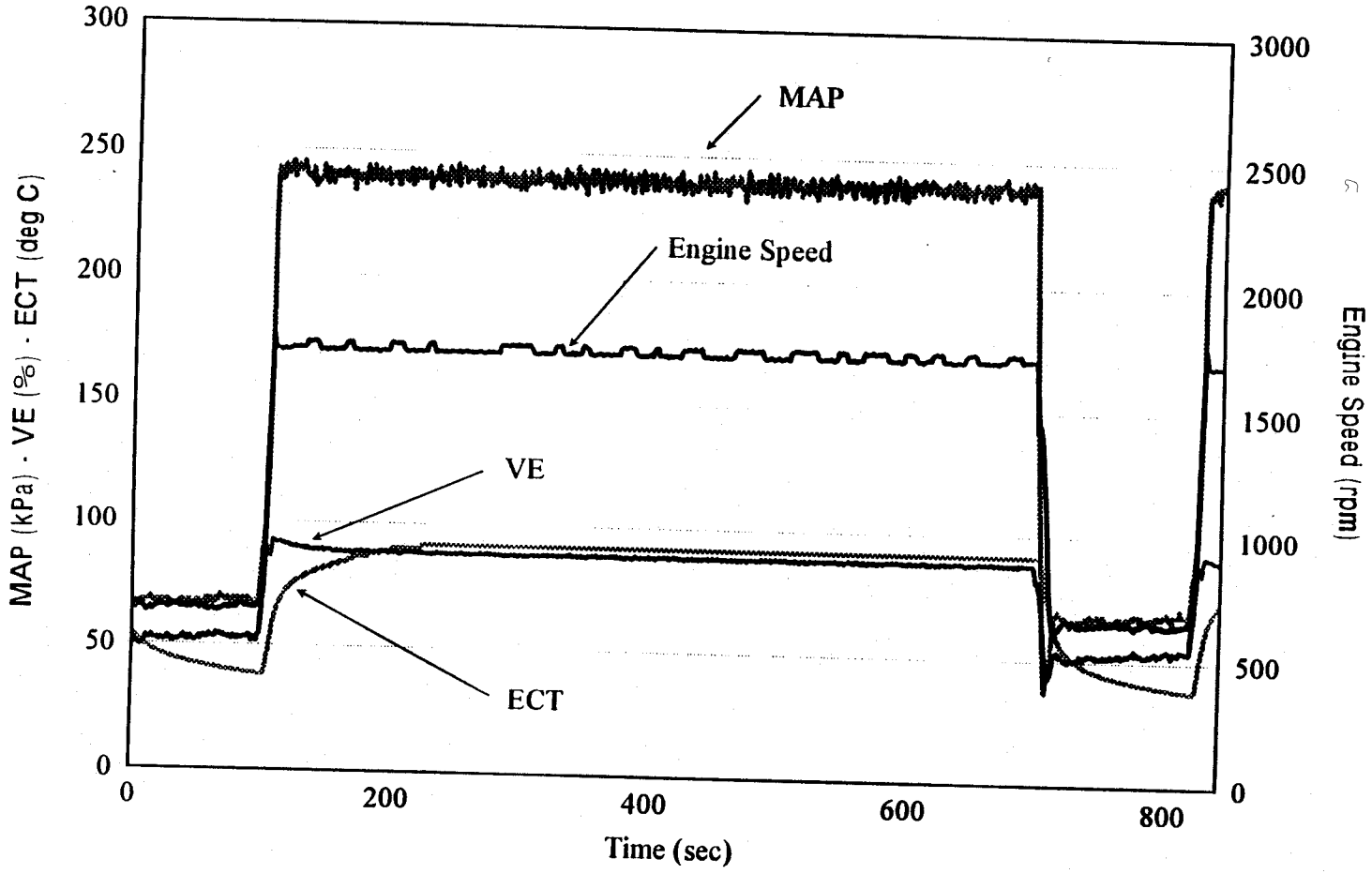
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 25 HOUR



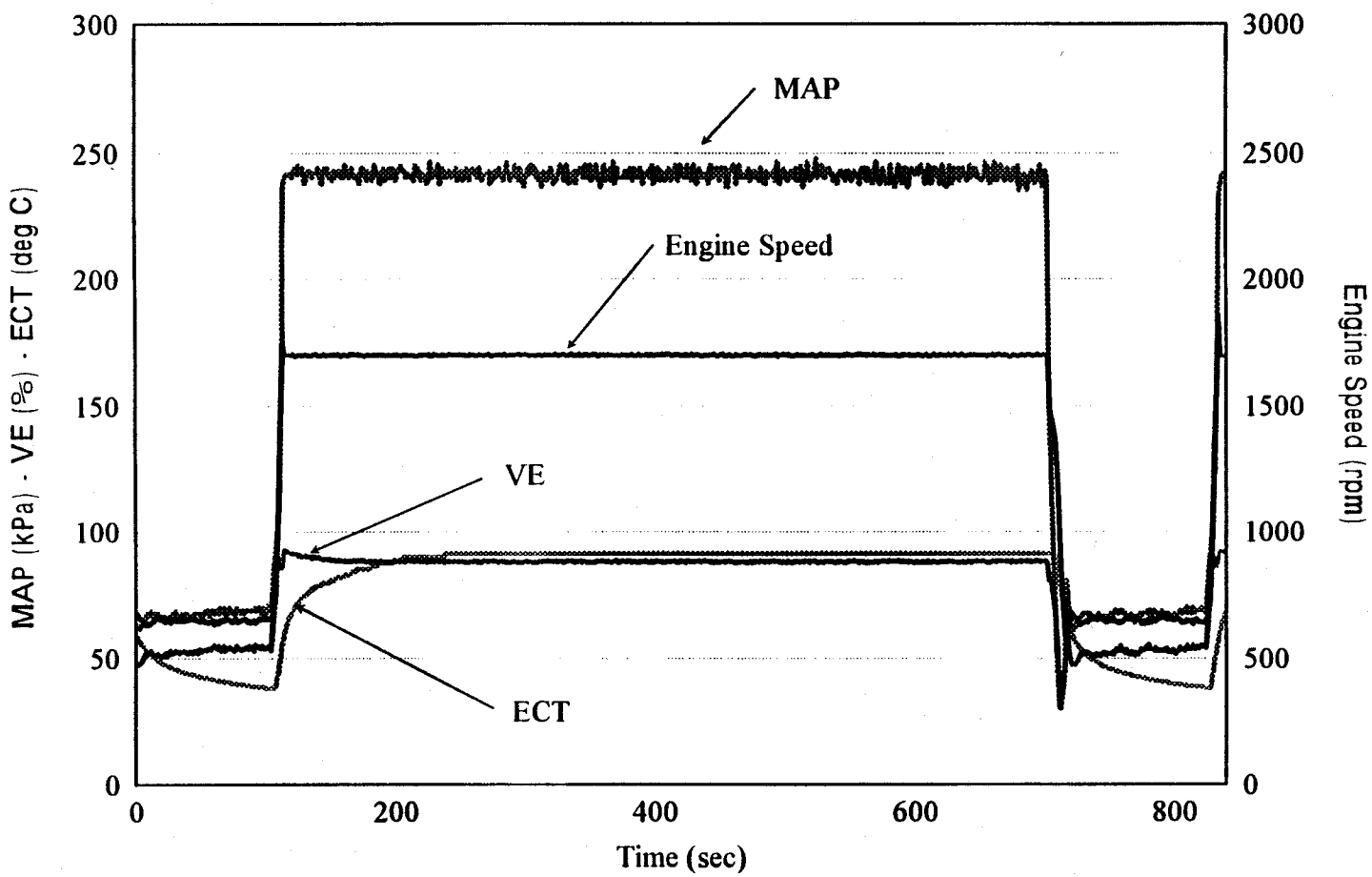
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 50 HOUR



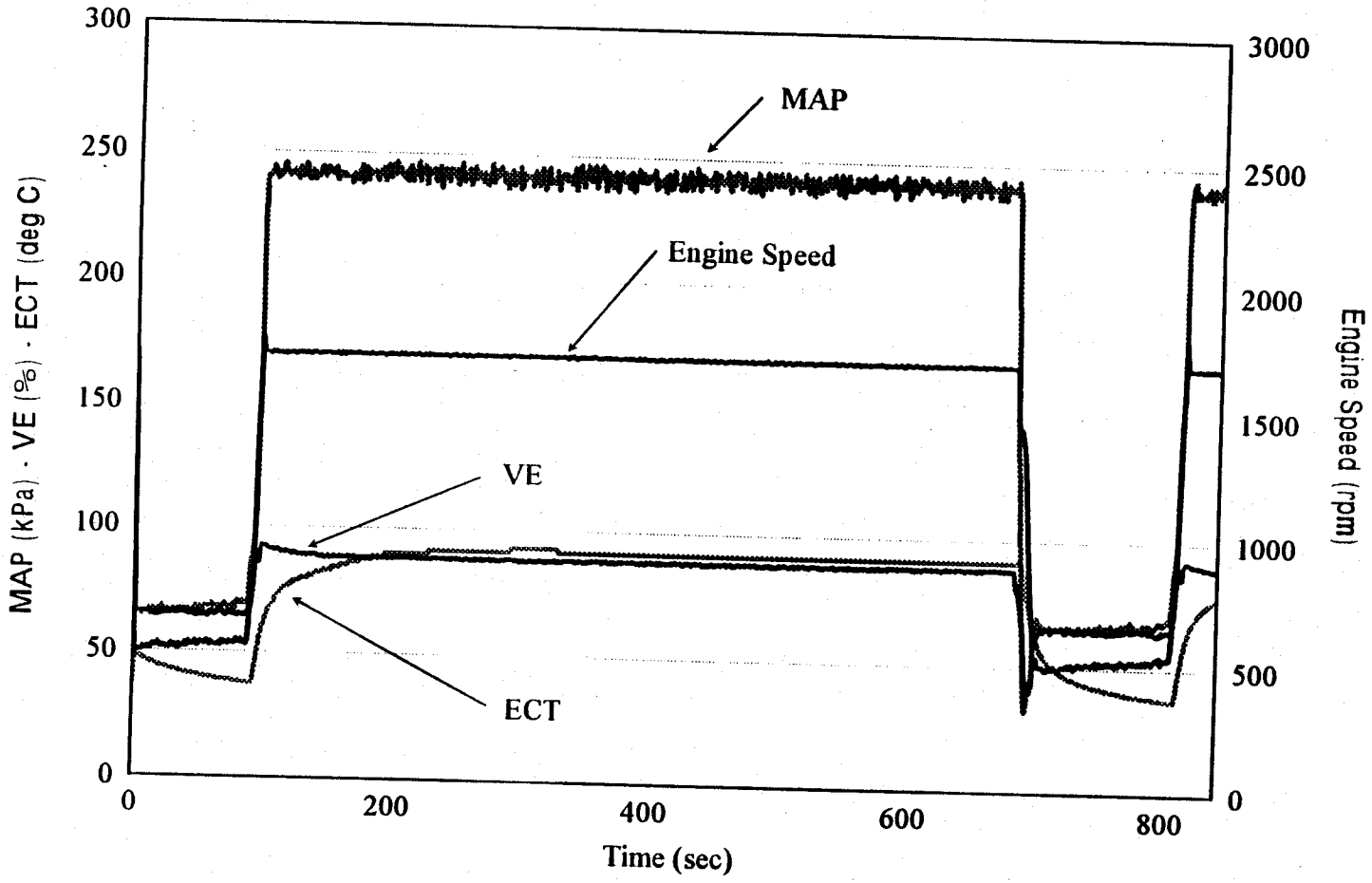
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 75 HOUR



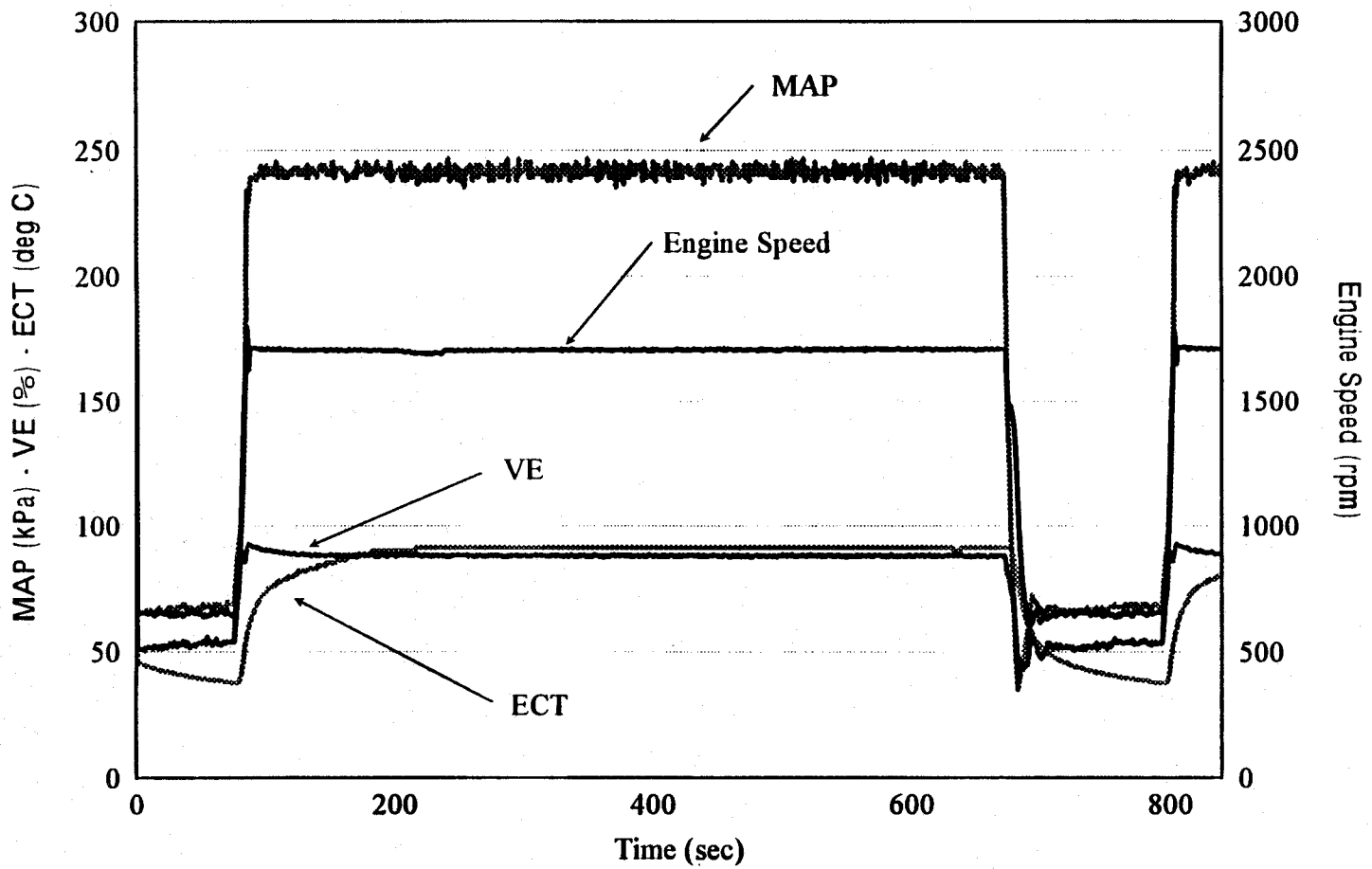
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 100 HOUR



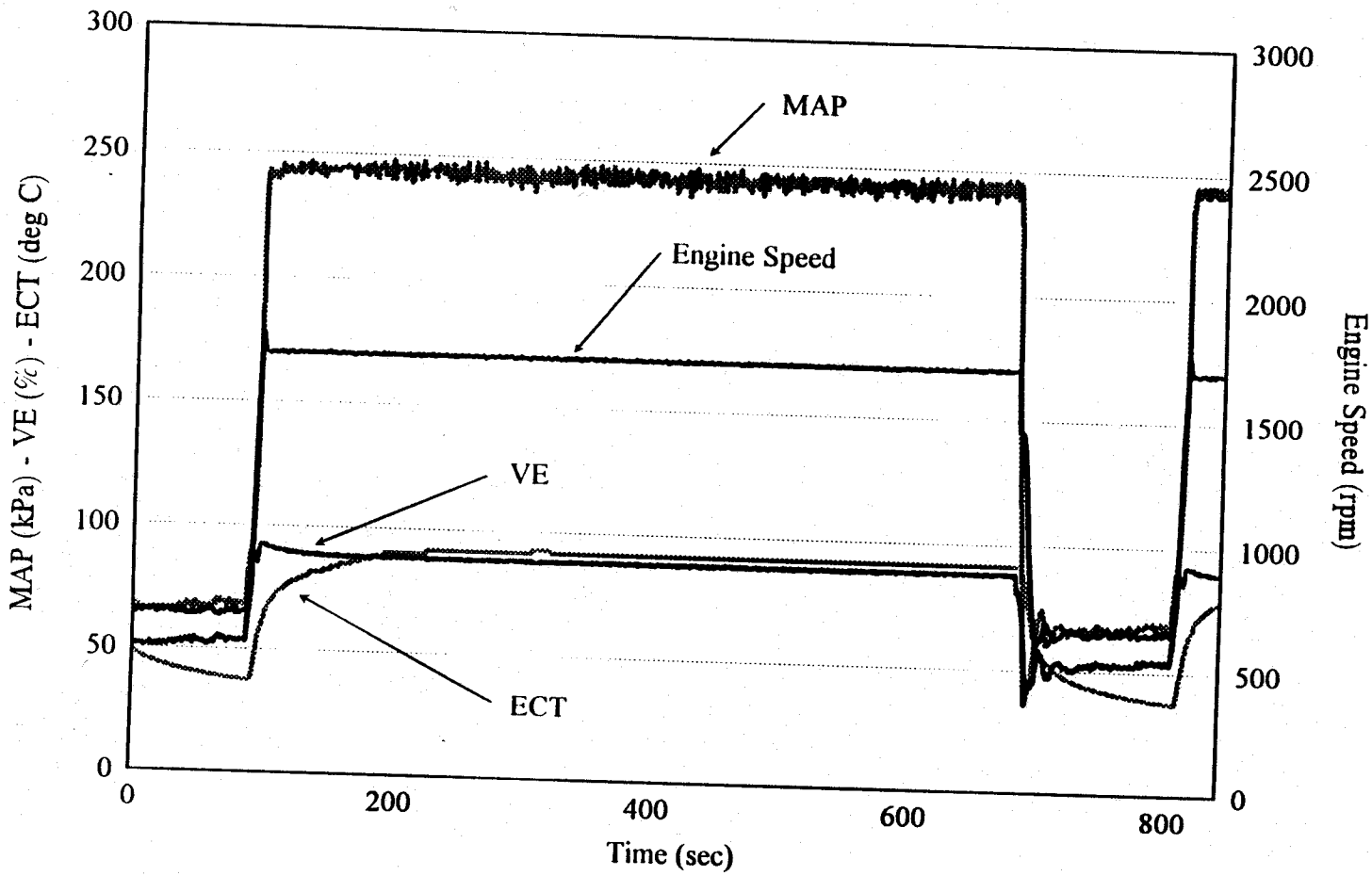
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 125 HOUR



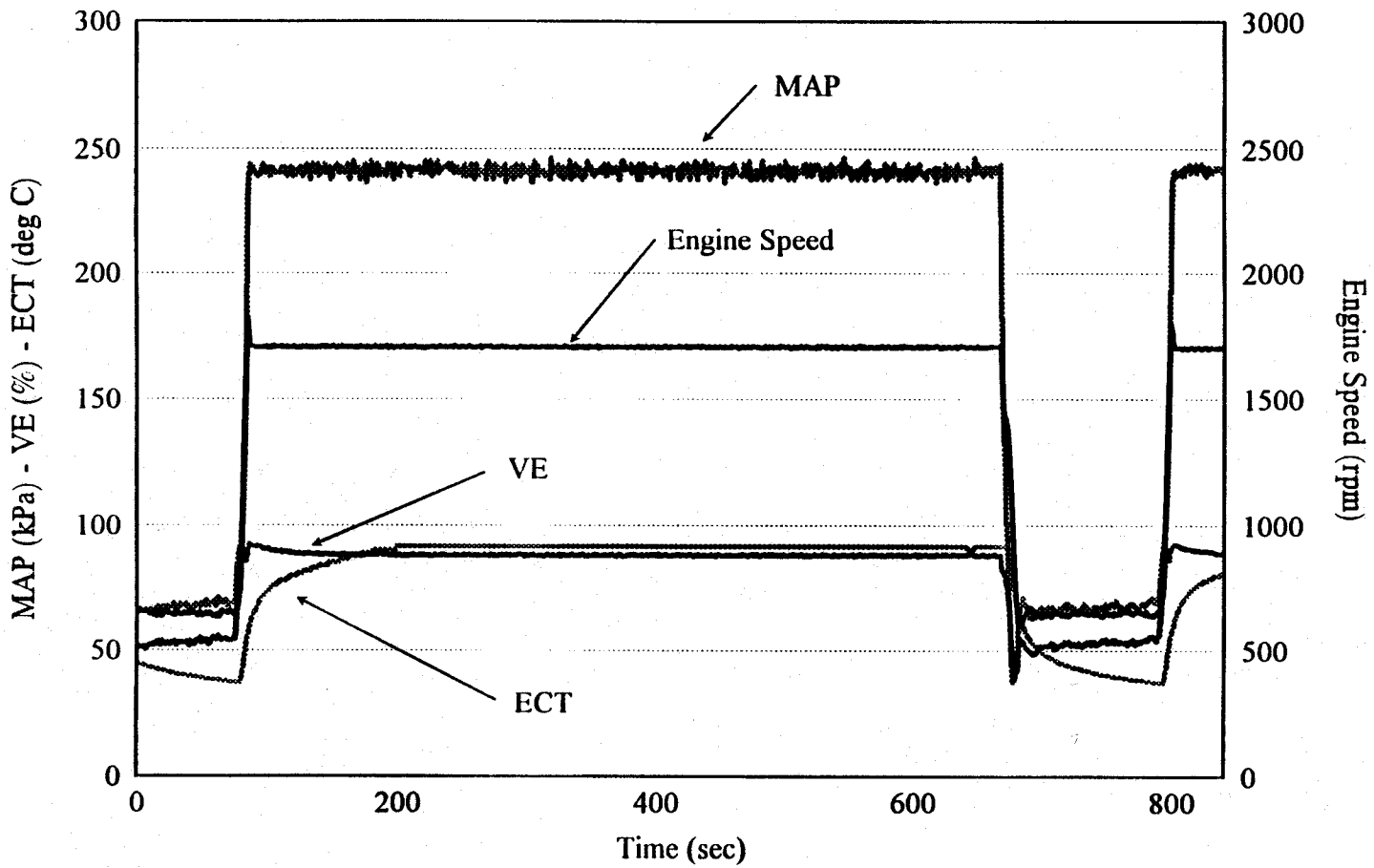
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 150 HOUR



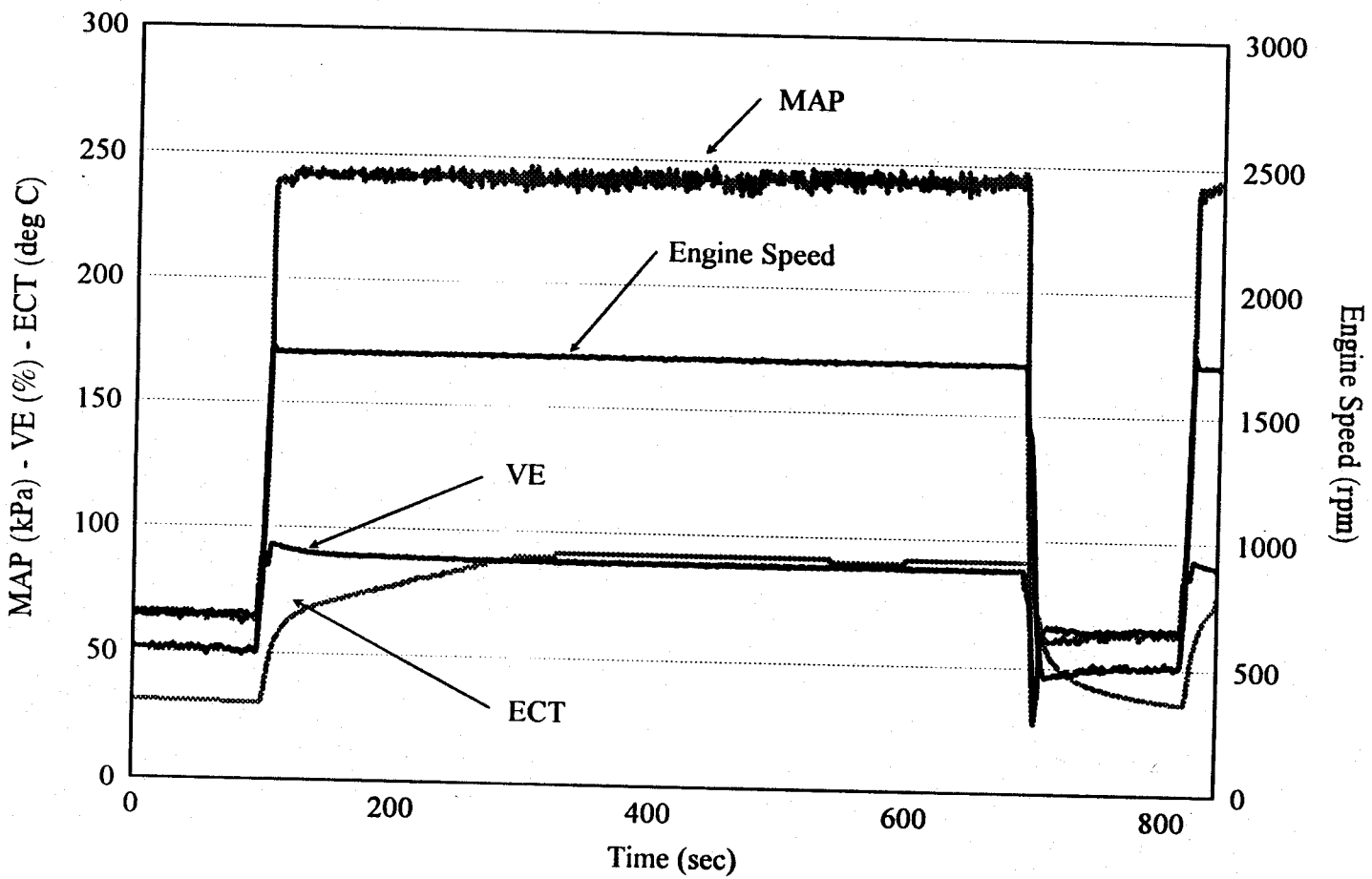
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 175 HOUR



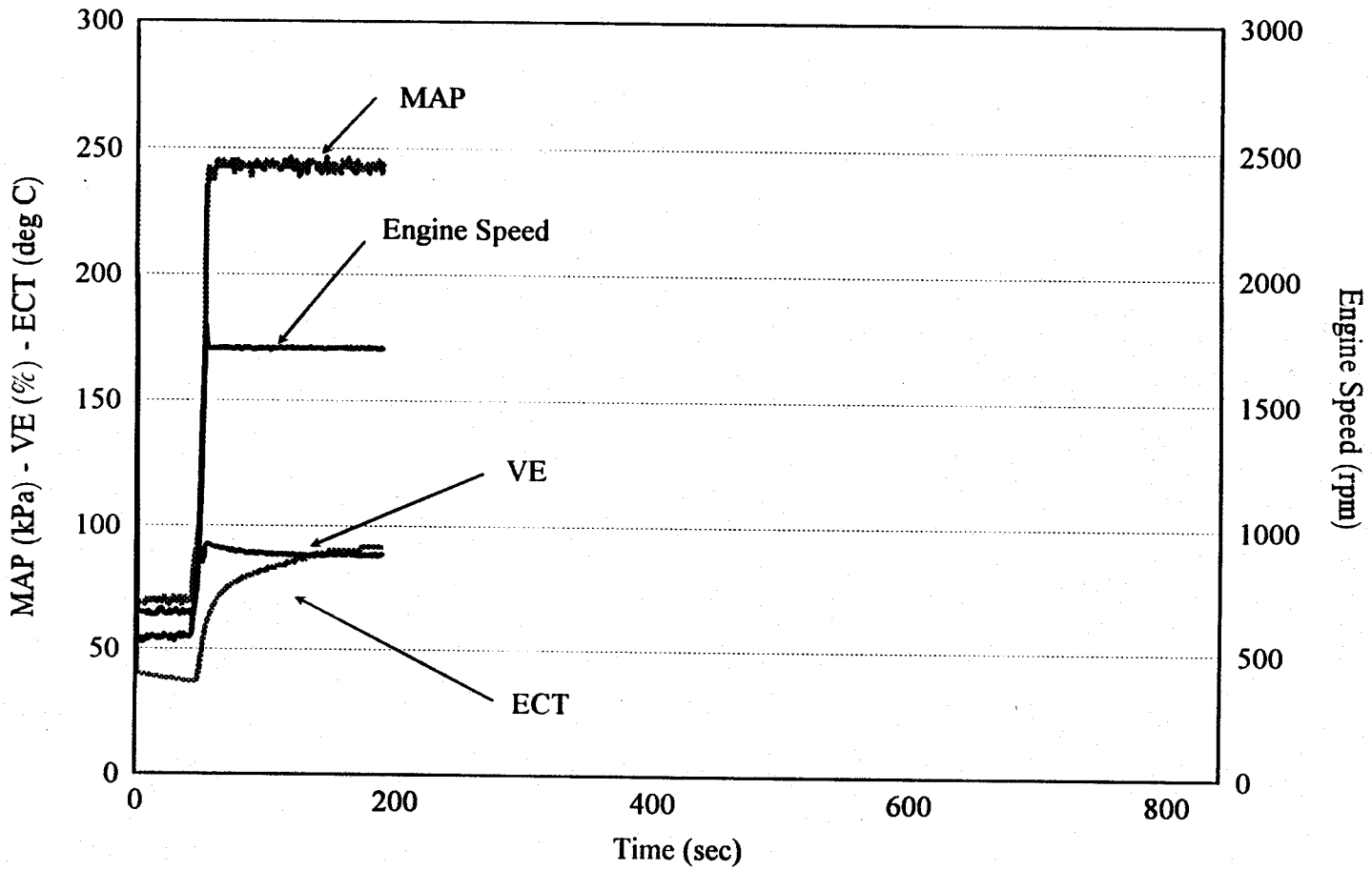
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 200 HOUR



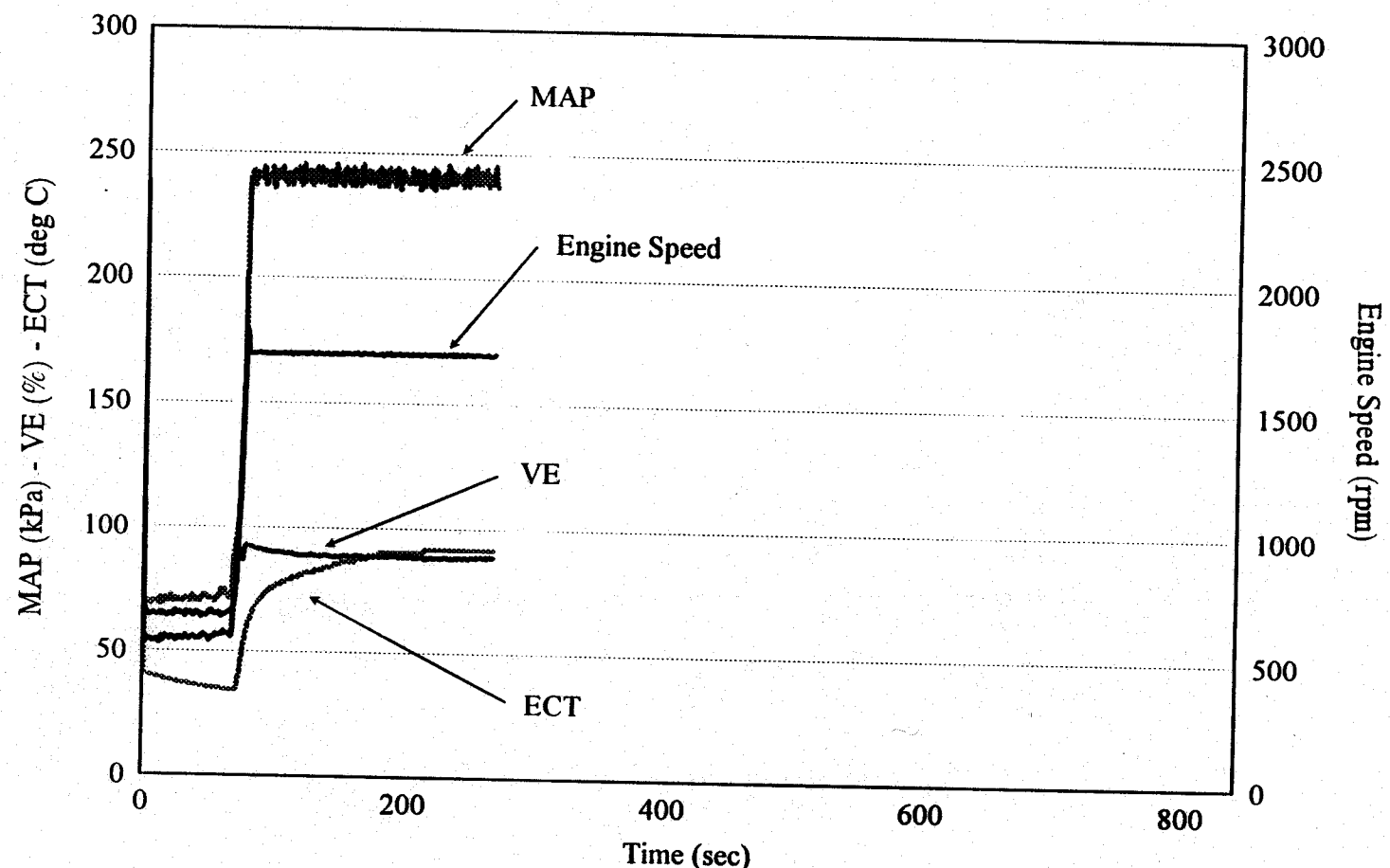
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 225 HOUR



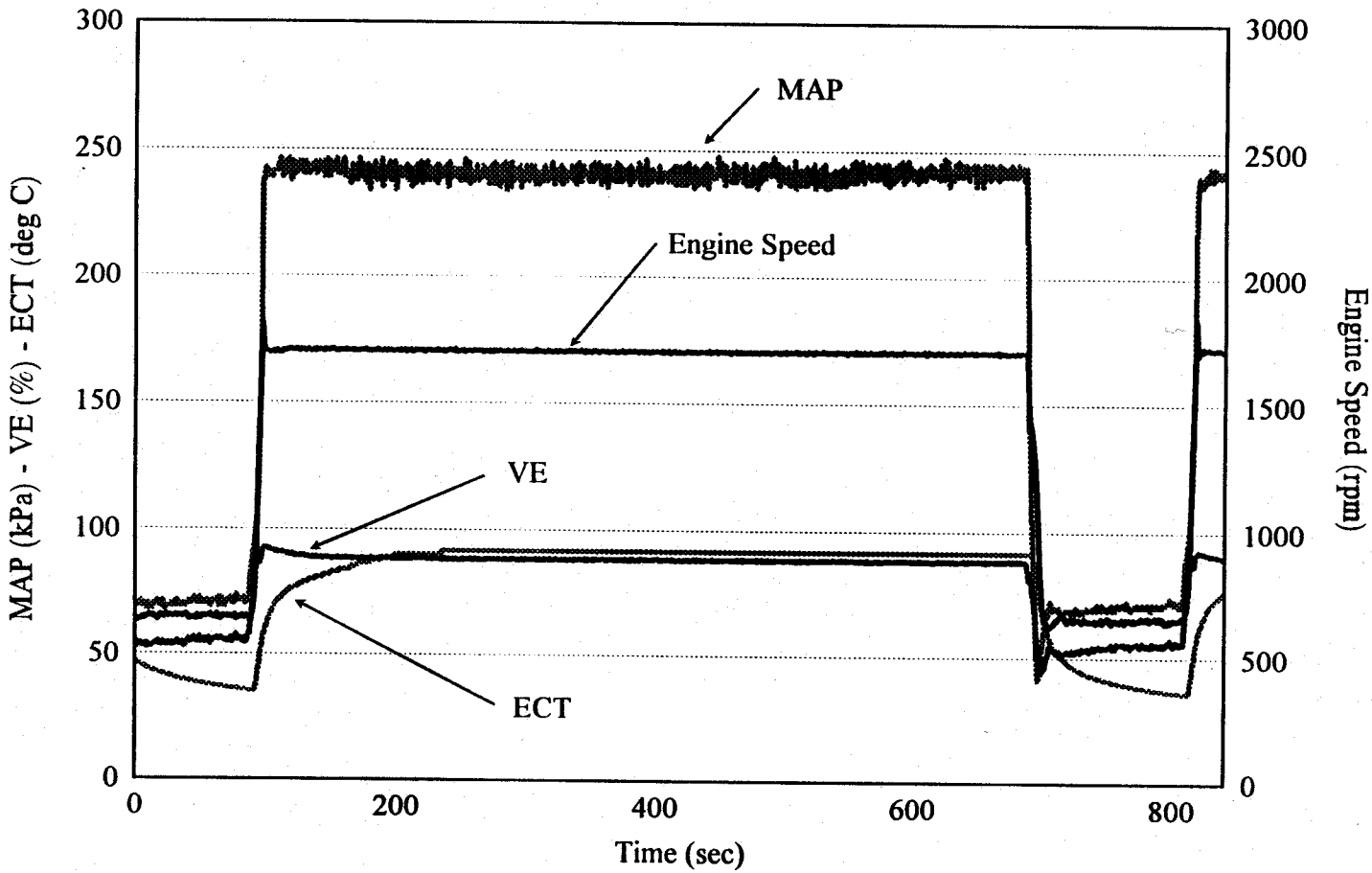
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 250 HOUR



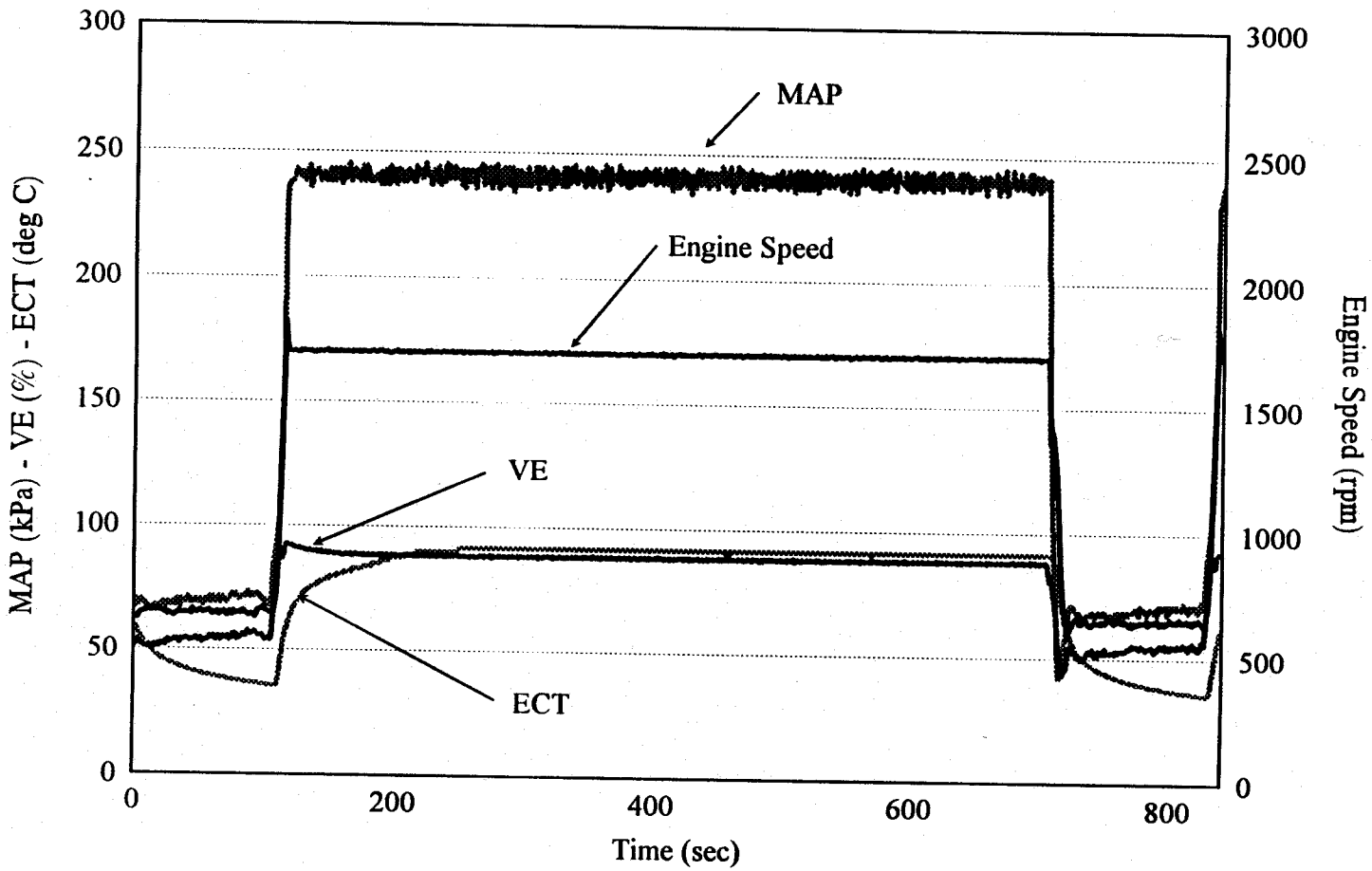
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 275 HOUR



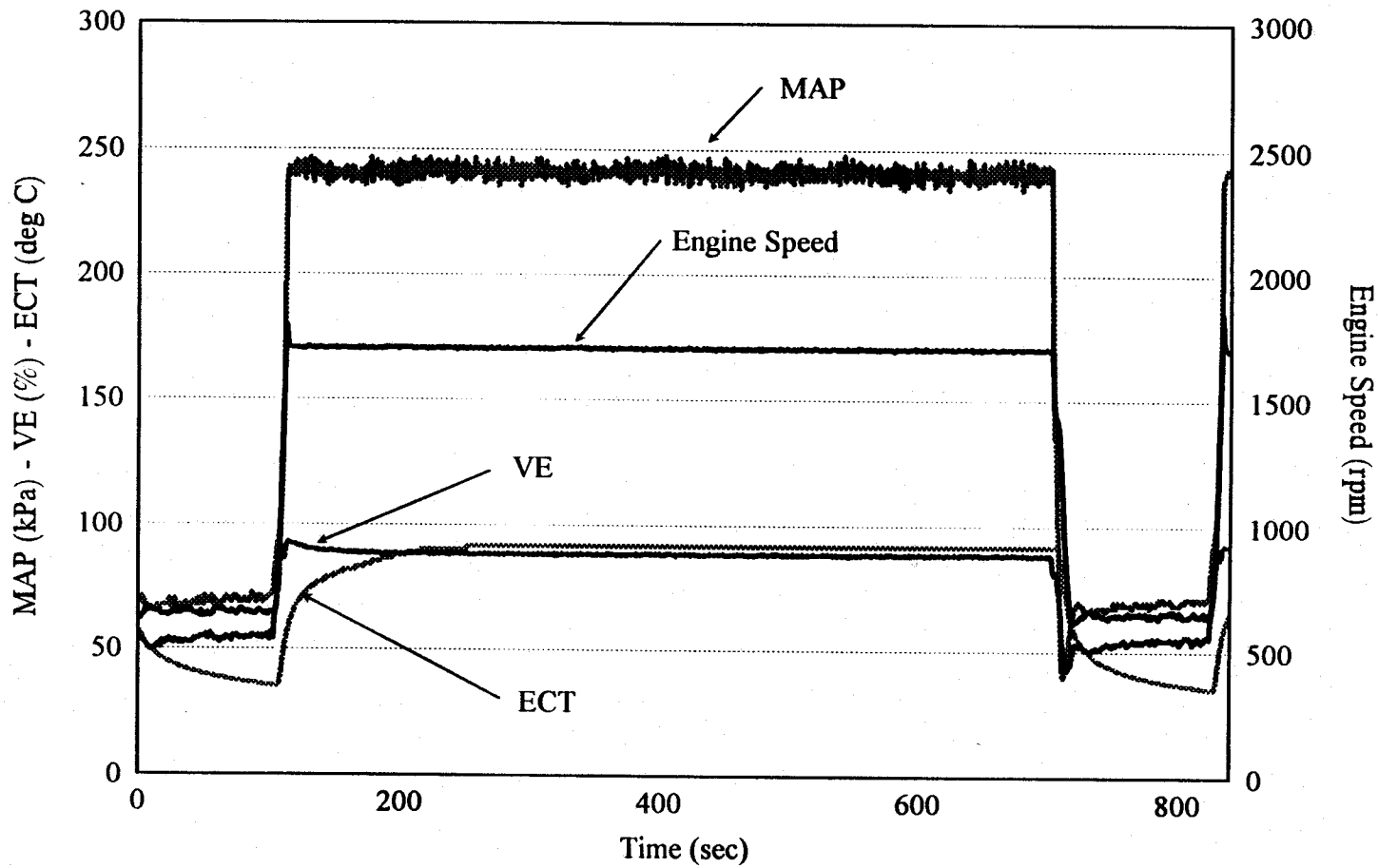
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 300 HOUR



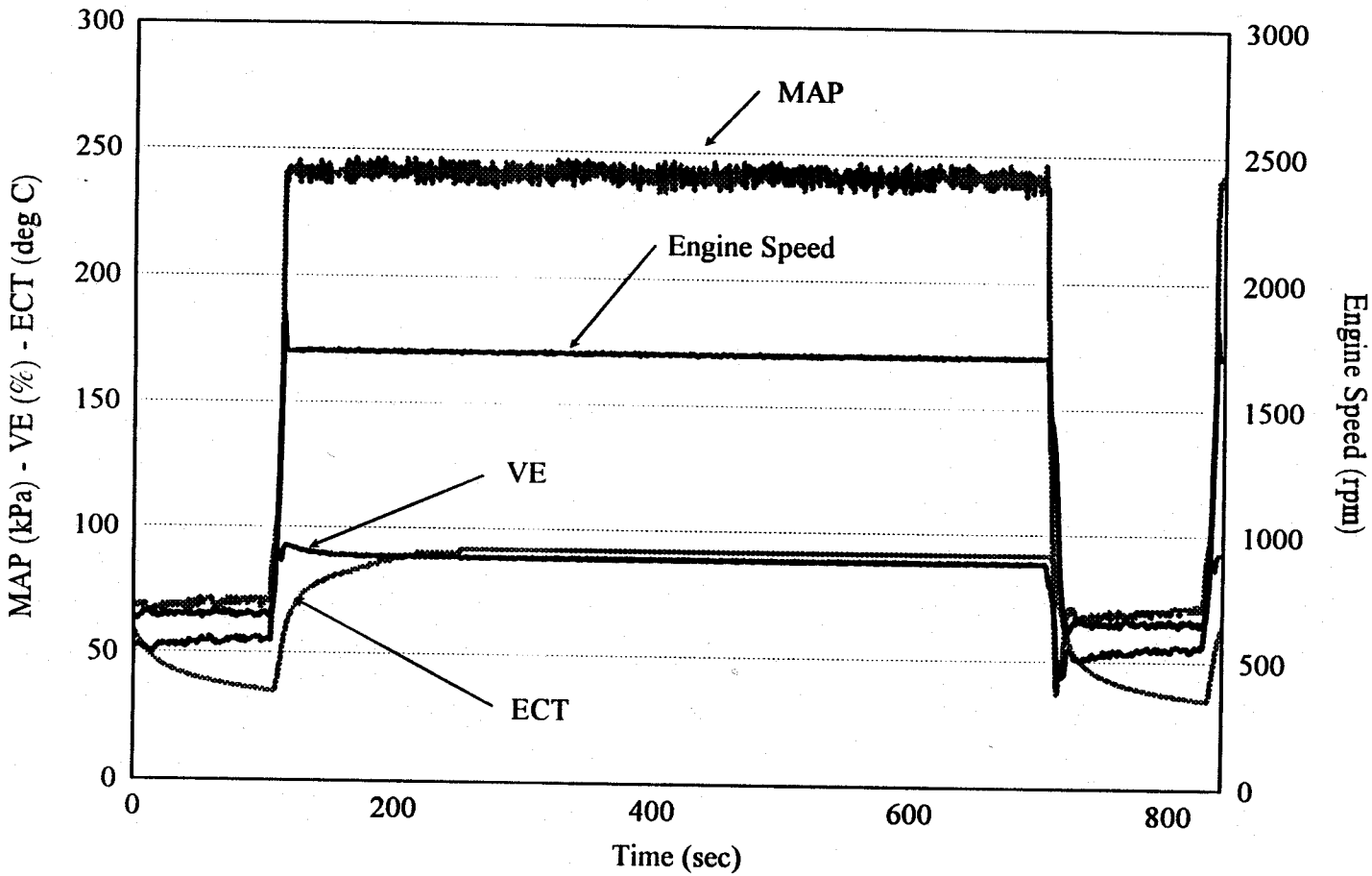
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 309 HOUR



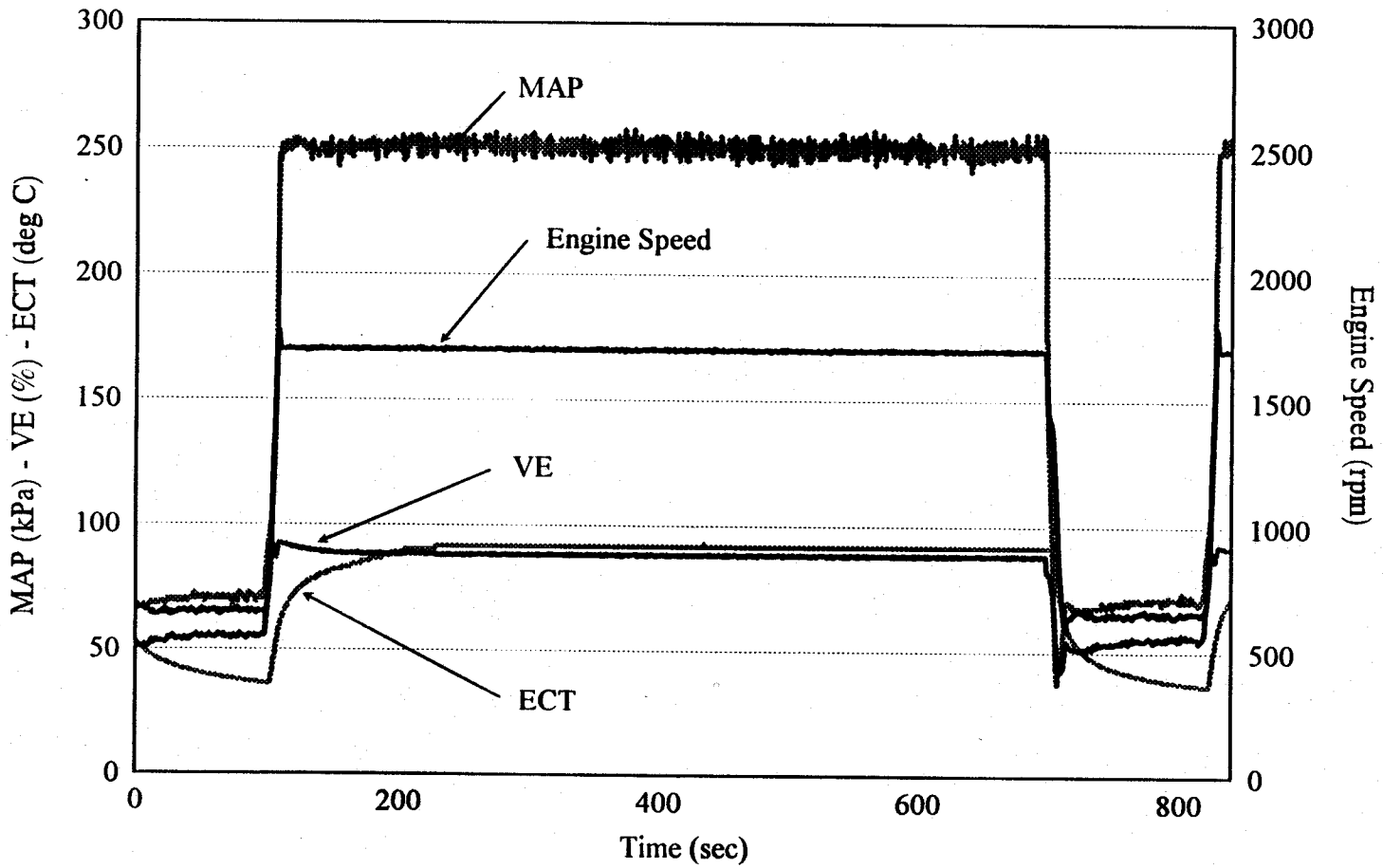
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 325 HOUR



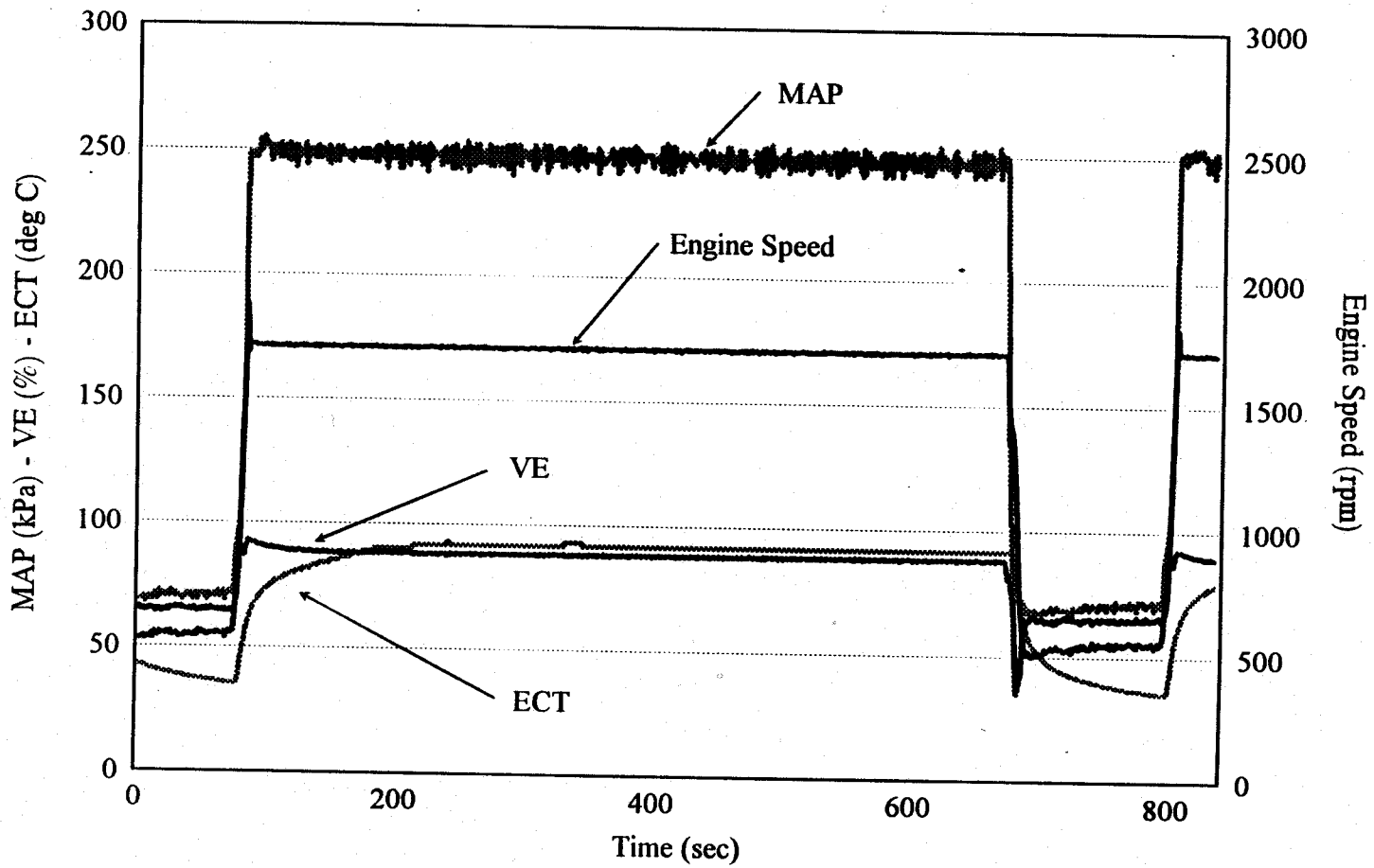
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 350 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 375 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 400 HOUR



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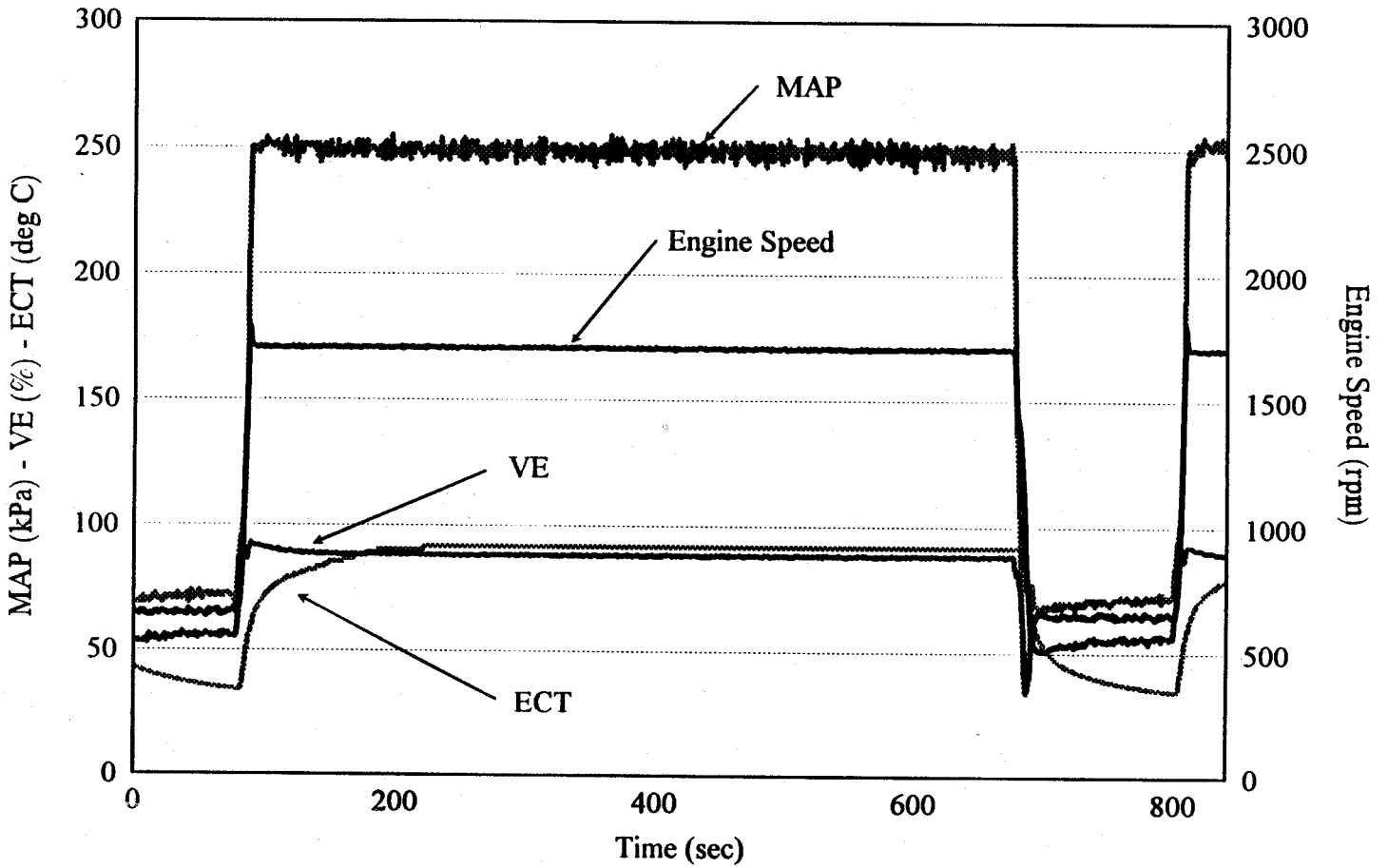

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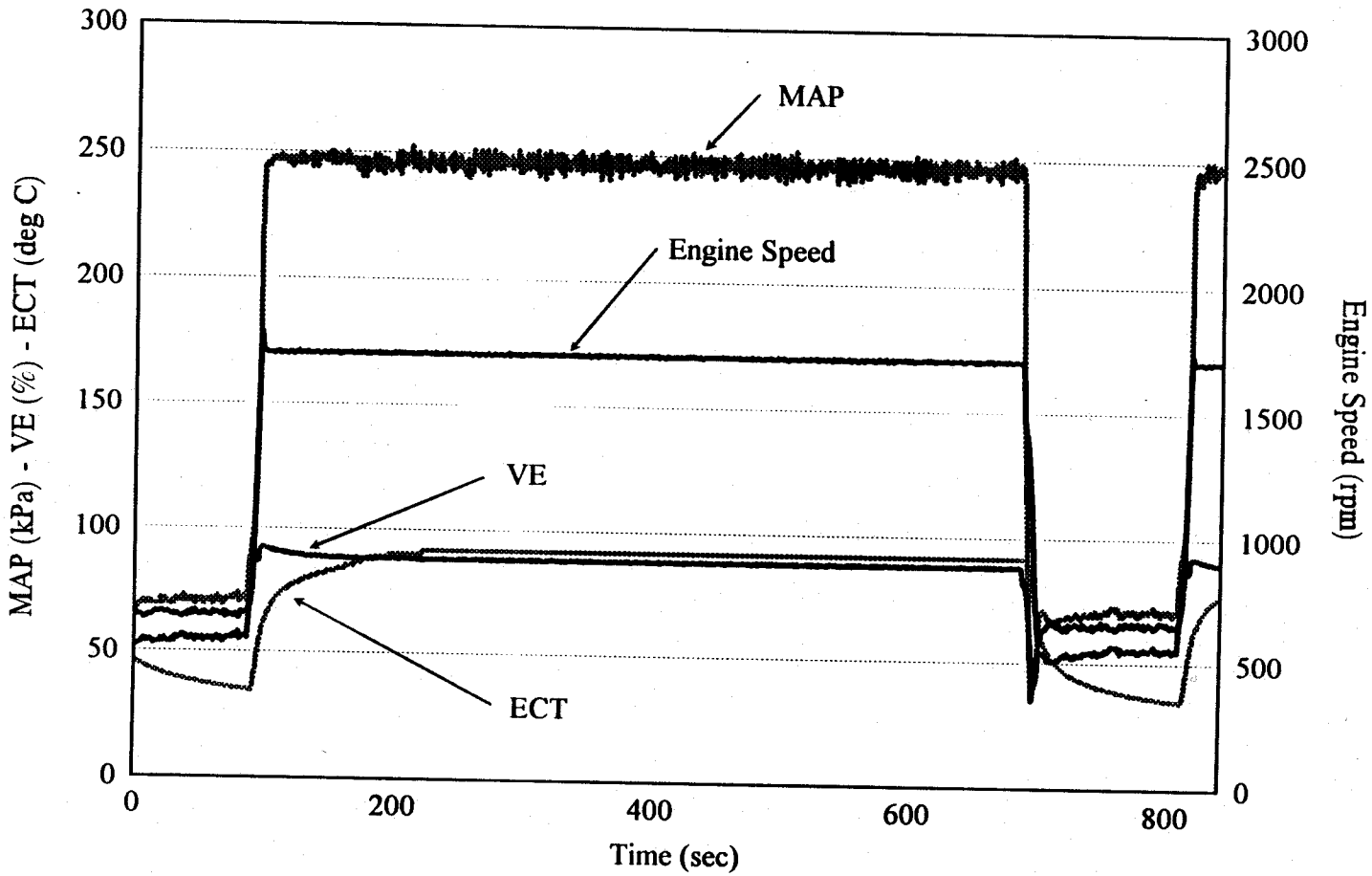
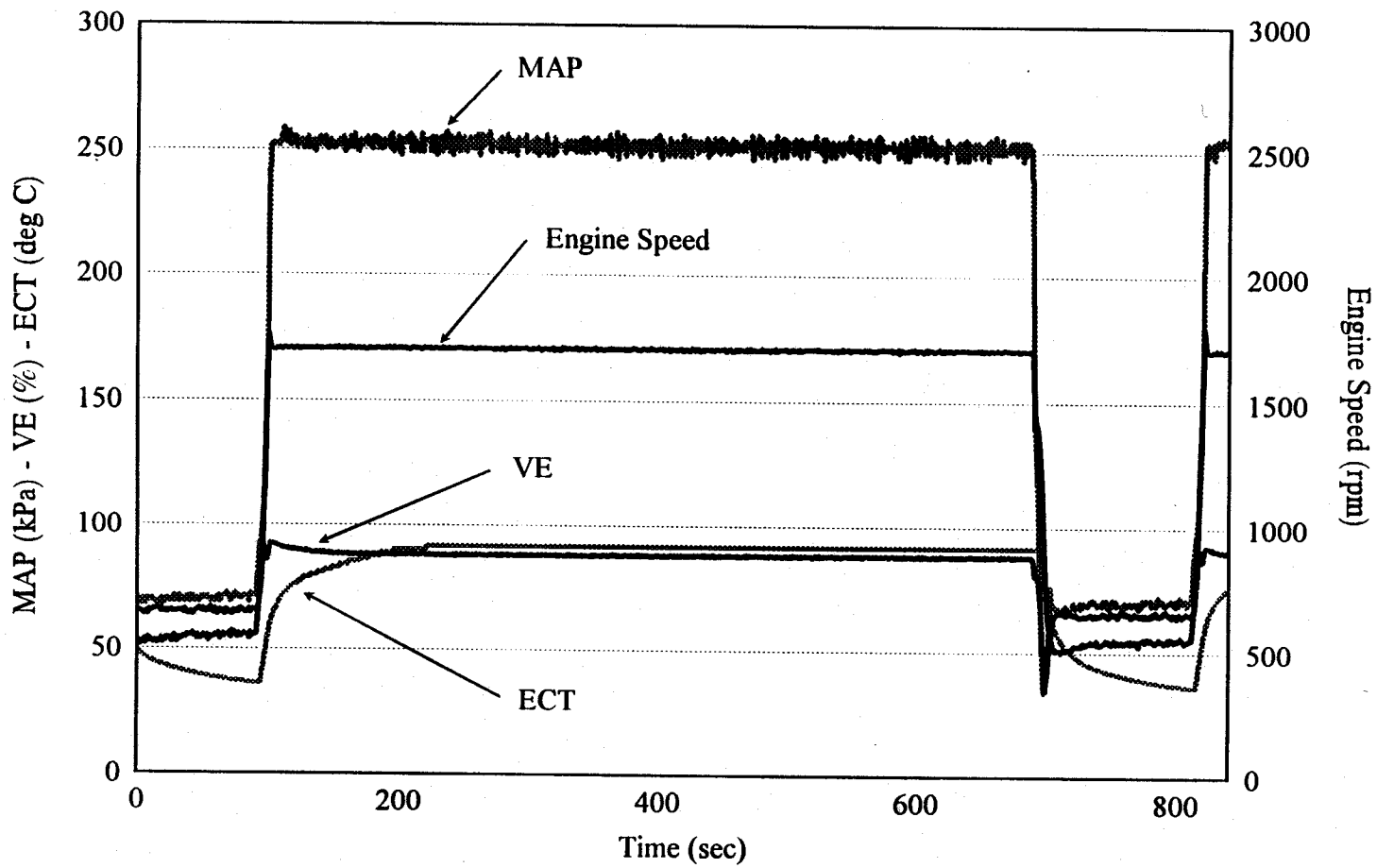


TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 475 HOUR



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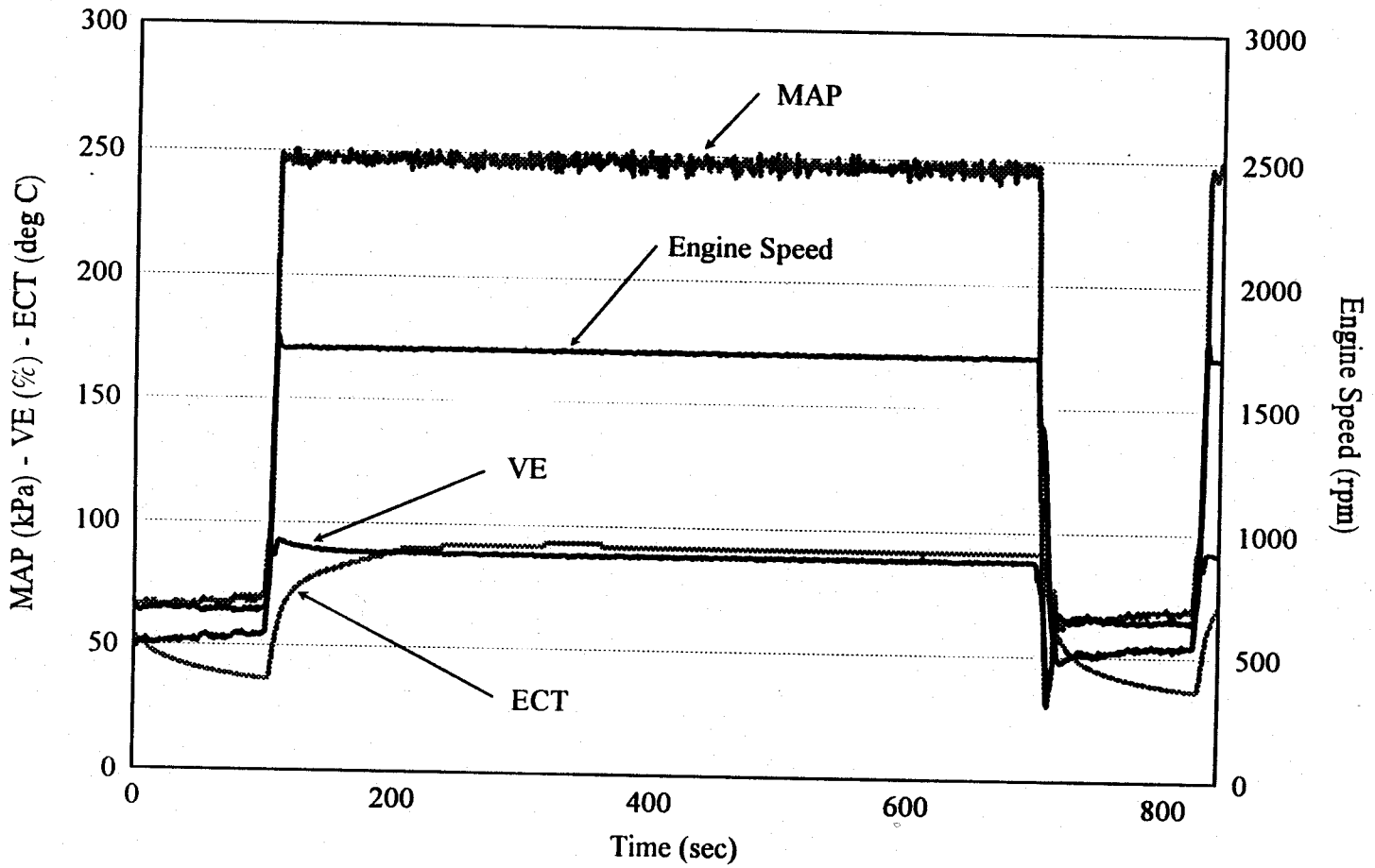
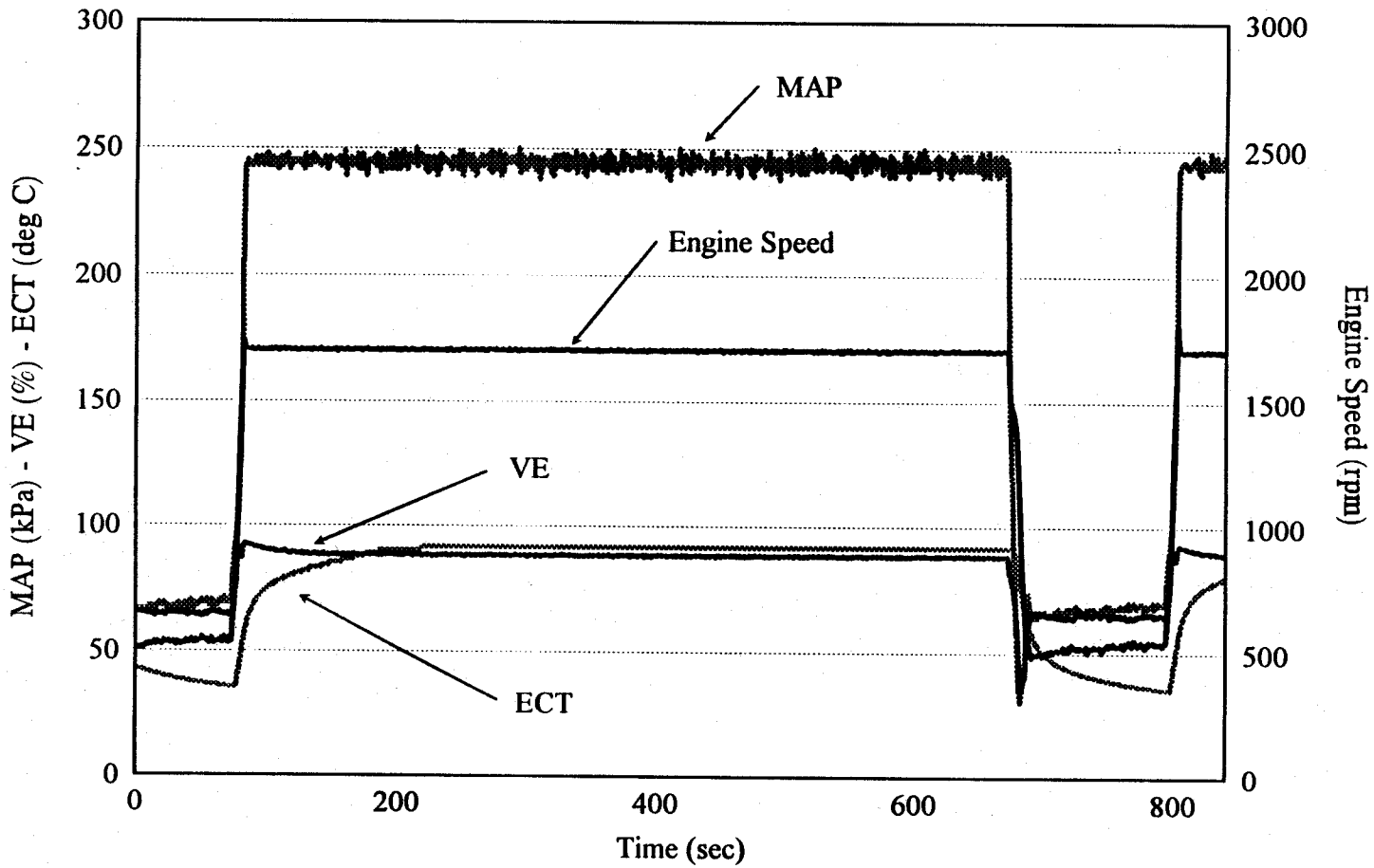


TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 525 HOUR



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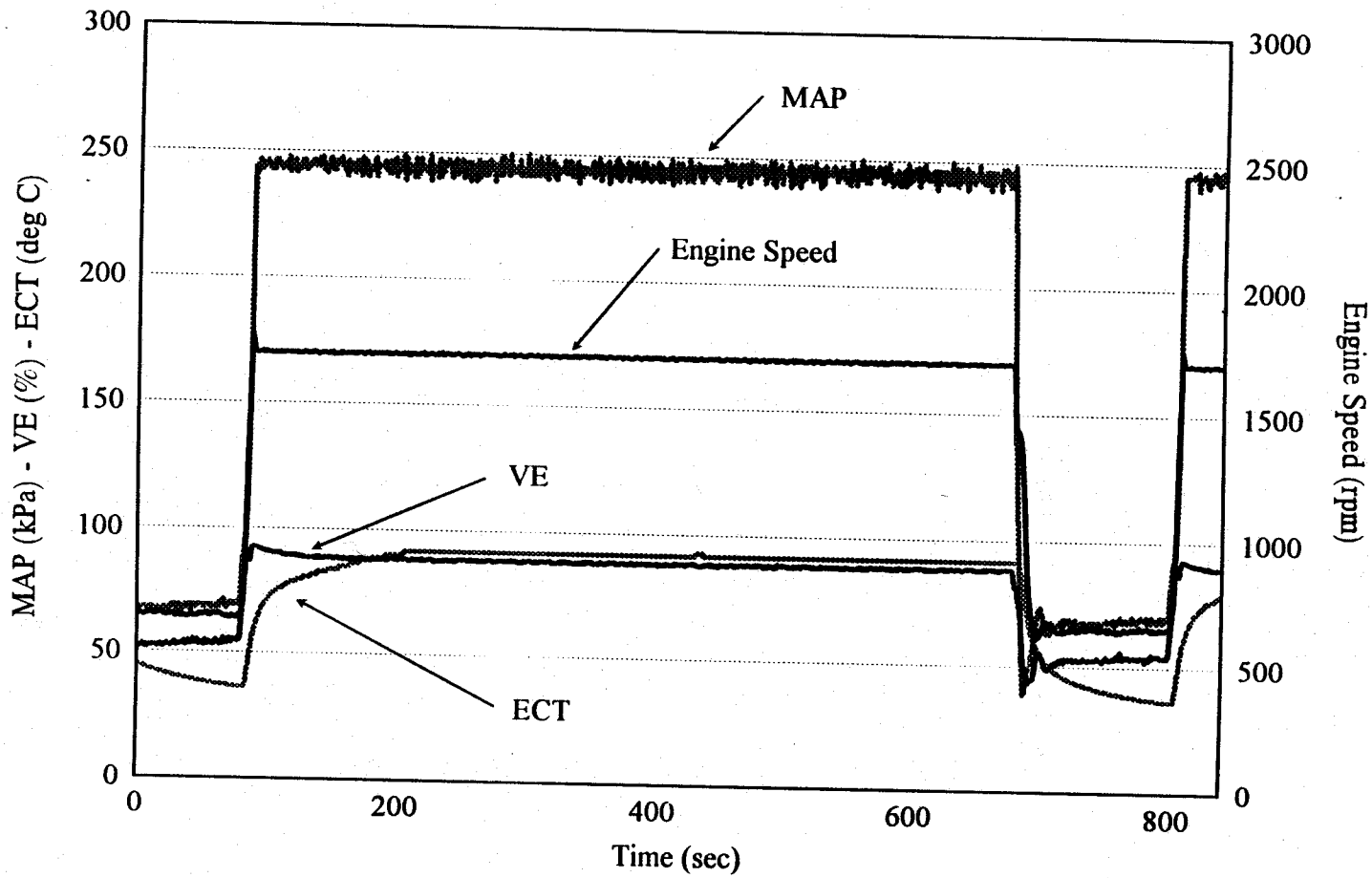
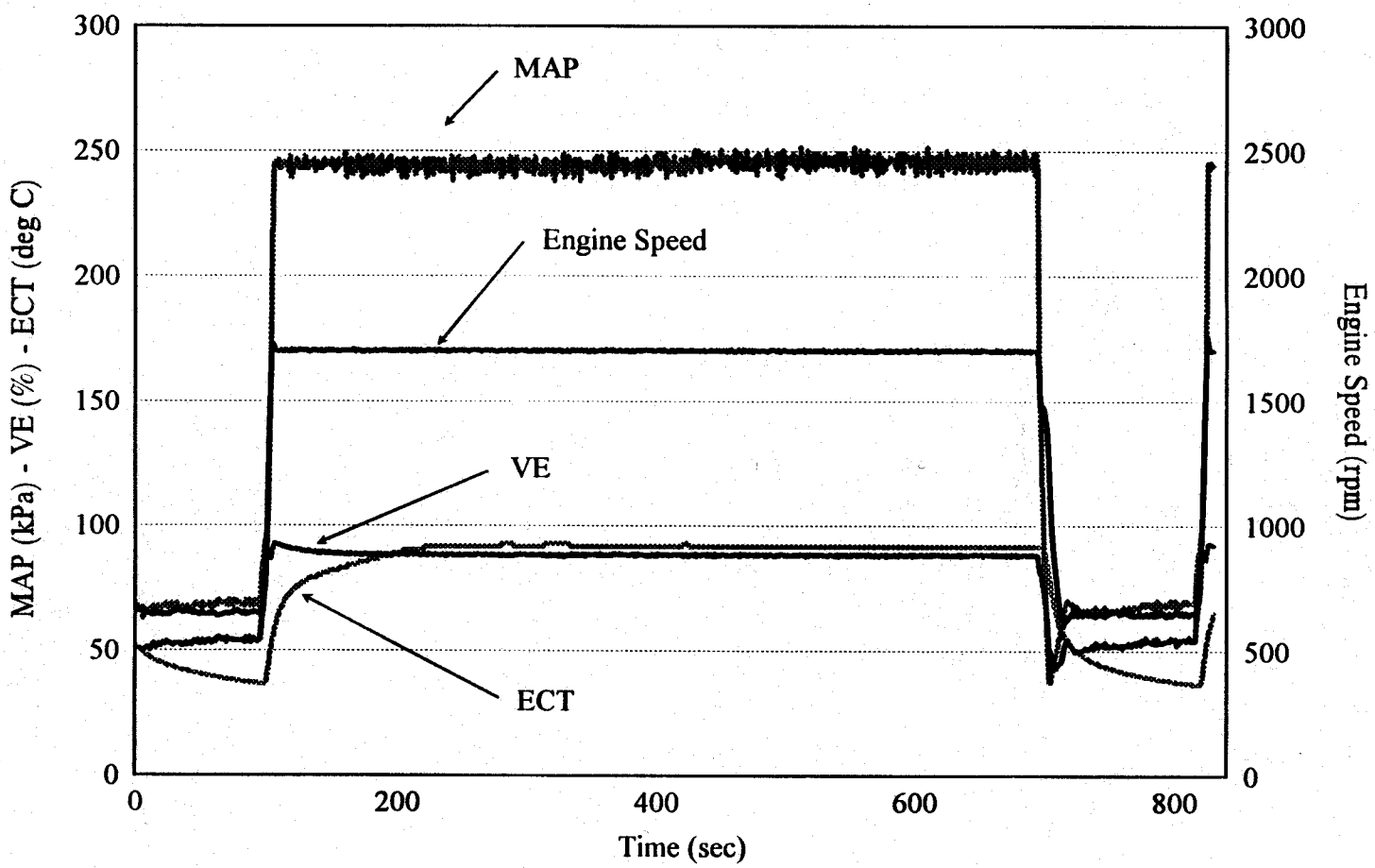
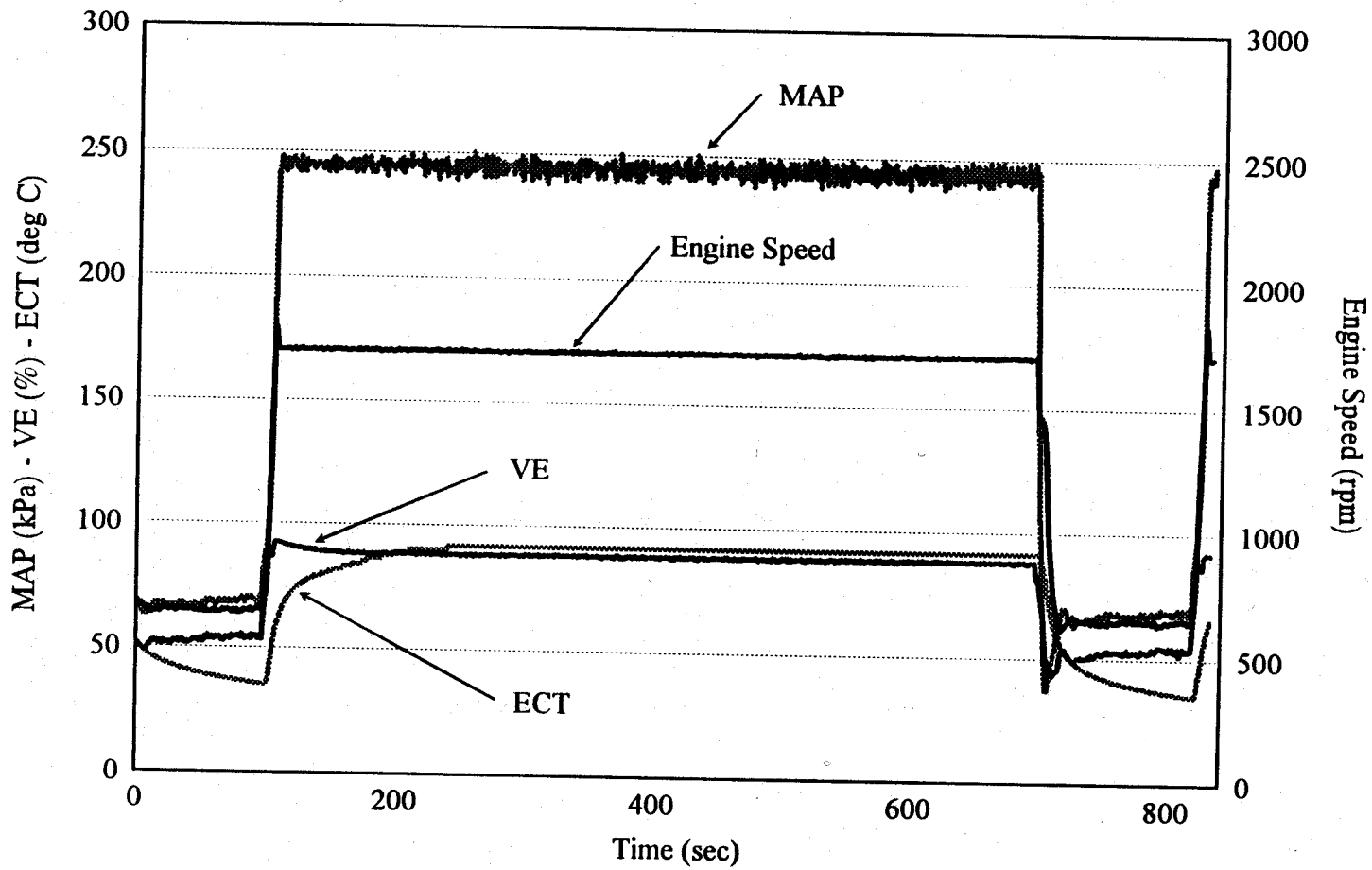


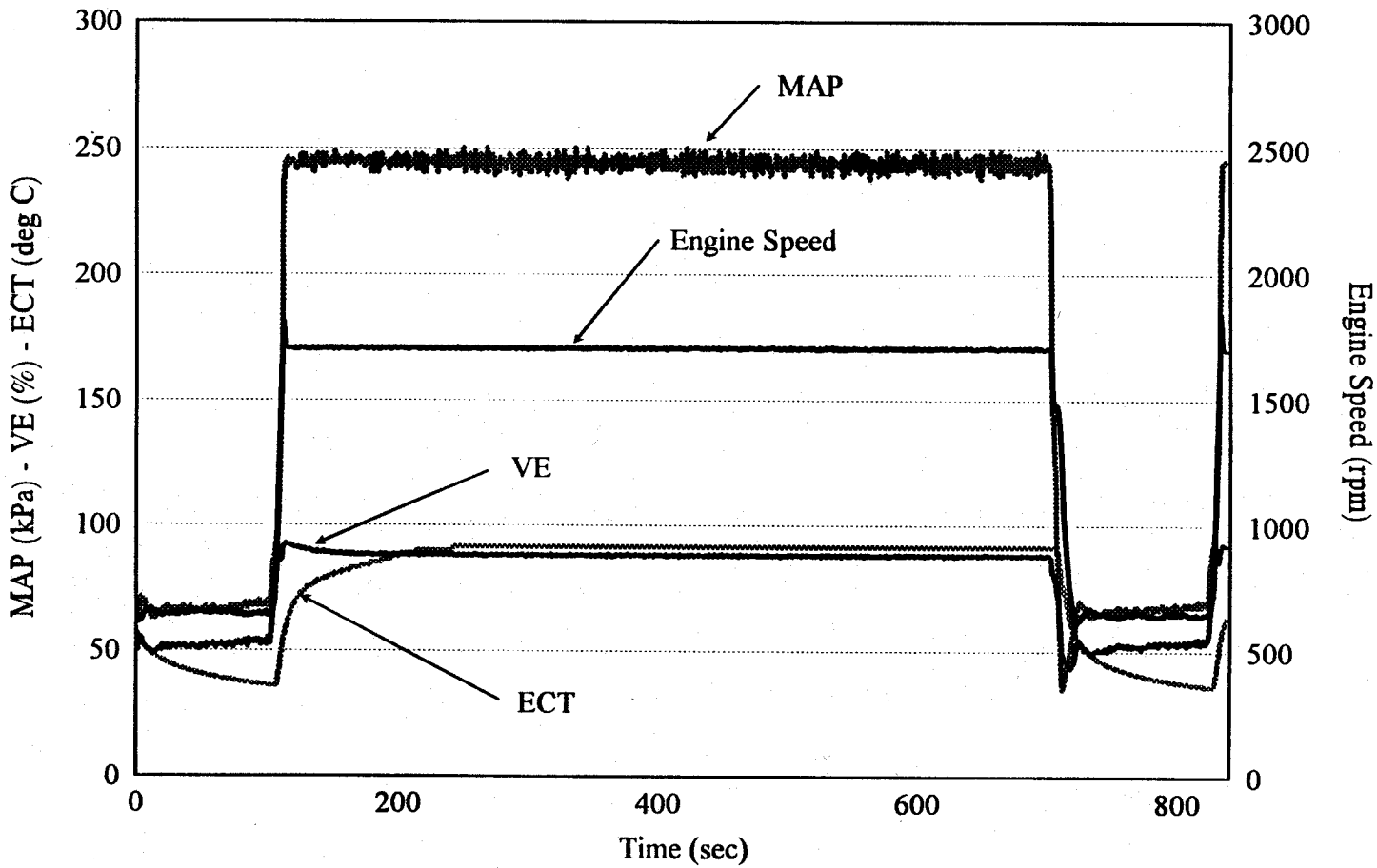
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 575 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 600 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 625 HOUR



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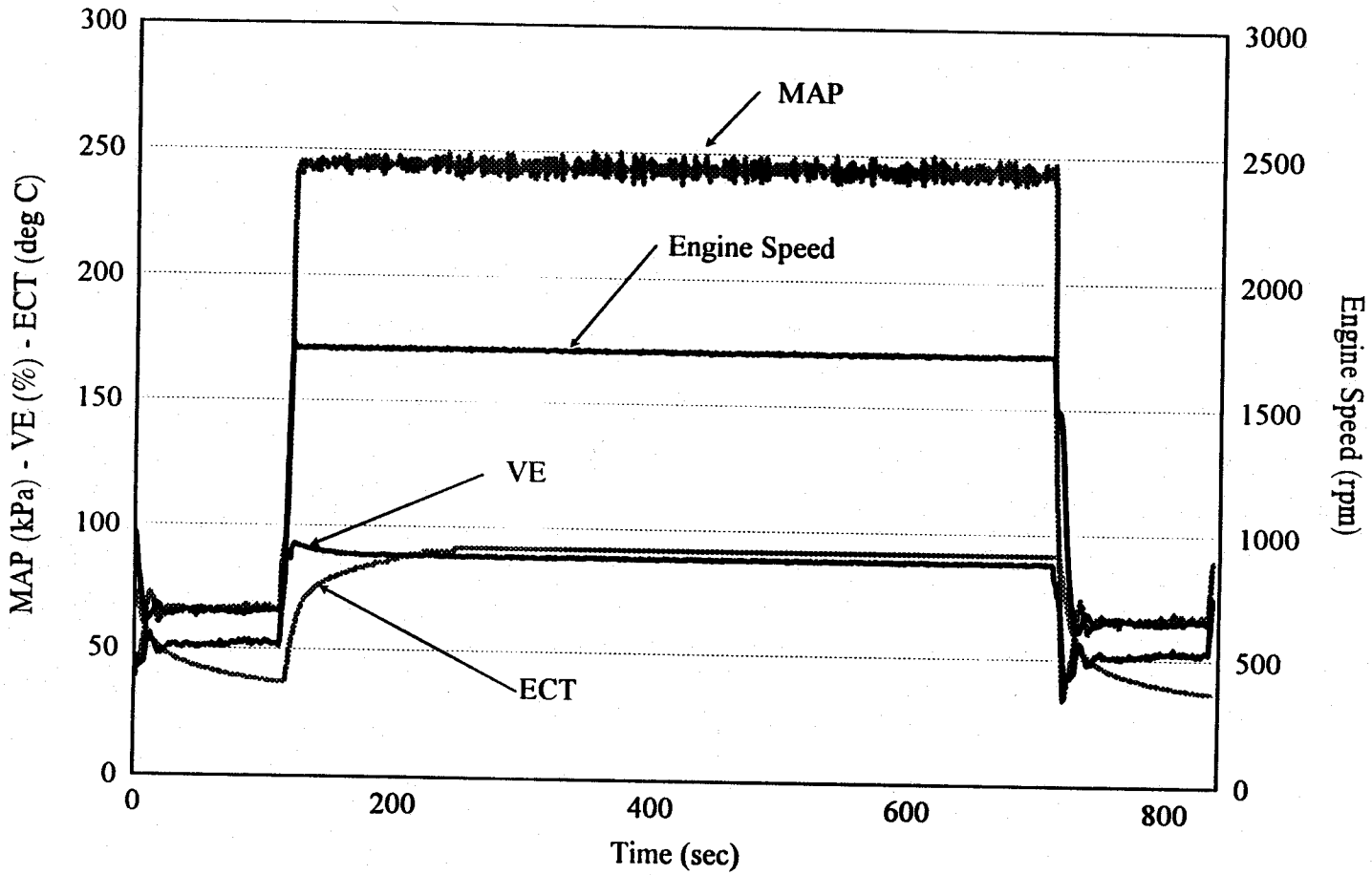
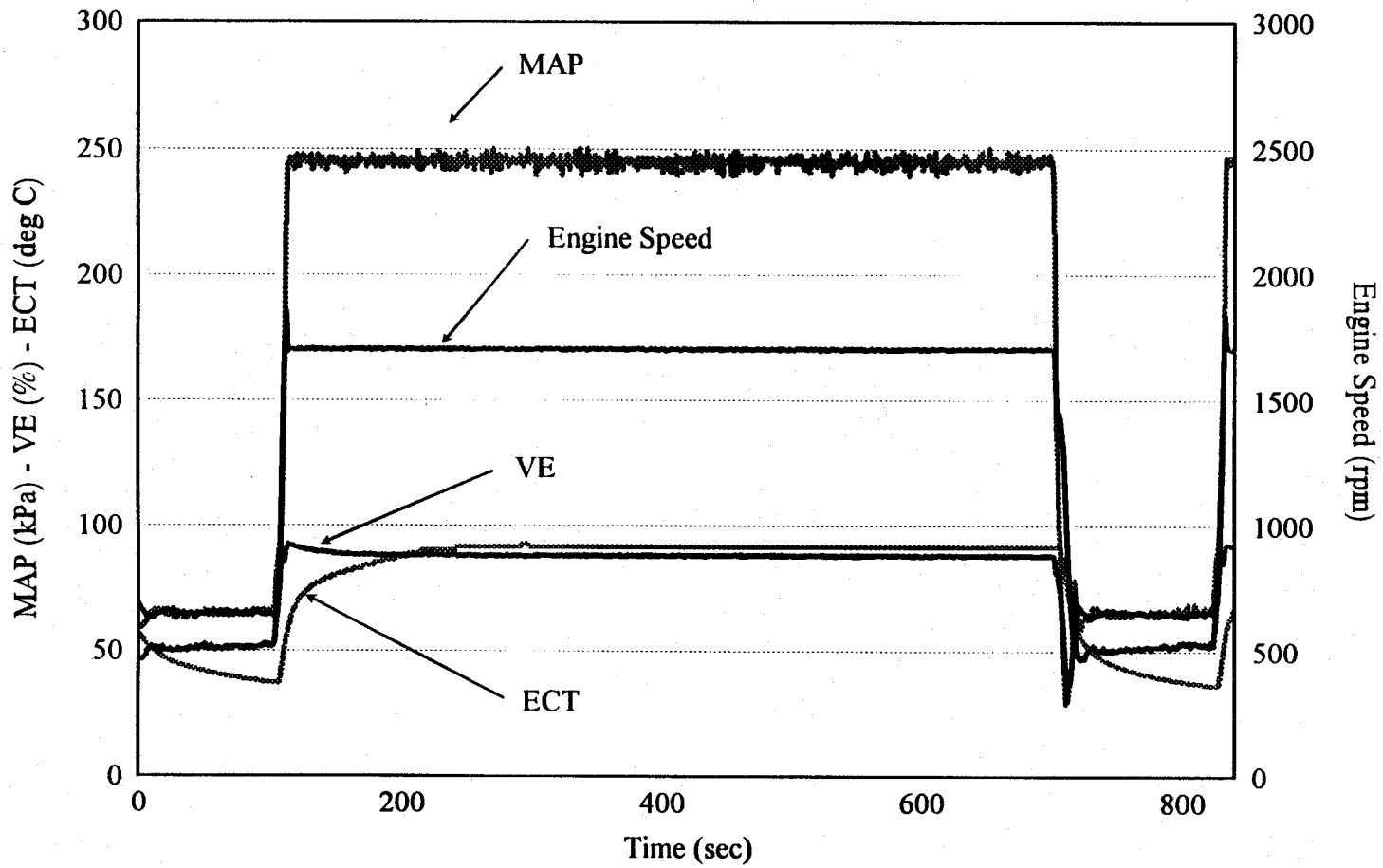
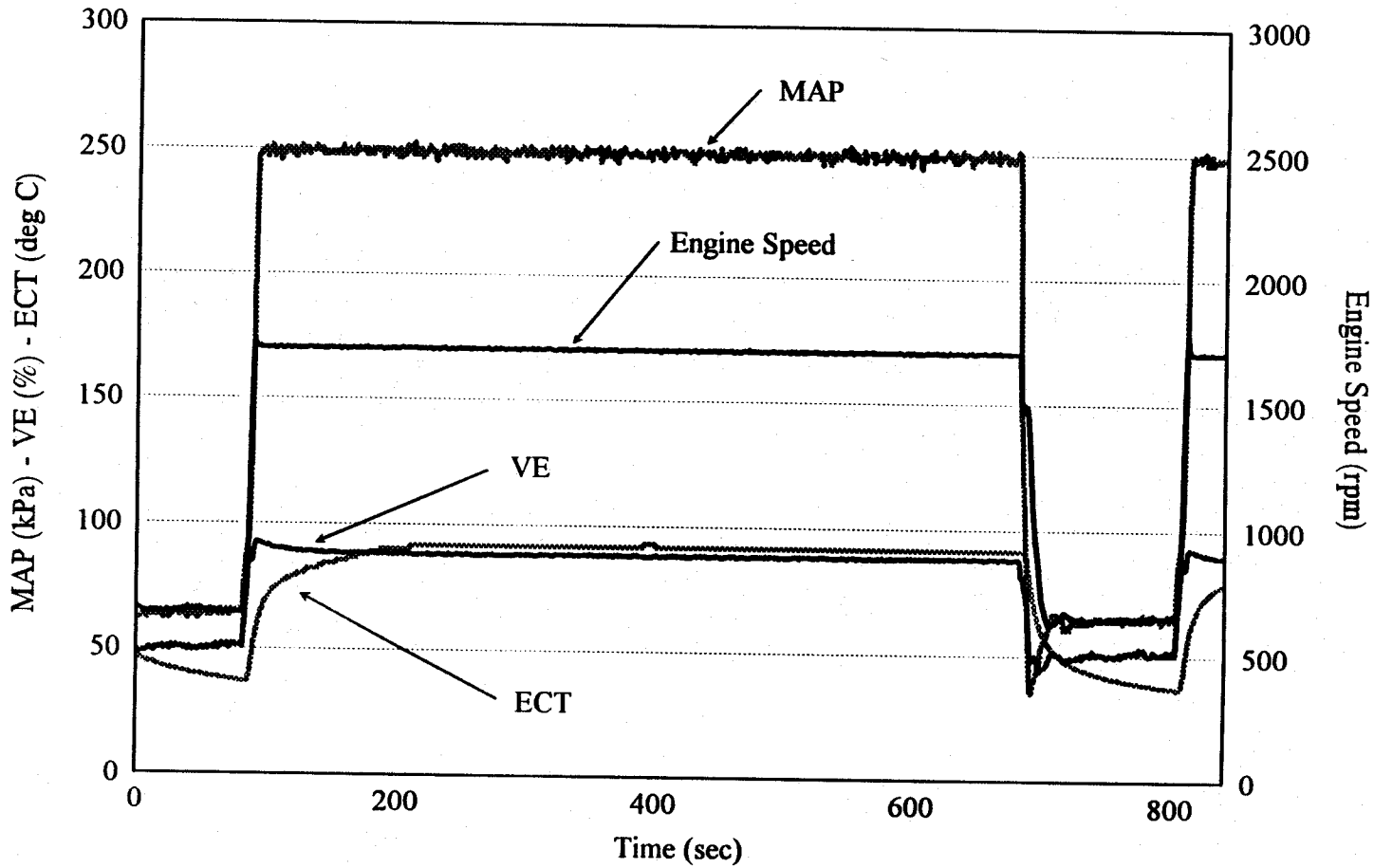


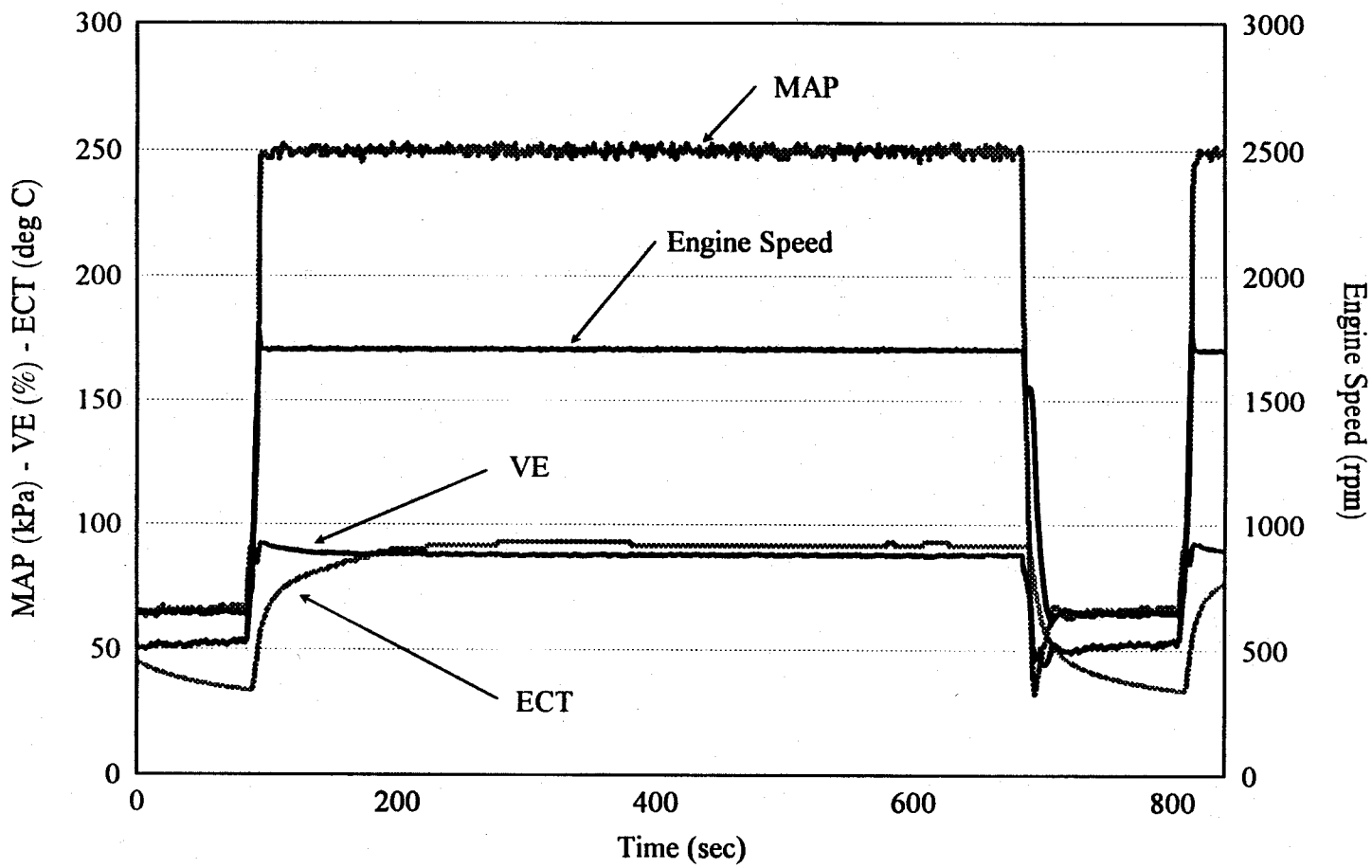
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 675 HOUR



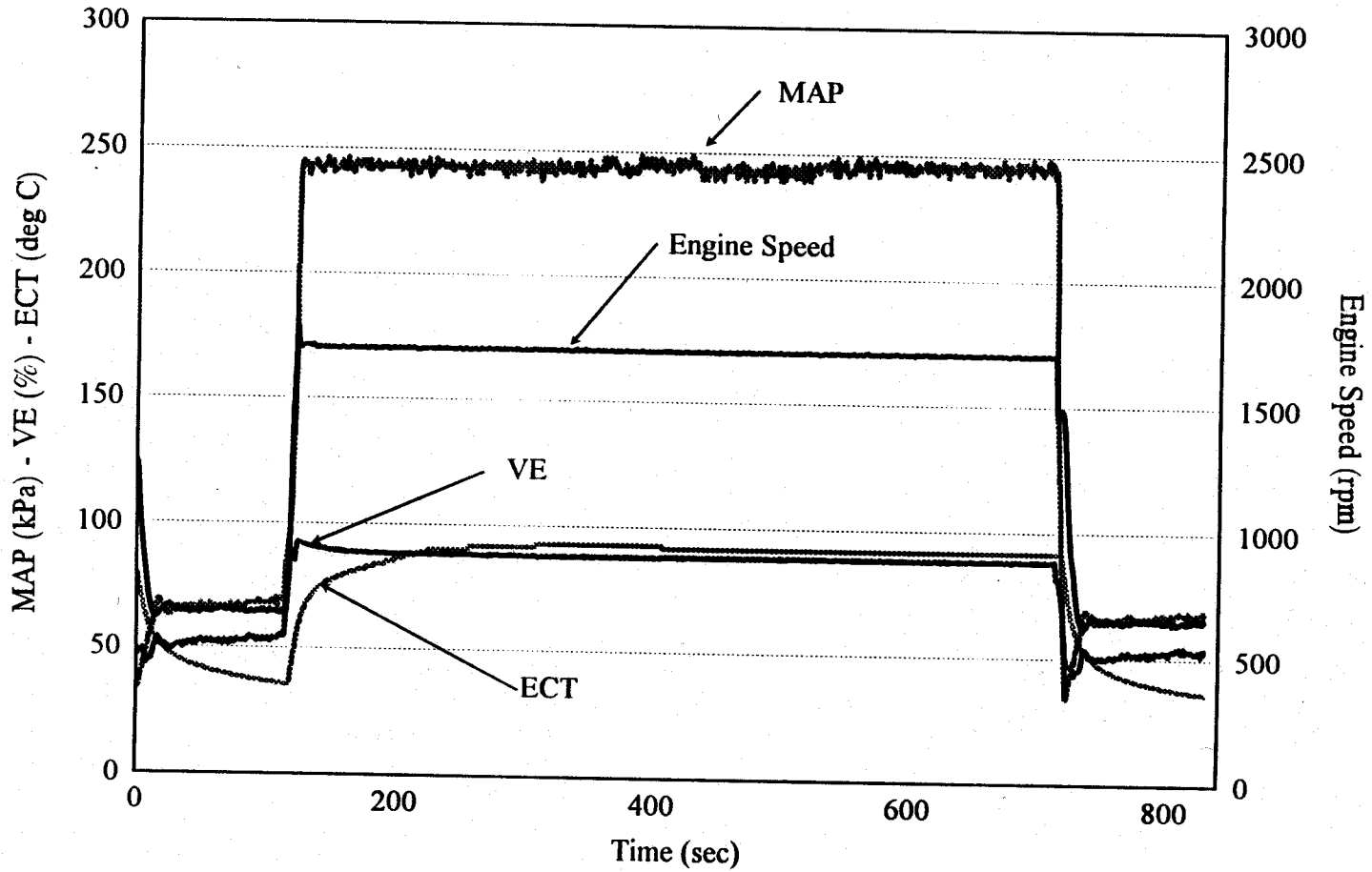
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 700 HOUR



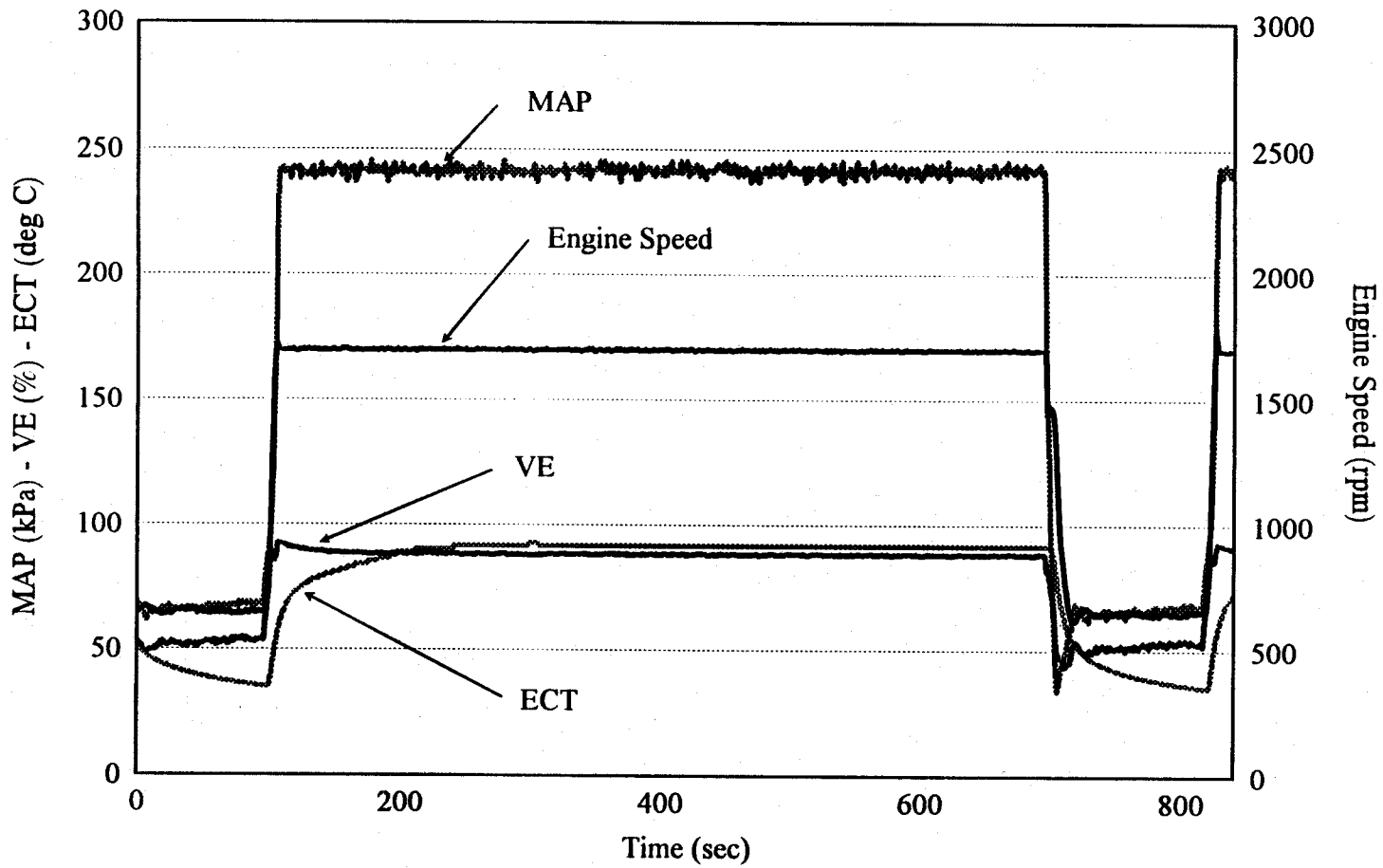
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 725 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 750 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 775 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 800 HOUR

APPENDIX C

VALVE STEM HEIGHT MEASUREMENTS

Valve Recession

Total Hours	0	24.8	24.8	129.3	129.3	104.5	386.9	386.9	257.6
STC Hours				0			250		
Intake	Reading	Reading	Recession	Reading	Recession	Recession	Reading	Recession	Recession
1 in	0.5409	0.5409	0.0000	0.5417	0.0008	0.0008	0.5422	0.0013	0.0005
1 ex	0.5380	0.5383	0.0003	0.5390	0.0010	0.0007	0.5392	0.0012	0.0002
2 in	0.5385	0.5386	0.0001	0.5392	0.0007	0.0006	0.5394	0.0009	0.0002
2 ex	0.5366	0.5367	0.0001	0.5372	0.0006	0.0005	0.5372	0.0006	0.0000
3 in	0.5369	0.5370	0.0001	0.5375	0.0006	0.0005	0.5377	0.0008	0.0002
3 ex	0.5364	0.5366	0.0002	0.5376	0.0012	0.0010	0.5379	0.0015	0.0003
4 in	0.5415	0.5414	-0.0001	0.5420	0.0005	0.0006	0.5426	0.0011	0.0006
4 ex	0.5375	0.5374	-0.0001	0.5376	0.0001	0.0002	0.5389	0.0014	0.0013
5 in	0.5371	0.5372	0.0001	0.5384	0.0013	0.0012	0.5399	0.0028	0.0015
5 ex	0.5366	0.5365	-0.0001	0.5375	0.0009	0.0010	0.5387	0.0021	0.0012
6 in	0.5385	0.5385	0.0000	0.5386	0.0001	0.0001	0.5393	0.0008	0.0007
6 ex	0.5369	0.5368	-0.0001	0.5369	0.0000	0.0001	0.5373	0.0004	0.0004
Average	0.5380	0.5380	0.0000	0.5386	0.0006	0.0006	0.5392	0.0012	0.0006
Exhaust	Reading	Reading	Recession	Reading	Recession	Recession	Reading	Recession	Recession
1 in	0.5148	0.5148	0.0000	0.5164	0.0016	0.0016	0.5200	0.0052	0.0036
1 ex	0.5136	0.5137	0.0001	0.5152	0.0016	0.0015	0.5163	0.0027	0.0011
2 in	0.5162	0.5165	0.0003	0.5179	0.0017	0.0014	0.5230	0.0068	0.0051
2 ex	0.5112	0.5117	0.0005	0.5130	0.0018	0.0013	0.5140	0.0028	0.0010
3 in	0.5159	0.5168	0.0009	0.5173	0.0014	0.0005	0.5188	0.0029	0.0015
3 ex	0.5151	0.5160	0.0009	0.5170	0.0019	0.0010	0.5188	0.0037	0.0018
4 in	0.5148	0.5155	0.0007	0.5162	0.0014	0.0007	0.5180	0.0032	0.0018
4 ex	0.5130	0.5135	0.0005	0.5147	0.0017	0.0012	0.5213	0.0083	0.0066
5 in	0.5142	0.5148	0.0006	0.5151	0.0009	0.0003	0.5164	0.0022	0.0013
5 ex	0.5128	0.5135	0.0007	0.5157	0.0029	0.0022	0.5180	0.0052	0.0023
6 in	0.5139	0.5157	0.0018	0.5171	0.0032	0.0014	0.5178	0.0039	0.0007
6 ex	0.5139	0.5152	0.0013	0.5181	0.0042	0.0029	0.5212	0.0073	0.0031
Average	0.5141	0.5148	0.0007	0.5161	0.0020	0.0013	0.5186	0.0045	0.0025

Valve Recession

Total Hours	640.6	640.6	253.7	895.5	895.5	254.9	1174.6	1174.6	279.1
STC Hours	500			750			1000		
Intake	Reading	Recession	Recession	Reading	Recession	Recession	Reading	Recession	Recession
1 in	0.5422	0.0013	0.0000	0.5423	0.0014	0.0001	0.5420	0.0011	-0.0003
1 ex	0.5392	0.0012	0.0000	0.5392	0.0012	0.0000	0.5379	-0.0001	-0.0013
2 in	0.5396	0.0011	0.0002	0.5398	0.0013	0.0002	0.5394	0.0009	-0.0004
2 ex	0.5374	0.0008	0.0002	0.5375	0.0009	0.0001	0.5375	0.0009	0.0000
3 in	0.5380	0.0011	0.0003	0.5381	0.0012	0.0001	0.5370	0.0001	-0.0011
3 ex	0.5380	0.0016	0.0001	0.5380	0.0016	0.0000	0.5371	0.0007	-0.0009
4 in	0.5427	0.0012	0.0001	0.5428	0.0013	0.0001	0.5430	0.0015	0.0002
4 ex	0.5390	0.0015	0.0001	0.5391	0.0016	0.0001	0.5392	0.0017	0.0001
5 in	0.5401	0.0030	0.0002	0.5401	0.0030	0.0000	0.5404	0.0033	0.0003
5 ex	0.5388	0.0022	0.0001	0.5389	0.0023	0.0001	0.5392	0.0026	0.0003
6 in	0.5396	0.0011	0.0003	0.5396	0.0011	0.0000	0.5400	0.0015	0.0004
6 ex	0.5375	0.0006	0.0002	0.5376	0.0007	0.0001	0.5382	0.0013	0.0006
Average	0.5393	0.0014	0.0001	0.5394	0.0015	0.0001	0.5392	0.0013	-0.0002
Exhaust	Reading	Recession	Recession	Reading	Recession	Recession	Reading	Recession	Recession
1 in	0.5205	0.0057	0.0005	0.5217	0.0069	0.0012	0.5221	0.0073	0.0004
1 ex	0.5172	0.0036	0.0009	0.5174	0.0038	0.0002	0.5179	0.0043	0.0005
2 in	0.5246	0.0084	0.0016	0.5258	0.0096	0.0012	0.5263	0.0101	0.0005
2 ex	0.5147	0.0035	0.0007	0.5154	0.0042	0.0007	0.5158	0.0046	0.0004
3 in	0.5191	0.0032	0.0003	0.5196	0.0037	0.0005	0.5200	0.0041	0.0004
3 ex	0.5192	0.0041	0.0004	0.5196	0.0045	0.0004	0.5202	0.0051	0.0006
4 in	0.5183	0.0035	0.0003	0.5204	0.0056	0.0021	0.5215	0.0067	0.0011
4 ex	0.5226	0.0096	0.0013	0.5237	0.0107	0.0011	0.5254	0.0124	0.0017
5 in	0.5172	0.0030	0.0008	0.5183	0.0041	0.0011	0.5187	0.0045	0.0004
5 ex	0.5202	0.0074	0.0022	0.5219	0.0091	0.0017	0.5235	0.0107	0.0016
6 in	0.5180	0.0041	0.0002	0.5183	0.0044	0.0003	0.5185	0.0046	0.0002
6 ex	0.5222	0.0083	0.0010	0.5231	0.0092	0.0009	0.5243	0.0104	0.0012
Average	0.5195	0.0054	0.0008	0.5204	0.0063	0.0010	0.5212	0.0071	0.0008

APPENDIX D

LETTERS SENT TO CHAMPION SPARK PLUGS

SOUTHWEST RESEARCH INSTITUTE

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

ENGINE AND VEHICLE RESEARCH DIVISION
FAX: (210) 522-2019

August 14, 1996

Mr. Bob Freeman
Staff Production Engineer
Cooper Automotive
Champion Spark Plug Division
P.O. Box 910
Toledo, OH 43661-0001

Dear Mr. Freeman:

Mr. John Bartel of Mack Trucks, Inc. requested that I send you this set of used spark plugs from a Mack E7 natural gas-fueled engine.

The enclosed spark plugs are marked with the cylinder number. The run time history of the spark plugs is shown in the table below.

Description	Engine Speed (rpm)	Power (bhp)	Time (hours)	Total Time (hours)
Steady State Test Time	1950	163	12.0	12.0
Steady State Test Time	1950	325	12.0	24.0
Steady State Test Time	1950	357	100.0	124.0
Cycle Test Time *	650/1700	5/389	273.5	397.5
Other Time (warm up, cool down, troubleshooting)			13.1	410.6
Replaced no. 4 spark plug due to misfires				
Cycle Test Time *	650/1700	5/389	5.4	416.0
Other Time (warm up, cool down, troubleshooting)			0.8	416.8
Replaced no. 5 spark plug due to misfires				
Cycle Test Time *	650/1700	5/389	10.6	427.4
Other Time (warm up, cool down, troubleshooting)			0.1	427.5
Replaced nos. 1, 2, 3, and 6 spark plugs at the request of John Bartel				

* 2 minutes at 650 rpm, 10 minutes at 1700 rpm

Cylinder no. 4 began to misfire first at 410.6 hours. The no. 4 spark plug was replaced and the misfires stopped. Cylinder no. 5 began to misfire at 416.8 hours. The no. 5 spark plug was replaced and the misfires stopped. The spark plugs in cylinder nos. 1, 2, 3, and 6 were not misfiring, but were replaced at the request of John Bartel. Spark plug gaps are shown below.

Cylinder	0.0 Total Engine Hours	129.3 Total Engine Hours	386.9 Total Engine Hours	410.6 Total Engine hours	416.8 Total Engine Hours	427.5 Total Engine hours
1	0.010"	0.012"	0.017"			0.019"
2	0.010"	0.012"	0.017"			0.019"
3	0.010"	0.013"	0.017"			0.019"
4	0.010"	0.013"	0.021"	0.032"		
5	0.010"	0.013"	0.020"		0.028"	
6	0.010"	0.014"	0.018"			0.019"

If you have any questions. please feel free to contact me. I can be reached by telephone at (210) 522-2570 or by fax at (210) 522-2019.

Sincerely,

James P. Chiu, P.E.
Senior Research Engineer
Gas and Industrial Engine Development
Department of Engine Research

/lmm

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ENGINE AND VEHICLE RESEARCH DIVISION
FAX: (210) 522-2019

September 13, 1996

Mr. Bob Freeman
Staff Product Engineer
Cooper Automotive
Champion Spark Plug Division
P.O. Box 910
Toledo, OH 43661-0001

Dear Mr. Freeman:

Enclosed are the parts of a spark plug from the durability test we are conducting for John Bartel at Mack Trucks.

The spark plug is a RX501PYP/2H6, and has 257.2 hours on it. The 257.2 hours include 252.0 hours of super thermal cycle (STC) test time and 5.2 hours of miscellaneous test time. The STC consists of 10 minutes at 1700 rpm and 389 bhp, and two(2) minutes at 650 rpm and six (6) bhp. The initial gap of the spark plug was 0.010". At 254.9 hours, the spark plug was removed, and the gap was 0.015". It was reinstalled, and at 257.2 hours it broke apart.

If you have any questions, please feel free to contact me. I can be reached by telephone at (210) 522-2570 or by fax at (210) 522-2019.

Sincerely,

James P. Chiu, P.E.
Senior Research Engineer
Gas and Industrial Engine Development
Department of Engine Research

/lmm

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ENGINE AND VEHICLE RESEARCH DIVISION
FAX: (210) 522-2019

September 20, 1996

Mr. Bill Squire
Senior Account Manager
OEM Sales & Marketing
Cooper Automotive
Champion Spark Plug Division
900 Upton Avenue
Toledo, OH 43607

Dear Mr. Squire:

Enclosed are two spark plugs from a durability test we are conducting for John Bartel at Mack Trucks. Mr. Bartel spoke to you today about these spark plugs and he requested that I send them to you.

The engine for the durability test operates on a cycle for two minutes at 650 rpm, minimum load, 100°F coolant out temperature and 10 minutes at 1700 rpm, 1202 lb-ft, 200°F coolant out temperature. The spark plugs enclosed (RX501PYP/2H6) were installed at 500 test hours. They were removed at 750 test hours for gap measurements and reinstalled. At 914.1 test hours, the spark plug on the no. 4 cylinder failed, and the spark plug from the no. 1 cylinder shows signs of combustion products between the ceramic and the shell next to the crimp. Both of these spark plugs are enclosed for you to examination. None of the spark plugs required high torques to remove them. In addition to the 414.1 hours of test time on the spark plugs, there were 6.1 hours of miscellaneous time (warm-ups and cool-downs).

Our procedure for installing spark plugs is to coat the threads with an anti-seize compound and insert the plug into the head until it is finger tight. The spark plug is then turned an additional 1/4 turn for new spark plugs or 1/8 turn for used spark plugs with a used gasket. An experiment, performed after this spark plug failure, showed:

(1) The torque required for installing a used spark plug (RX501PYP/1E5) at 1/8 turn after it is finger tight is 10 ft-lb.
(2) To torque a new spark plug (RX501PYP/1E5 or 1E5) to 20 ft-lbs requires a 1/2 - 3/4 turn after it is finger tight.
(3) To torque a used spark plug (RX501PYP/2H6) with a used gasket to 20 ft-lbs requires a 1/8-1/4 turn after it is finger tight.

The gasket thickness of a spark plug (RX501PYP/1E5) for a given tightening torque are as follows:

New	0.080"
20 ft-lbs	0.050"
30 ft-lbs	0.043"
40 ft-lbs	0.043"

A torque of 40 ft-lbs was the highest we felt comfortable with, in order to avoid damaging the engine.

If you have any questions, please feel free to contact me. I can be reached by telephone at (210) 522-2570 or by fax at (210) 522-2019.

Sincerely,

James P. Chiu, P.E.
Senior Research Engineer
Gas and Industrial Engine Development
Department of Engine Research

/lmm

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Enclosures

cc: John Bartel, Mack Trucks (w/o enclosures)

SOUTHWEST RESEARCH INSTITUTE

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ENGINE AND VEHICLE RESEARCH DIVISION
FAX: (210) 522-2019

September 30, 1996

Mr. Bob Freeman
Staff Product Engineer
Cooper Automotive
Champion Spark Plug Division
P.O. Box 910
Toledo, OH 43661-0001

Dear Mr. Freeman:

This letter is a follow-up to the letter I sent to Mr. Bill Squire dated September 20, 1996 regarding spark plugs from a durability test we are conducting for John Bartel at Mack Trucks.

In the previous letter, the gasket thickness of a spark plug for a given tightening torque was given. The spark plug was torqued into the head, but was never operated in an engine. Further experiments on gasket thicknesses were performed on spark plugs that have been operated in an engine. Two new spark plugs with different date codes were torqued to 20 ft-lbs. The spark plugs were operated for 86.8 hours, and the gasket thickness (after the 86.8 hours) for the RX501PYP/1E5 was 0.048" and for the RX501PYP/2H6 was 0.044".

The results indicate that either the gasket thickness after running in an engine may not be a good indicator of initial tightening torque, or that the spark plug gasket thicknesses are different for spark plugs with different date codes and the same tightening torque. The gasket thickness experiment on the from the previous letter was performed on a RX501PYP/1E5. The 0.048" gasket thickness of the used RX501PYP/1E5 is closest to the 0.050" results for 20 ft-lbs of torque on a new spark plug, where as the 0.044" gasket thickness of the used RX501PYP/2H6 is closest to the 0.043" result for 30-40 ft-lbs of torque on a new RX501PYP/1E5 spark plug. Since I do not have any more new RX501PYP/2H6 spark plugs, I currently cannot perform a new gasket thickness experiment on this spark plug.

If you have any questions, please feel free to contact me. I can be reached by telephone at (210) 522-2570 or by fax at (210) 522-2019.

Sincerely,

James P. Chiu, P.E.
Senior Research Engineer
Gas and Industrial Engine Development
Department of Engine Research

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cc: John Bartel, Mack Trucks

APPENDIX E

LOW SPEED DATA FOR EMISSIONS TEST AT 0 HOURS ON THE STC TEST

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	890	891	894	895	896
Year	1996	1996	1996	1996	1996
Operator Initials	<.. ..>	<.. ..>	<.. ..>	<.. ..>	<.. ..>
Julian Day	JULY, 17	JULY, 17	JULY, 17	JULY, 17	JULY, 17
Time (Seconds)	14:19:15	14:22:27	15:06:16	15:08:47	15:13:53
Ignition Timing	15.0	15.0	23.5	23.5	25.0
Test Hours	0.0	0.0	0.0	0.0	0.0
Test Type Code	0	0	0	0	0

***** Engine Performance Data *****

Engine Speed (rpm)	1248	1249	1254	1252	1253
Torque (ft/lbs)	1022.2	1000.3	125.1	124.0	321.3
BHP	243.0	237.8	29.9	29.6	76.7
BSFC (#/BHp-Hr)	.318	.318	.588	.594	.377
BTE (%)	39.2	39.2	21.2	21.0	33.1
BMEP (psi)	211.7	207.2	25.9	25.7	66.6
N.G. Flow (lbs/Hr)	77.37	75.67	17.56	17.55	28.89
NG Flow/E+6 (BTU/Hr)	1.579	1.545	.358	.358	.589
Air Flow (#/Hr)	1973.4	1947.0	390.32	390.48	708.56
Volumetric Eff (%)	91.4	91.7	64.2	64.0	74.4
Equivalence Ratio	.643	.638	.737	.736	.668
O2 Volts	1.228	1.208	.165	.179	.342
Equiv O2	3.312	3.362	7.112	7.042	6.290
GEM Equiv. Ratio	.65	.65	.71	.71	.67
GEM Vol. Eff.	91.50	91.50	66.00	66.00	75.50
BlowBy (cfm)	******	******	******	******	******

***** Engine Temperature Data *****

Water In (Deg F)	184	178	183	179	181
Water Out (Deg F)	196	190	188	186	188
Oil Sump (Deg F)	228	227	202	203	207
Oil GALLERY (DEG F)	213	210	195	195	198
Intake @ LFE (Deg F)	93	93	95	95	96
Boost B4 IC (Deg F)	285	281	108	108	133
Boost AF IC (Deg F)	97	96	91	90	91
Pre-Turbine (Deg F)	1103	1098	835	848	911
Stack (Deg F)	938	936	717	743	823
Exhaust 1 (Deg F)	965	960	747	755	809
Exhaust 2 (Deg F)	1030	1027	731	737	823
Exhaust 3 (Deg F)	1015	1012	750	757	830
Exhaust 4 (Deg F)	1008	1005	760	769	827
Exhaust 5 (Deg F)	996	991	739	749	803
Exhaust 6 (Deg F)	946	939	740	749	780
Intake (Deg F)	113	113	112	110	99
Gas @ Meter (Deg F)	105	106	100	101	104

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	890	891	894	895	896
***** Engine Pressures Data *****					
Main Oil Pres (psig)	41.5	42.1	52.4	52.3	49.3
Fuel Pressure (psig)	92.6	94.6	99.4	100.2	100.5
Compress Out (psig)	16.97	16.41	.14	.15	2.18
Inlet Manifold(psig)	16.17	15.63	-5.80	-5.76	-1.05
Inlet Manifold(psia)	30.50	29.96	8.53	8.56	13.28
Pre-Turbine (psig)	10.38	10.06	.74	.74	1.62
Exhaust Bk Pr ("HG)	2.05	2.00	.16	.16	.37
LFE Filter Pr ("H2O)	.87	.85	.14	.14	.26
LFE Delta Pr ("H2O)	3.94	3.89	.76	.76	1.39
H (lbH2O/lbAir)	.009	.010	.009	.009	.009
RH (out) (%)	23.54	24.22	21.52	21.22	21.15
Barometer ("Hg)	29.18	29.18	29.17	29.17	29.17
***** Natural Gas Composition *****					
NG % Methane	94.71	94.71	94.56	94.56	94.56
NG % Ethane	2.55	2.55	2.56	2.56	2.56
NG % Propane	.49	.49	.52	.52	.52
NG % CO2	1.09	1.09	1.08	1.08	1.08
NG % Nitrogen	.92	.92	1.00	1.00	1.00
Butane Actual(%)	.24	.24	.28	.28	.28
MWT	17.05	17.05	17.09	17.09	17.09
Fuel LHV	20412.	20412.	20392.	20392.	20392.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number		897	898	899	900	901
Year		1996	1996	1996	1996	1996
Operator Initials		<.. ..>	<.. ..>	<.. ..>	<.. ..>	<.. ..>
Julian Day		JULY, 17	JULY, 17	JULY, 17	JULY, 17	JULY, 17
Time (Seconds)		15:17:11	15:22:45	15:25:39	15:29:54	15:32:59
Ignition Timing		25.0	20.5	20.5	17.0	17.0
Test Hours		0.0	0.0	0.0	0.0	0.0
Test Type Code		0	0	0	0	0

***** Engine Performance Data *****

Engine Speed	(rpm)	1249	1253	1253	1255	1253
Torque	(ft/lbs)	317.5	627.3	624.8	945.0	916.8
BHP		75.5	149.6	149.0	225.8	218.7
BSFC	(#/BHp-Hr)	.381	.326	.327	.316	.316
BTE	(%)	32.7	38.3	38.2	39.6	39.5
BMEP	(psi)	65.8	129.9	129.4	195.8	189.9
N.G. Flow	(lbs/Hr)	28.78	48.74	48.69	71.25	69.17
NG Flow/E+6	(BTU/Hr)	.587	.994	.993	1.453	1.411
Air Flow	(#/Hr)	703.15	1234.6	1228.1	1824.3	1774.5
Volumetric Eff	(%)	74.3	86.4	86.2	91.7	91.2
Equivalence Ratio		.671	.647	.650	.640	.639
O2 Volts		.336	.672	.671	1.103	1.087
Equiv O2		6.317	4.975	4.980	3.631	3.675
GEM Equiv. Ratio		.67	.65	.65	.65	.65
GEM Vol. Eff.		75.50	85.50	85.50	90.00	90.00
BlowBy	(cfm)	******	******	******	******	******

***** Engine Temperature Data *****

Water In	(Deg F)	177	173	173	179	173
Water Out	(Deg F)	185	185	186	190	186
Oil Sump	(Deg F)	208	213	213	219	220
Oil GALLERY	(DEG F)	198	200	201	205	204
Intake @ LFE	(Deg F)	95	95	96	96	97
Boost B4 IC	(Deg F)	132	191	192	266	261
Boost AF IC	(Deg F)	92	93	94	97	95
Pre-Turbine	(Deg F)	915	1002	1007	1076	1074
Stack	(Deg F)	826	881	886	903	904
Exhaust 1	(Deg F)	811	877	880	938	935
Exhaust 2	(Deg F)	826	919	923	988	984
Exhaust 3	(Deg F)	831	922	925	986	983
Exhaust 4	(Deg F)	828	907	911	980	978
Exhaust 5	(Deg F)	805	898	901	973	972
Exhaust 6	(Deg F)	780	858	860	924	922
Intake	(Deg F)	100	99	99	105	107
Gas @ Meter	(Deg F)	106	111	111	109	106

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	897	898	899	900	901
***** Engine Pressures Data *****					
Main Oil Pres (psig)	49.3	46.9	46.7	44.5	44.5
Fuel Pressure (psig)	100.2	98.2	98.6	94.9	94.9
Compress Out (psig)	2.15	7.11	7.09	14.55	13.81
Inlet Manifold(psig)	-1.05	5.65	5.63	13.61	12.91
Inlet Manifold(psia)	13.28	19.98	19.96	27.93	27.24
Pre-Turbine (psig)	1.61	4.03	4.02	9.01	8.56
Exhaust Bk Pr ("HG)	.38	.89	.89	1.70	1.62
LFE Filter Pr ("H2O)	.25	.48	.48	.78	.75
LFE Delta Pr ("H2O)	1.38	2.45	2.44	3.67	3.57
H (lbH2O/lbAir)	.009	.009	.009	.008	.009
RH (out) (%)	21.08	21.25	21.44	20.16	20.29
Barometer ("Hg)	29.17	29.17	29.17	29.16	29.16
***** Natural Gas Composition *****					
NG % Methane	94.56	94.56	94.56	94.56	94.56
NG % Ethane	2.56	2.56	2.56	2.56	2.56
NG % Propane	.52	.52	.52	.52	.52
NG % CO2	1.08	1.08	1.08	1.08	1.08
NG % Nitrogen	1.00	1.00	1.00	1.00	1.00
Butane Actual(%)	.28	.28	.28	.28	.28
MWT	17.09	17.09	17.09	17.09	17.09
Fuel LHV	20392.	20392.	20392.	20392.	20392.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	902	903	904	905	906
Year	1996	1996	1996	1996	1996
Operator Initials	<.. ..>	<.. ..>	<.. ..>	<.. ..>	<.. ..>
Julian Day	JULY, 17	JULY, 17	JULY, 17	JULY, 17	JULY, 17
Time (Seconds)	15:36:14	15:38:46	15:45:17	15:50:27	15:54:26
Ignition Timing	15.0	15.0	20.5	20.5	21.0
Test Hours	0.0	0.0	0.0	0.0	0.0
Test Type Code	0	0	0	0	0

***** Engine Performance Data *****

Engine Speed	(rpm)	1253	1253	1901	1901	1900
Torque	(ft/lbs)	1037.0	1033.6	988.2	979.1	740.0
BHP		247.4	246.5	357.6	354.3	267.6
BSFC	(#/BHp-Hr)	.323	.323	.337	.338	.351
BTE	(%)	38.6	38.6	36.9	36.8	35.5
BMEP	(psi)	214.8	214.1	204.7	202.8	153.3
N.G. Flow	(lbs/Hr)	79.87	79.68	120.67	119.91	93.96
NG Flow/E+6	(BTU/Hr)	1.631	1.627	2.464	2.448	1.919
Air Flow	(#/Hr)	2051.6	2047.1	3056.1	3035.4	2378.2
Volumetric Eff	(%)	92.1	91.9	81.0	81.0	81.2
Equivalence Ratio		.639	.639	.648	.648	.648
O2 Volts		1.315	1.317	2.283	2.265	1.617
Equiv O2		3.105	3.101	1.552	1.571	2.488
GEM Equiv. Ratio		.65	.65	.65	.65	.65
GEM Vol. Eff.		91.00	91.00	86.50	86.50	86.00
BlowBy	(cfm)	******	******	******	******	******

***** Engine Temperature Data *****

Water In	(Deg F)	176	169	178	176	172
Water Out	(Deg F)	189	185	190	188	186
Oil Sump	(Deg F)	221	221	233	236	232
Oil GALLERY	(DEG F)	205	204	216	217	215
Intake @ LFE	(Deg F)	97	96	96	96	97
Boost B4 IC	(Deg F)	295	295	338	336	269
Boost AF IC	(Deg F)	97	98	102	102	98
Pre-Turbine	(Deg F)	1105	1108	1220	1220	1185
Stack	(Deg F)	915	920	996	997	1008
Exhaust 1	(Deg F)	966	971	1115	1115	1069
Exhaust 2	(Deg F)	1034	1040	1160	1161	1103
Exhaust 3	(Deg F)	1026	1030	1157	1159	1108
Exhaust 4	(Deg F)	1011	1015	1134	1135	1092
Exhaust 5	(Deg F)	1000	1002	1130	1132	1090
Exhaust 6	(Deg F)	949	951	1100	1101	1056
Intake	(Deg F)	112	115	125	124	112
Gas @ Meter	(Deg F)	103	101	94	92	95

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	902	903	904	905	906
***** Engine Pressures Data *****					
Main Oil Pres (psig)	43.7	43.9	65.2	64.5	66.3
Fuel Pressure (psig)	92.5	93.1	81.0	82.0	88.6
Compress Out (psig)	17.85	17.85	22.90	22.63	14.88
Inlet Manifold(psig)	17.02	17.02	21.03	20.76	12.93
Inlet Manifold(psia)	31.34	31.34	35.35	35.08	27.25
Pre-Turbine (psig)	10.95	10.94	19.44	19.17	11.80
Exhaust Bk Pr ("HG)	2.06	2.07	4.03	4.00	2.74
LFE Filter Pr ("H2O)	.91	.91	1.56	1.53	1.11
LFE Delta Pr ("H2O)	4.15	4.13	6.28	6.23	4.83
H (lbH2O/lbAir)	.009	.008	.008	.008	.008
RH (out) (%)	20.78	20.02	19.73	19.40	19.87
Barometer ("Hg)	29.17	29.16	29.16	29.16	29.16
***** Natural Gas Composition *****					
NG % Methane	94.68	94.68	94.68	94.68	94.68
NG % Ethane	2.58	2.58	2.58	2.58	2.58
NG % Propane	.47	.47	.47	.47	.47
NG % CO2	1.09	1.09	1.09	1.09	1.09
NG % Nitrogen	.89	.89	.89	.89	.89
Butane Actual(%)	.27	.27	.27	.27	.27
MWT	17.07	17.07	17.07	17.07	17.07
Fuel LHV	20419.	20419.	20419.	20419.	20419.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	907	908	909	910	911
Year	1996	1996	1996	1996	1996
Operator Initials	<.. ..>	<.. ..>	<.. ..>	<.. ..>	<.. ..>
Julian Day	JULY, 17	JULY, 17	JULY, 17	JULY, 17	JULY, 17
Time (Seconds)	15:57:40	16:02:42	16:06:05	16:11:10	16:13:26
Ignition Timing	21.0	21.5	21.5	24.0	24.0
Test Hours	0.0	0.0	0.0	0.0	0.0
Test Type Code	0	0	0	0	0

***** Engine Performance Data *****

Engine Speed	(rpm)	1899	1898	1898	1895	1894
Torque	(ft/lbs)	742.5	489.3	491.2	254.1	245.7
BHP		268.5	176.8	177.5	91.7	88.6
BSFC	(#/BHp-Hr)	.351	.382	.381	.448	.457
BTE	(%)	35.6	32.6	32.7	27.8	27.3
BMEP	(psi)	153.8	101.4	101.8	52.6	50.9
N.G. Flow	(lbs/Hr)	94.10	67.62	67.66	41.06	40.51
NG Flow/E+6	(BTU/Hr)	1.922	1.381	1.382	.838	.827
Air Flow	(#/Hr)	2368.2	1728.4	1723.2	1042.5	1032.6
Volumetric Eff	(%)	81.4	78.6	78.4	70.9	70.7
Equivalence Ratio		.652	.642	.644	.646	.644
O2 Volts		1.590	1.042	1.045	.544	.535
Equiv O2		2.539	3.797	3.789	5.455	5.488
GEM Equiv. Ratio		.65	.65	.65	.67	.67
GEM Vol. Eff.		86.00	84.00	84.00	70.50	70.50
BlowBy	(cfm)	******	******	******	******	******

***** Engine Temperature Data *****

Water In	(Deg F)	176	177	180	187	176
Water Out	(Deg F)	188	187	188	194	184
Oil Sump	(Deg F)	231	227	226	224	222
Oil GALLERY	(DEG F)	215	212	212	213	208
Intake @ LFE	(Deg F)	97	97	98	96	95
Boost B4 IC	(Deg F)	268	209	210	173	171
Boost AF IC	(Deg F)	102	97	97	92	94
Pre-Turbine	(Deg F)	1183	1143	1139	1079	1071
Stack	(Deg F)	1005	1002	1000	950	944
Exhaust 1	(Deg F)	1064	1010	1008	953	949
Exhaust 2	(Deg F)	1102	1040	1039	966	961
Exhaust 3	(Deg F)	1106	1049	1046	976	970
Exhaust 4	(Deg F)	1091	1044	1041	980	975
Exhaust 5	(Deg F)	1090	1040	1036	968	963
Exhaust 6	(Deg F)	1054	1005	1002	945	939
Intake	(Deg F)	112	102	103	100	101
Gas @ Meter	(Deg F)	98	102	105	106	107

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	907	908	909	910	911
***** Engine Pressures Data *****					
Main Oil Pres (psig)	66.6	68.7	69.1	70.2	71.3
Fuel Pressure (psig)	89.5	93.0	94.8	96.2	97.7
Compress Out (psig)	14.89	8.70	8.69	5.37	5.22
Inlet Manifold(psig)	12.93	6.10	6.09	-.75	-.82
Inlet Manifold(psia)	27.25	20.42	20.41	13.57	13.51
Pre-Turbine (psig)	11.72	6.60	6.60	3.51	3.46
Exhaust Bk Pr ("HG)	2.74	1.74	1.74	.79	.77
LFE Filter Pr ("H2O)	1.11	.74	.73	.40	.40
LFE Delta Pr ("H2O)	4.81	3.48	3.48	2.07	2.04
H (lbH2O/lbAir)	.008	.008	.008	.009	.008
RH (out) (%)	19.21	19.40	19.67	20.42	20.58
Barometer ("Hg)	29.16	29.16	29.16	29.16	29.16
***** Natural Gas Composition *****					
NG % Methane	94.68	94.68	94.68	94.68	94.68
NG % Ethane	2.58	2.58	2.58	2.58	2.58
NG % Propane	.47	.47	.47	.47	.47
NG % CO2	1.09	1.09	1.09	1.09	1.09
NG % Nitrogen	.89	.89	.89	.89	.89
Butane Actual(%)	.27	.27	.27	.27	.27
MWT	17.07	17.07	17.07	17.07	17.07
Fuel LHV	20419.	20419.	20419.	20419.	20419.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	912	913	914	915
Year	1996	1996	1996	1996
Operator Initials	<.. ..>	<.. ..>	<.. ..>	<.. ..>
Julian Day	JULY, 17	JULY, 17	JULY, 17	JULY, 17
Time (Seconds)	16:23:27	16:25:56	16:40:39	16:43:58
Ignition Timing	19.0	19.0	17.0	17.0
Test Hours	0.0	0.0	0.0	0.0
Test Type Code	0	0	0	0

***** Engine Performance Data *****

Engine Speed (rpm)	1889	1890	653	654
Torque (ft/lbs)	96.6	97.1	126.8	127.7
BHP	34.8	34.9	15.8	15.9
BSFC (#/BHp-Hr)	.755	.749	.718	.715
BTE (%)	16.5	16.6	17.4	17.5
BMEP (psi)	20.0	20.1	26.3	26.5
N.G. Flow (lbs/Hr)	26.25	26.16	11.31	11.36
NG Flow/E+6 (BTU/Hr)	.536	.534	.231	.232
Air Flow (#/Hr)	632.10	632.30	171.80	172.03
Volumetric Eff (%)	64.9	65.0	51.1	51.6
Equivalence Ratio	.681	.679	1.079	1.083
O2 Volts	.295	.299	.061	.073
Equiv O2	6.501	6.483	7.636	7.571
GEM Equiv. Ratio	.71	.71	.89	.89
GEM Vol. Eff.	65.00	65.00	58.00	58.00
BlowBy (cfm)	******	******	******	******

***** Engine Temperature Data *****

Water In (Deg F)	184	184	170	176
Water Out (Deg F)	189	189	182	186
Oil Sump (Deg F)	217	217	200	198
Oil GALLERY (DEG F)	207	207	190	190
Intake @ LFE (Deg F)	96	97	97	97
Boost B4 IC (Deg F)	116	117	112	111
Boost AF IC (Deg F)	92	92	90	90
Pre-Turbine (Deg F)	1046	1048	741	733
Stack (Deg F)	942	945	600	598
Exhaust 1 (Deg F)	925	930	598	602
Exhaust 2 (Deg F)	921	925	574	571
Exhaust 3 (Deg F)	936	939	652	651
Exhaust 4 (Deg F)	950	952	646	640
Exhaust 5 (Deg F)	939	940	617	613
Exhaust 6 (Deg F)	927	929	613	615
Intake (Deg F)	106	107	134	132
Gas @ Meter (Deg F)	108	108	103	103

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	912	913	914	915
***** Engine Pressures Data *****				
Main Oil Pres (psig)	72.9	72.9	23.1	23.4
Fuel Pressure (psig)	97.2	99.0	101.5	103.0
Compress Out (psig)	.65	.65	.01	.01
Inlet Manifold(psig)	-5.30	-5.31	-5.00	-5.06
Inlet Manifold(psia)	9.02	9.01	9.32	9.26
Pre-Turbine (psig)	1.22	1.23	.47	.47
Exhaust Bk Pr ("HG)	.40	.40	.04	.04
LFE Filter Pr ("H2O)	.24	.23	.08	.08
LFE Delta Pr ("H2O)	1.24	1.25	.34	.34
H (lbH2O/lbAir)	.008	.008	.008	.008
RH (out) (%)	19.90	20.00	19.59	20.15
Barometer ("Hg)	29.16	29.16	29.15	29.15
***** Natural Gas Composition *****				
NG % Methane	94.68	94.68	94.43	94.43
NG % Ethane	2.58	2.58	2.61	2.61
NG % Propane	.47	.47	.58	.58
NG % CO2	1.09	1.09	1.11	1.11
NG % Nitrogen	.89	.89	.93	.93
Butane Actual(%)	.27	.27	.33	.33
MWT	17.07	17.07	17.13	17.13
Fuel LHV	20419.	20419.	20395.	20395.

APPENDIX F

EMISSIONS RESULTS FOR TESTS AT 0 HOURS ON THE STC TEST

RUN	Mode	Cat	Engine Speed (rpm)	MAP (kPa)	Load	Equiv Ratio	Ignition Timing (deg BTDC)	Degrees from MBT	BSTHC (g/kw-hr)	BSCO (g/kw-hr)	BSNOx (g/kw-hr)	BTE (%)	Power (kw)	HC eff	CO eff	Stack Temp (deg C)	B4 Cat Temp (deg C)	AF Cat Temp (deg C)
890	6*	Before	1248	270	100%	0.653	15.0	-4	6.08	1.09	3.07	38.5	181.2			919	914	956
891	6*	After	1249	270	100%	0.648	15.0	-4	1.42	0.00	3.18	38.4	177.3	77%	100%	917	911	953
894	2	Before	1254	146	10%	0.716	23.5	0	11.89	3.28	0.54	21.8	22.3			698	626	544
895	2	After	1252	145	10%	0.709	23.5	0	11.78	0.00	0.72	21.8	22.1	1%	100%	724	651	586
896	3	Before	1253	228	25%	0.673	25.0	0	4.72	1.60	1.43	32.8	57.2			804	757	728
897	3	After	1249	225	25%	0.667	25.0	0	3.19	0.00	1.54	32.8	56.3	32%	100%	807	760	739
898	4	Before	1253	264	50%	0.656	20.5	0	3.03	1.25	3.14	37.6	111.6			862	828	824
899	4	After	1253	263	50%	0.653	20.5	0	0.92	0.00	3.23	37.9	111.1	70%	101%	847	830	829
900	5	Before	1255	273	75%	0.653	17.0	-3	5.31	1.12	3.48	38.6	168.4			884	859	888
901	5	After	1253	272	75%	0.649	17.0	-3	1.50	0.00	3.79	38.7	163.1	72%	101%	885	859	887
902	6	Before	1253	266	100%	0.653	15.0	-4	6.55	1.12	2.40	37.6	184.5			896	873	908
903	6	After	1253	266	100%	0.647	15.0	-4	1.44	0.00	2.61	37.9	183.8	78%	101%	901	878	918
904	8	Before	1901	254	100%	0.653	20.5	-3	2.28	1.56	2.13	36.5	266.7			977	955	960
905	8	After	1901	254	100%	0.648	20.5	-3	0.40	0.00	2.22	36.7	264.2	83%	101%	978	958	963
906	9	Before	1900	245	75%	0.655	21.0	-3	3.47	1.67	1.47	35.0	199.5			989	964	978
907	9	After	1899	245	75%	0.651	21.0	-3	0.32	0.00	1.77	35.5	200.2	91%	101%	986	964	978
908	10	Before	1898	225	50%	0.655	21.5	-3	7.01	2.07	0.85	31.8	131.8			983	955	993
909	10	After	1898	225	50%	0.650	21.5	-3	0.31	0.00	1.01	32.3	132.4	96%	101%	981	954	991
910	11	Before	1895	192	25%	0.674	24.0	-3	9.95	2.60	0.75	26.6	68.4			931	886	935
911	11	After	1894	188	25%	0.669	24.0	-3	1.20	0.00	0.93	26.2	66.1	88%	100%	925	886	35
912	12	Before	1889	114	10%	0.713	19.0	-3	21.47	5.68	0.68	15.7	26.0			923	859	901
913	12	After	1890	114	10%	0.706	19.0	-3	3.41	0.00	0.91	15.9	26.0	84%	100%	926	859	901
914	1	Before	653	120		0.875	17.0	0	16.40	2.90	0.62	21.4	11.8			581	510	476
915	1	After	654	121		0.833	17.0	0	13.91	0.00	0.71	22.6	11.9	15%	101%	579	509	457

* Insulated exhaust pipe

RUN	Mode	Cat	Engine Speed (rpm)	MAP (psia)	Load	Equiv Ratio	Ignition Timing (deg BTDC)	Degrees from MBT	BSTHC (g/bhp-hr)	BSCO (g/bhp-hr)	BSNOx (g/bhp-hr)	BTE (%)	Power (bhp)	HC eff	CO eff	Stack Temp (deg F)	B4 Cat Temp (deg F)	AF Cat Temp (deg F)
890	6*	Before	1248	39.2	100%	0.653	15.0	-4	4.53	0.81	2.29	38.5	243.0			938	933	975
891	6*	After	1249	39.2	100%	0.648	15.0	-4	1.06	0.00	2.37	38.4	237.8	77%	100%	936	930	972
894	2	Before	1254	21.2	10%	0.716	23.5	0	8.87	2.44	0.41	21.8	29.9			717	645	563
895	2	After	1252	21	10%	0.709	23.5	0	8.78	0.00	0.54	21.8	29.6	1%	100%	743	670	605
896	3	Before	1253	33.1	25%	0.673	25.0	0	3.52	1.19	1.07	32.8	76.7			823	776	747
897	3	After	1249	32.7	25%	0.667	25.0	0	2.38	0.00	1.15	32.8	75.5	32%	100%	826	779	758
898	4	Before	1253	38.3	50%	0.656	20.5	0	2.26	0.93	2.34	37.6	149.6			881	847	843
899	4	After	1253	38.2	50%	0.653	20.5	0	0.69	0.00	2.41	37.9	149.0	70%	101%	866	849	848
900	5	Before	1255	39.6	75%	0.653	17.0	-3	3.96	0.83	2.60	38.6	225.8			903	878	907
901	5	After	1253	39.5	75%	0.649	17.0	-3	1.12	0.00	2.83	38.7	218.7	72%	101%	904	878	906
902	6	Before	1253	38.6	100%	0.653	15.0	-4	4.89	0.83	1.79	37.6	247.4			915	892	927
903	6	After	1253	38.6	100%	0.647	15.0	-4	1.07	0.00	1.94	37.9	246.5	78%	101%	920	897	937
904	8	Before	1901	36.9	100%	0.653	20.5	-3	1.70	1.16	1.59	36.5	357.6			996	974	979
905	8	After	1901	36.8	100%	0.648	20.5	-3	0.30	0.00	1.66	36.7	354.3	83%	101%	997	977	982
906	9	Before	1900	35.5	75%	0.655	21.0	-3	2.59	1.25	1.09	35.0	267.6			1008	983	997
907	9	After	1899	35.6	75%	0.651	21.0	-3	0.24	0.00	1.32	35.5	268.5	91%	101%	1005	983	997
908	10	Before	1898	32.6	50%	0.655	21.5	-3	5.23	1.54	0.63	31.8	176.8			1002	974	1012
909	10	After	1898	32.7	50%	0.650	21.5	-3	0.23	0.00	0.75	32.3	177.5	96%	101%	1000	973	1010
910	11	Before	1895	27.8	25%	0.674	24.0	-3	7.42	1.94	0.56	26.6	91.7			950	905	954
911	11	After	1894	27.3	25%	0.669	24.0	-3	0.89	0.00	0.69	26.2	88.6	88%	100%	944	905	54
912	12	Before	1889	16.5	10%	0.713	19.0	-3	16.01	4.23	0.51	15.7	34.8			942	878	920
913	12	After	1890	16.6	10%	0.706	19.0	-3	2.54	0.00	0.68	15.9	34.9	84%	100%	945	878	920
914	1	Before	653	17.4		0.875	17.0	0	12.23	2.16	0.46	21.4	15.8			600	529	495
915	1	After	654	17.5		0.833	17.0	0	10.37	0.00	0.53	22.6	15.9	15%	101%	598	528	476

* Insulated exhaust pipe

RUN	Mode	Cat	Engine Speed (rpm)	MAP (psia)	Load	Equiv Ratio	Ignition Timing (deg BTDC)	Degrees from MBT	BSTHC (g/bhp-hr)	BSCO (g/bhp-hr)	BSNOx (g/bhp-hr)	BTE (%)	Power (bhp)	HC eff	CO eff	Stack Temp (deg F)	B4 Cat Temp (deg F)	AF Cat Tenp (deg F)
3269	6*	Before	1245	35.8	100%	0.654	15.0	-4	4.10	0.97	1.00	37.0	238.0			961	954	975
3270	6*	After	1245	35.6	100%	0.648	15.0	-4	1.53	0.00	1.27	37.1	234.0	63%	100%	961	953	972
3271	2	Before	1245	15.4	10%	0.706	23.5	0	14.75	3.27	0.25	21.1	29.7			786	722	698
3272	2	After	1245	15.5	10%	0.704	23.5	0	13.55	-0.01	0.40	21.3	30.0	8%	100%	777	711	678
3273	3	Before	1246	27.6	25%	0.668	25.0	0	4.36	1.59	0.48	32.2	76.0			828	780	750
3274	3	After	1247	27.7	25%	0.666	25.0	0	3.75	-0.01	0.67	32.4	76.1	14%	100%	831	785	760
3275	4	Before	1248	33.7	50%	0.649	20.5	0	2.12	1.10	1.22	37.3	149.8			889	854	834
3276	4	After	1248	33.7	50%	0.645	20.5	0	1.60	-0.01	1.32	37.3	149.4	25%	100%	894	859	842
3277	5	Before	1248	35.9	75%	0.646	17.0	-3	3.96	0.99	1.21	37.5	220.3			919	892	888
3278	5	After	1248	35.8	75%	0.643	17.0	-3	3.01	-0.01	1.40	37.6	219.9	24%	101%	920	893	890
3279	6	Before	1248	35.2	100%	0.647	15.0	-4	4.50	1.00	0.90	36.7	229.0			937	911	908
3280	6	After	1247	35.3	100%	0.644	15.0	-4	3.28	0.00	1.17	36.9	229.6	27%	100%	937	910	908
3281	8	Before	1896	31.9	100%	0.643	20.5	-3	8.22	1.95	0.58	32.7	326.4			991	967	987
3282	8	After	1892	32.2	100%	0.637	20.5	-3	5.53	0.00	0.73	33.3	330.9	33%	100%	991	969	986
3283	9	Before	1889	31.8	75%	0.647	21.0	-3	6.11	1.74	0.62	33.0	265.8			1012	986	999
3284	9	After	1888	31.8	75%	0.641	21.0	-3	4.38	-0.01	0.72	33.3	264.7	28%	100%	1008	983	994
3285	10	Before	1884	28.6	50%	0.646	21.5	-3	11.47	2.25	0.38	30.0	177.1			1000	974	1003
3286	10	After	1885	28.9	50%	0.639	21.5	-3	6.43	-0.01	0.47	30.7	179.9	44%	100%	1000	974	999
3287	11	Before	1896	23.2	25%	0.667	24.0	-3	12.13	2.65	0.39	25.3	90.3			952	910	920
3288	11	After	1895	23.2	25%	0.662	24.0	-3	9.20	-0.01	0.52	25.5	90.6	24%	100%	944	904	907
3289	12	Before	1891	13.1	10%	0.700	19.0	-3	26.80	5.32	0.41	14.9	34.2			944	884	872
3290	12	After	1892	13	10%	0.696	19.0	-3	20.50	-0.02	0.55	15.1	34.4	24%	100%	935	870	855
3291	1	Before	654	12.5		0.873	17.0	0	13.64	2.68	0.30	20.9	16.0			644	595	
3292	1	After	649	12.4		0.869	17.0	0	13.47	-0.01	0.48	21.1	15.9	1%	101%	634	568	563

* Insulated exhaust pipe

RUN	Mode	Cat	Engine Speed (rpm)	MAP (kPa)	Load	Equiv Ratio	Ignition Timing (deg BTDC)	Degrees from MBT	BSTHC (g/kw-hr)	BSCO (g/kw-hr)	BSNOx (g/kw-hr)	BTE (%)	Power (kw)	HC eff	CO eff	Stack Temp (deg C)	B4 Cat Temp (deg C)	AF Cat Tenp (deg C)
3269	6*	Before	1245	247	100%	0.654	15.0	-4	5.49	1.30	1.35	37.0	177.5			942	935	956
3270	6*	After	1245	245	100%	0.648	15.0	-4	2.06	0.00	1.70	37.1	174.5	63%	100%	942	934	953
3271	2	Before	1245	106	10%	0.706	23.5	0	19.78	4.38	0.34	21.1	22.1			767	703	679
3272	2	After	1245	107	10%	0.704	23.5	0	18.18	-0.01	0.54	21.3	22.4	8%	100%	758	692	659
3273	3	Before	1246	190	25%	0.668	25.0	0	5.85	2.13	0.64	32.2	56.7			809	761	731
3274	3	After	1247	191	25%	0.666	25.0	0	5.03	-0.01	0.90	32.4	56.7	14%	100%	812	766	741
3275	4	Before	1248	232	50%	0.649	20.5	0	2.85	1.48	1.63	37.3	111.7			870	835	815
3276	4	After	1248	232	50%	0.645	20.5	0	2.14	-0.01	1.77	37.3	111.4	25%	100%	875	840	823
3277	5	Before	1248	248	75%	0.646	17.0	-3	5.31	1.33	1.63	37.5	164.3			900	873	869
3278	5	After	1248	247	75%	0.643	17.0	-3	4.04	-0.01	1.87	37.6	164.0	24%	101%	901	874	871
3279	6	Before	1248	243	100%	0.647	15.0	-4	6.03	1.34	1.21	36.7	170.8			918	892	889
3280	6	After	1247	243	100%	0.644	15.0	-4	4.40	-0.01	1.57	36.9	171.2	27%	100%	918	891	889
3281	8	Before	1896	220	100%	0.643	20.5	-3	11.03	2.61	0.78	32.7	243.4			972	948	968
3282	8	After	1892	222	100%	0.637	20.5	-3	7.41	0.00	0.98	33.3	246.8	33%	100%	972	950	967
3283	9	Before	1889	219	75%	0.647	21.0	-3	8.19	2.33	0.83	33.0	198.2			993	967	980
3284	9	After	1888	219	75%	0.641	21.0	-3	5.87	-0.01	0.96	33.3	197.4	28%	100%	989	964	975
3285	10	Before	1884	197	50%	0.646	21.5	-3	15.38	3.01	0.51	30.0	132.1			981	955	984
3286	10	After	1885	199	50%	0.639	21.5	-3	8.62	-0.01	0.64	30.7	134.2	44%	100%	981	955	980
3287	11	Before	1896	160	25%	0.667	24.0	-3	16.27	3.56	0.52	25.3	67.3			933	891	901
3288	11	After	1895	160	25%	0.662	24.0	-3	12.34	-0.02	0.70	25.5	67.6	24%	100%	925	885	888
3289	12	Before	1891	90	10%	0.700	19.0	-3	35.94	7.14	0.55	14.9	25.5			925	865	853
3290	12	After	1892	90	10%	0.696	19.0	-3	27.49	-0.03	0.74	15.1	25.7	24%	100%	916	851	836
3291	1	Before	654	86	0	0.873	17.0	0	18.29	3.59	0.40	20.9	11.9			625	576	-19
3292	1	After	649	85	0	0.869	17.0	0	18.06	-0.02	0.64	21.1	11.9	1%	101%	615	549	544

* Insulated exhaust pipe

APPENDIX G

LOW SPEED DATA FOR EMISSIONS TEST AT 500 HOURS ON THE STC TEST

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	3269	3270	3271	3272	3273
Year	1996	1996	1996	1996	1996
Operator Initials	<..jc..>	<..JC..>	<..JC..>	<..JC..>	<..JC..>
Julian Day	AUG., 27	AUG., 27	AUG., 27	AUG., 27	AUG., 27
Time (Seconds)	10:02:26	10:13:35	10:47:35	10:51:37	10:57:44
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	500.0	500.0	500.0
Test Type Code	1	1	1	1	1

***** Engine Performance Data *****

Engine Speed (rpm)	1245	1245	1245	1245	1246
Torque (ft/lbs)	1004.5	987.3	125.4	126.5	320.1
BHP	238.0	234.0	29.7	30.0	76.0
BSFC (#/BHp-Hr)	.347	.350	.802	.797	.447
BTE (%)	35.8	35.6	15.4	15.5	27.6
BMEP (psi)	208.1	204.5	26.0	26.2	66.3
N.G. Flow (lbs/Hr)	82.68	81.79	23.84	23.90	34.00
NG Flow/E+6 (BTU/Hr)	1.691	1.672	.491	.492	.700
Air Flow (#/Hr)	2007.9	1980.4	406.78	407.35	720.29
Volumetric Eff (%)	94.7	94.4	66.1	66.2	75.9
Equivalence Ratio	.677	.679	.970	.971	.781
O2 Volts	1.243	1.218	.166	.159	.338
Equiv O2	3.275	3.337	7.108	7.141	6.307
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	2.35	2.36	.79	.78	1.02

***** Engine Temperature Data *****

Water In (Deg F)	178	178	170	170	169
Water Out (Deg F)	189	190	181	181	183
Oil Sump (Deg F)	218	218	198	197	200
Oil GALLERY (DEG F)	203	203	190	189	191
Intake @ LFE (Deg F)	79	80	79	79	79
Boost B4 IC (Deg F)	274	272	94	93	118
Boost AF IC (Deg F)	97	97	85	85	87
Pre-Turbine (Deg F)	1116	1112	875	866	917
Stack (Deg F)	961	961	786	777	828
Exhaust 1 (Deg F)	984	983	761	757	810
Exhaust 2 (Deg F)	1063	1066	759	753	832
Exhaust 3 (Deg F)	1050	1053	780	773	839
Exhaust 4 (Deg F)	1020	1020	771	764	830
Exhaust 5 (Deg F)	1003	999	770	765	806
Exhaust 6 (Deg F)	950	947	762	757	782
Intake (Deg F)	95	95	99	99	93
Gas @ Meter (Deg F)	87	92	88	88	90

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	3269	3270	3271	3272	3273
***** Engine Pressures Data *****					
Main Oil Pres (psig)	44.7	44.4	54.1	54.3	51.6
Fuel Pressure (psig)	98.5	98.6	109.1	108.4	108.7
Compress Out (psig)	17.10	16.79	.16	.16	2.29
Inlet Manifold(psig)	16.28	15.99	-5.40	-5.39	-.76
Inlet Manifold(psia)	30.61	30.32	8.94	8.94	13.57
Pre-Turbine (psig)	10.72	10.55	.84	.84	2.00
Exhaust Bk Pr ("HG)	2.59	2.56	.27	.26	.46
LFE Filter Pr ("H2O)	.93	.91	.15	.15	.27
LFE Delta Pr ("H2O)	3.87	3.83	.76	.76	1.36
H (lbH2O/lbAir)	.020	.020	.020	.020	.020
RH (out) (%)	87.46	83.03	83.09	81.71	83.05
Barometer ("Hg)	29.18	29.18	29.18	29.18	29.18
***** Natural Gas Composition *****					
NG % Methane	95.01	95.01	95.43	95.43	95.43
NG % Ethane	2.47	2.47	2.62	2.62	2.62
NG % Propane	.42	.42	.25	.25	.25
NG % CO2	1.13	1.13	.98	.98	.98
NG % Nitrogen	.77	.77	.59	.59	.59
Butane Actual(%)	.20	.20	.12	.12	.12
MWT	17.00	17.00	16.88	16.88	16.88
Fuel LHV	20447.	20447.	20595.	20595.	20595.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	3279	3280	3281	3282	3283
Year	1996	1996	1996	1996	1996
Operator Initials	<..JC..>	<..JC..>	<..JC..>	<..JC..>	<..JC..>
Julian Day	AUG., 27	AUG., 27	AUG., 27	AUG., 27	AUG., 27
Time (Seconds)	11:25:09	11:27:36	11:34:42	11:37:57	11:43:08
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	500.0	500.0	500.0
Test Type Code	1	1	1	1	1

***** Engine Performance Data *****

Engine Speed (rpm)	1248	1247	1896	1892	1889
Torque (ft/lbs)	964.1	966.5	904.2	918.6	739.3
BHP	229.0	229.6	326.4	330.9	265.8
BSFC (#/BHp-Hr)	.353	.352	.390	.387	.392
BTE (%)	35.2	35.3	31.9	32.2	31.8
BMEP (psi)	199.7	200.2	187.3	190.3	153.1
N.G. Flow (lbs/Hr)	80.94	80.91	127.34	128.02	104.28
NG Flow/E+6 (BTU/Hr)	1.653	1.653	2.601	2.615	2.130
Air Flow (#/Hr)	1967.9	1969.4	3161.7	3180.8	2533.4
Volumetric Eff (%)	94.2	94.4	83.4	83.1	82.8
Equivalence Ratio	.675	.675	.661	.661	.676
O2 Volts	1.201	1.219	1.931	1.924	1.452
Equiv O2	3.378	3.335	1.985	1.995	2.808
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	2.41	2.44	3.82	3.93	3.19

***** Engine Temperature Data *****

Water In (Deg F)	170	169	169	169	170
Water Out (Deg F)	186	186	185	185	184
Oil Sump (Deg F)	215	216	224	225	223
Oil GALLERY (DEG F)	200	200	208	209	208
Intake @ LFE (Deg F)	82	82	83	82	83
Boost B4 IC (Deg F)	272	272	340	341	273
Boost AF IC (Deg F)	97	97	107	107	99
Pre-Turbine (Deg F)	1108	1108	1227	1232	1197
Stack (Deg F)	937	937	991	991	1012
Exhaust 1 (Deg F)	980	981	1100	1100	1070
Exhaust 2 (Deg F)	1061	1062	1157	1153	1114
Exhaust 3 (Deg F)	1052	1052	1162	1162	1127
Exhaust 4 (Deg F)	1018	1019	1143	1148	1108
Exhaust 5 (Deg F)	996	997	1133	1139	1101
Exhaust 6 (Deg F)	942	941	1103	1108	1062
Intake (Deg F)	96	96	105	105	102
Gas @ Meter (Deg F)	100	100	96	93	91

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	3279	3280	3281	3282	3283
***** Engine Pressures Data *****					
Main Oil Pres (psig)	45.2	45.1	68.0	67.3	68.8
Fuel Pressure (psig)	99.0	98.7	85.3	85.5	93.8
Compress Out (psig)	16.54	16.52	24.15	24.59	16.91
Inlet Manifold(psig)	15.72	15.71	22.18	22.58	14.81
Inlet Manifold(psia)	30.06	30.04	36.51	36.91	29.14
Pre-Turbine (psig)	10.35	10.36	21.26	21.21	13.34
Exhaust Bk Pr ("HG)	2.09	2.09	4.27	4.22	3.03
LFE Filter Pr ("H2O)	.90	.89	1.68	1.70	1.24
LFE Delta Pr ("H2O)	3.83	3.83	6.30	6.31	4.98
H (lbH2O/lbAir)	.020	.019	.019	.018	.018
RH (out) (%)	71.83	69.28	66.86	64.58	63.88
Barometer ("Hg)	29.19	29.19	29.19	29.19	29.19
***** Natural Gas Composition *****					
NG % Methane	94.95	94.95	94.95	94.95	94.95
NG % Ethane	2.48	2.48	2.48	2.48	2.48
NG % Propane	.41	.41	.41	.41	.41
NG % CO2	1.16	1.16	1.16	1.16	1.16
NG % Nitrogen	.78	.78	.78	.78	.78
Butane Actual(%)	.22	.22	.22	.22	.22
MWT	17.01	17.01	17.01	17.01	17.01
Fuel LHV	20429.	20429.	20429.	20429.	20429.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	3284	3285	3286	3287	3288
Year	1996	1996	1996	1996	1996
Operator Initials	<..JC..>	<..JC..>	<..JC..>	<..JC..>	<..JC..>
Julian Day	AUG., 27	AUG., 27	AUG., 27	AUG., 27	AUG., 27
Time (Seconds)	11:46:14	11:51:43	11:54:31	11:59:12	12:02:40
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	500.0	500.0	500.0
Test Type Code	1	1	1	1	1

***** Engine Performance Data *****

Engine Speed	(rpm)	1888	1884	1885	1896	1895
Torque	(ft/lbs)	736.2	493.6	501.5	250.0	251.1
BHP		264.7	177.1	179.9	90.3	90.6
BSFC	(#/BHp-Hr)	.392	.436	.430	.538	.538
BTE	(%)	31.8	28.6	28.9	23.2	23.2
BMEP	(psi)	152.5	102.3	103.9	51.8	52.0
N.G. Flow	(lbs/Hr)	103.63	77.24	77.45	48.53	48.73
NG Flow/E+6	(BTU/Hr)	2.117	1.578	1.582	.991	.995
Air Flow	(#/Hr)	2523.4	1863.6	1869.9	1090.0	1092.9
Volumetric Eff	(%)	83.0	80.6	80.7	72.6	72.8
Equivalence Ratio		.674	.681	.680	.731	.732
O2 Volts		1.461	1.000	.989	.522	.517
Equiv O2		2.789	3.918	3.949	5.539	5.559
GEM Equiv. Ratio		0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.		0.00	0.00	0.00	0.00	0.00
BlowBy	(cfm)	3.23	2.61	2.54	1.85	1.80

***** Engine Temperature Data *****

Water In	(Deg F)	169	169	169	169	169
Water Out	(Deg F)	184	183	183	182	182
Oil Sump	(Deg F)	223	219	217	214	213
Oil GALLERY	(DEG F)	207	204	204	202	201
Intake @ LFE	(Deg F)	84	83	83	82	82
Boost B4 IC	(Deg F)	273	202	202	162	161
Boost AF IC	(Deg F)	99	93	93	89	89
Pre-Turbine	(Deg F)	1194	1147	1147	1082	1075
Stack	(Deg F)	1008	1000	1000	952	944
Exhaust 1	(Deg F)	1066	1004	1007	944	940
Exhaust 2	(Deg F)	1112	1037	1039	963	958
Exhaust 3	(Deg F)	1124	1045	1048	977	972
Exhaust 4	(Deg F)	1104	1047	1049	978	971
Exhaust 5	(Deg F)	1098	1044	1044	969	963
Exhaust 6	(Deg F)	1058	1004	1004	946	941
Intake	(Deg F)	102	99	99	96	95
Gas @ Meter	(Deg F)	92	94	96	97	99

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	3284	3285	3286	3287	3288
***** Engine Pressures Data *****					
Main Oil Pres (psig)	69.0	71.1	71.4	73.0	73.2
Fuel Pressure (psig)	92.6	101.2	99.8	105.6	104.4
Compress Out (psig)	16.75	9.36	9.40	5.50	5.54
Inlet Manifold(psig)	14.68	7.52	7.56	-.28	-.26
Inlet Manifold(psia)	29.02	21.86	21.89	14.05	14.07
Pre-Turbine (psig)	13.11	7.20	7.25	3.81	3.83
Exhaust Bk Pr ("HG)	3.01	1.92	1.92	1.15	1.15
LFE Filter Pr ("H2O)	1.24	.82	.82	.43	.43
LFE Delta Pr ("H2O)	4.98	3.62	3.63	2.09	2.09
H (lbH2O/lbAir)	.018	.018	.017	.018	.018
RH (out) (%)	64.46	64.23	62.36	63.61	65.21
Barometer ("Hg)	29.19	29.19	29.19	29.18	29.18
***** Natural Gas Composition *****					
NG % Methane	94.95	94.95	94.95	94.95	94.95
NG % Ethane	2.48	2.48	2.48	2.48	2.48
NG % Propane	.41	.41	.41	.41	.41
NG % CO2	1.16	1.16	1.16	1.16	1.16
NG % Nitrogen	.78	.78	.78	.78	.78
Butane Actual(%)	.22	.22	.22	.22	.22
MWT	17.01	17.01	17.01	17.01	17.01
Fuel LHV	20429.	20429.	20429.	20429.	20429.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	3289	3290	3291	3292
Year	1996	1996	1996	1996
Operator Initials	<..JC..>	<..JC..>	<..JC..>	<..JC..>
Julian Day	AUG., 27	AUG., 27	AUG., 27	AUG., 27
Time (Seconds)	12:06:41	12:11:07	12:21:15	12:22:51
Ignition Timing	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	500.0	500.0
Test Type Code	1	1	1	1

***** Engine Performance Data *****

Engine Speed	(rpm)	1891	1892	654	649
Torque	(ft/lbs)	95.1	95.6	128.4	128.6
BHP		34.2	34.4	16.0	15.9
BSFC	(#/BHp-Hr)	.953	.955	.993	.999
BTE	(%)	13.1	13.0	12.5	12.4
BMEP	(psi)	19.7	19.8	26.6	26.6
N.G. Flow	(lbs/Hr)	32.64	32.88	15.86	15.88
NG Flow/E+6	(BTU/Hr)	.667	.672	.325	.325
Air Flow	(#/Hr)	667.41	669.15	179.14	177.12
Volumetric Eff	(%)	67.3	67.5	53.9	54.0
Equivalence Ratio		.803	.807	1.458	1.476
O2 Volts		.299	.299	.092	.070
Equiv O2		6.483	6.484	7.476	7.588
GEM Equiv. Ratio		0.00	0.00	0.00	0.00
GEM Vol. Eff.		0.00	0.00	0.00	0.00
BlowBy	(cfm)	1.42	1.39	.80	.81

***** Engine Temperature Data *****

Water In	(Deg F)	170	169	160	161
Water Out	(Deg F)	181	180	180	180
Oil Sump	(Deg F)	210	208	195	194
Oil GALLERY	(DEG F)	199	198	185	185
Intake @ LFE	(Deg F)	83	83	84	84
Boost B4 IC	(Deg F)	106	104	101	100
Boost AF IC	(Deg F)	88	87	85	84
Pre-Turbine	(Deg F)	1052	1042	759	751
Stack	(Deg F)	944	935	644	634
Exhaust 1	(Deg F)	907	900	596	591
Exhaust 2	(Deg F)	911	904	619	613
Exhaust 3	(Deg F)	934	929	667	662
Exhaust 4	(Deg F)	944	936	645	640
Exhaust 5	(Deg F)	941	933	648	641
Exhaust 6	(Deg F)	928	922	633	630
Intake	(Deg F)	98	98	123	124
Gas @ Meter	(Deg F)	99	99	97	97

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

Run Number	3289	3290	3291	3292
***** Engine Pressures Data *****				
Main Oil Pres (psig)	74.3	74.6	23.0	23.2
Fuel Pressure (psig)	107.1	108.8	110.6	111.0
Compress Out (psig)	.73	.72	-.01	-.01
Inlet Manifold(psig)	-4.98	-4.99	-4.76	-4.81
Inlet Manifold(psia)	9.36	9.34	9.57	9.53
Pre-Turbine (psig)	1.41	1.35	.55	.55
Exhaust Bk Pr ("HG)	.86	.40	.23	.23
LFE Filter Pr ("H2O)	.24	.24	.08	.08
LFE Delta Pr ("H2O)	1.27	1.28	.34	.34
H (lbH2O/lbAir)	.018	.018	.018	.018
RH (out) (%)	66.10	65.18	61.69	61.96
Barometer ("Hg)	29.18	29.18	29.18	29.18
***** Natural Gas Composition *****				
NG % Methane	94.95	94.95	95.21	95.21
NG % Ethane	2.48	2.48	2.49	2.49
NG % Propane	.41	.41	.33	.33
NG % CO2	1.16	1.16	1.14	1.14
NG % Nitrogen	.78	.78	.66	.66
Butane Actual(%)	.22	.22	.17	.17
MWT	17.01	17.01	16.96	16.96
Fuel LHV	20429.	20429.	20482.	20482.

= Cell 05 MAC3 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	3274	3275	3276	3277	3278
Year	1996	1996	1996	1996	1996
Operator Initials	<..JC..>	<..JC..>	<..JC..>	<..JC..>	<..JC..>
Julian Day	AUG., 27	AUG., 27	AUG., 27	AUG., 27	AUG., 27
Time (Seconds)	11:00:59	11:08:01	11:11:37	11:17:36	11:20:23
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	500.0	500.0	500.0
Test Type Code	1	1	1	1	1

***** Engine Performance Data *****

Engine Speed	(rpm)	1247	1248	1248	1248	1248
Torque	(ft/lbs)	320.6	630.6	628.7	927.0	924.9
BHP		76.1	149.8	149.4	220.3	219.9
BSFC	(#/BHp-Hr)	.447	.366	.367	.344	.345
BTE	(%)	27.7	33.7	33.7	35.9	35.8
BMEP	(psi)	66.4	130.6	130.2	192.0	191.6
N.G. Flow	(lbs/Hr)	33.98	54.88	54.76	75.86	75.93
NG Flow/E+6	(BTU/Hr)	.700	1.130	1.128	1.562	1.564
Air Flow	(#/Hr)	719.68	1262.7	1264.0	1853.3	1851.6
Volumetric Eff	(%)	75.8	87.7	87.7	93.8	93.8
Equivalence Ratio		.782	.719	.717	.678	.679
O2 Volts		.334	.679	.688	1.125	1.124
Equiv O2		6.324	4.949	4.919	3.573	3.575
GEM Equiv. Ratio		0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.		0.00	0.00	0.00	0.00	0.00
BlowBy	(cfm)	1.08	1.59	1.65	2.27	2.27

***** Engine Temperature Data *****

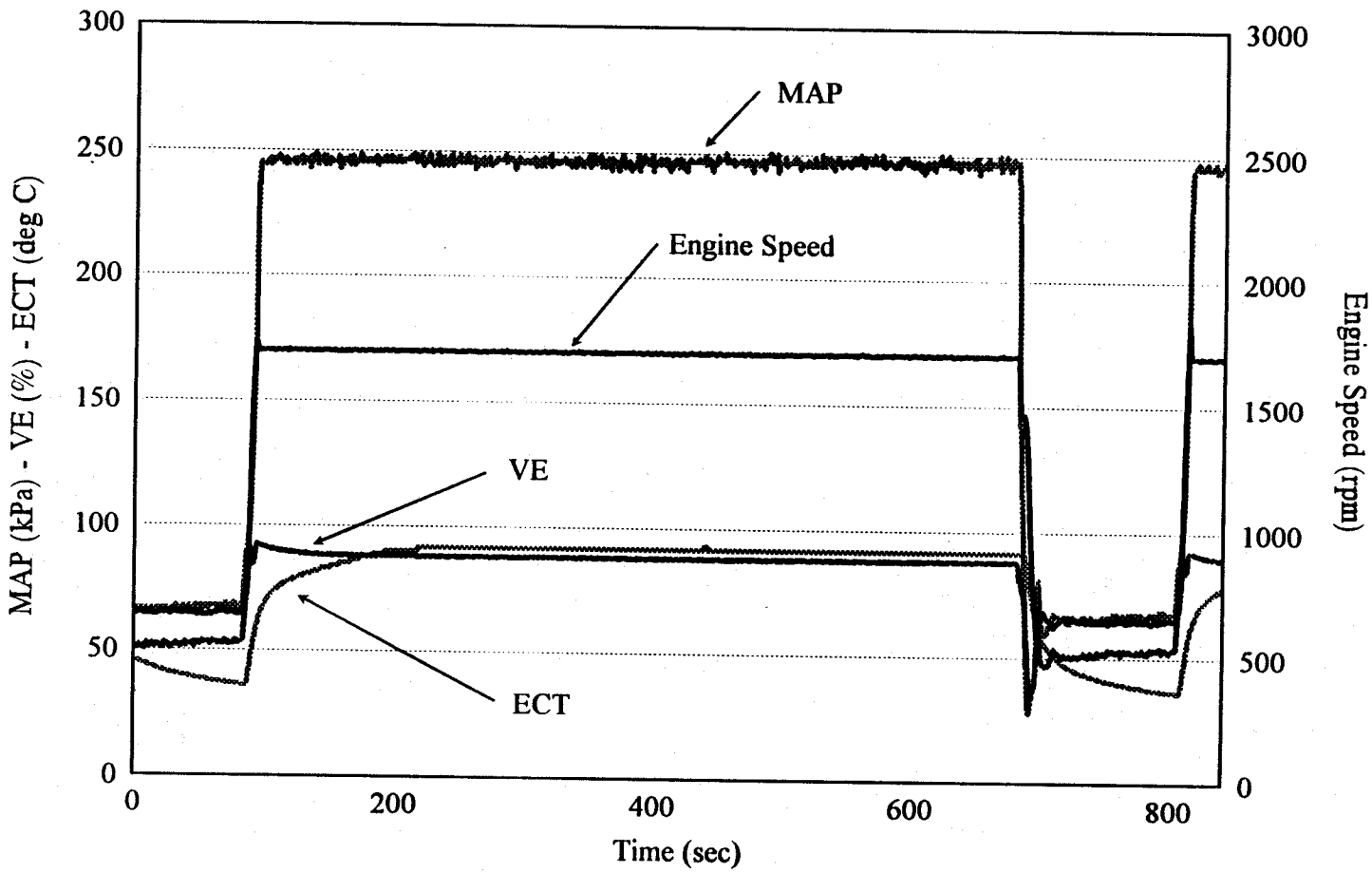
Water In	(Deg F)	169	169	169	169	169
Water Out	(Deg F)	183	184	184	186	186
Oil Sump	(Deg F)	201	207	208	213	214
Oil GALLERY	(DEG F)	192	196	196	199	199
Intake @ LFE	(Deg F)	79	80	81	81	82
Boost B4 IC	(Deg F)	119	179	181	255	255
Boost AF IC	(Deg F)	87	89	89	95	95
Pre-Turbine	(Deg F)	921	1009	1014	1078	1080
Stack	(Deg F)	831	889	894	919	920
Exhaust 1	(Deg F)	814	883	888	952	953
Exhaust 2	(Deg F)	836	938	942	1031	1032
Exhaust 3	(Deg F)	842	944	949	1023	1024
Exhaust 4	(Deg F)	833	922	925	988	990
Exhaust 5	(Deg F)	809	903	906	971	970
Exhaust 6	(Deg F)	785	857	861	917	917
Intake	(Deg F)	93	94	94	94	94
Gas @ Meter	(Deg F)	91	98	100	101	101

= Cell 05 MAC3 Project Low-Speed Data =
(continued)

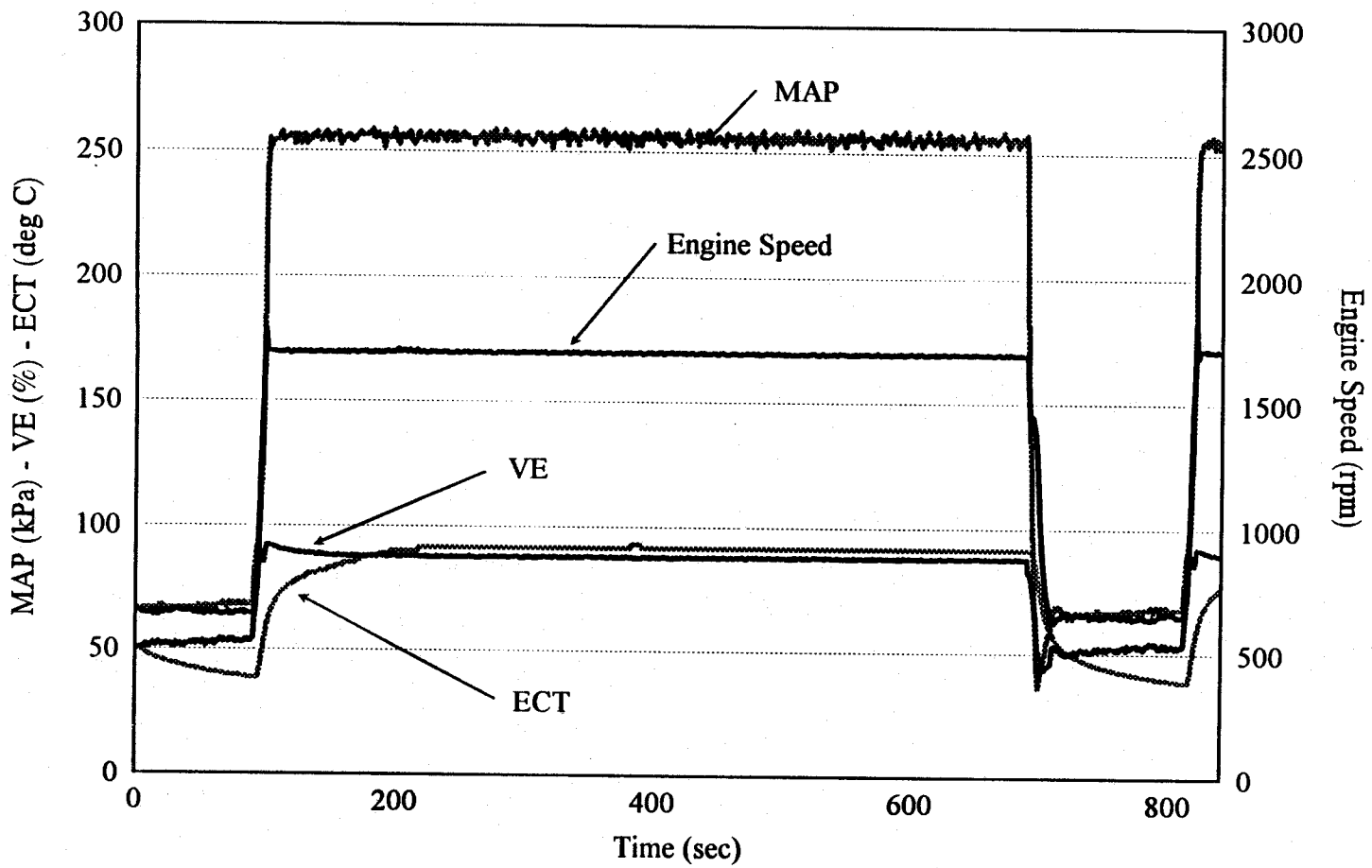
Run Number	3274	3275	3276	3277	3278
***** Engine Pressures Data *****					
Main Oil Pres (psig)	51.3	48.3	48.0	46.0	45.7
Fuel Pressure (psig)	108.7	103.3	103.3	99.8	99.0
Compress Out (psig)	2.30	7.44	7.45	14.78	14.76
Inlet Manifold(psig)	-.75	6.19	6.20	14.04	14.02
Inlet Manifold(psia)	13.59	20.52	20.54	28.37	28.35
Pre-Turbine (psig)	2.00	4.81	4.82	9.24	9.23
Exhaust Bk Pr ("HG)	.47	.97	.98	1.89	1.90
LFE Filter Pr ("H2O)	.27	.52	.52	.84	.83
LFE Delta Pr ("H2O)	1.36	2.41	2.42	3.59	3.59
H (lbH2O/lbAir)	.020	.020	.020	.020	.020
RH (out) (%)	82.49	80.43	79.04	76.38	74.58
Barometer ("Hg)	29.18	29.18	29.19	29.19	29.19
***** Natural Gas Composition *****					
NG % Methane	95.43	95.43	95.43	95.43	95.43
NG % Ethane	2.62	2.62	2.62	2.62	2.62
NG % Propane	.25	.25	.25	.25	.25
NG % CO2	.98	.98	.98	.98	.98
NG % Nitrogen	.59	.59	.59	.59	.59
Butane Actual(%)	.12	.12	.12	.12	.12
MWT	16.88	16.88	16.88	16.88	16.88
Fuel LHV	20595.	20595.	20595.	20595.	20595.

APPENDIX H

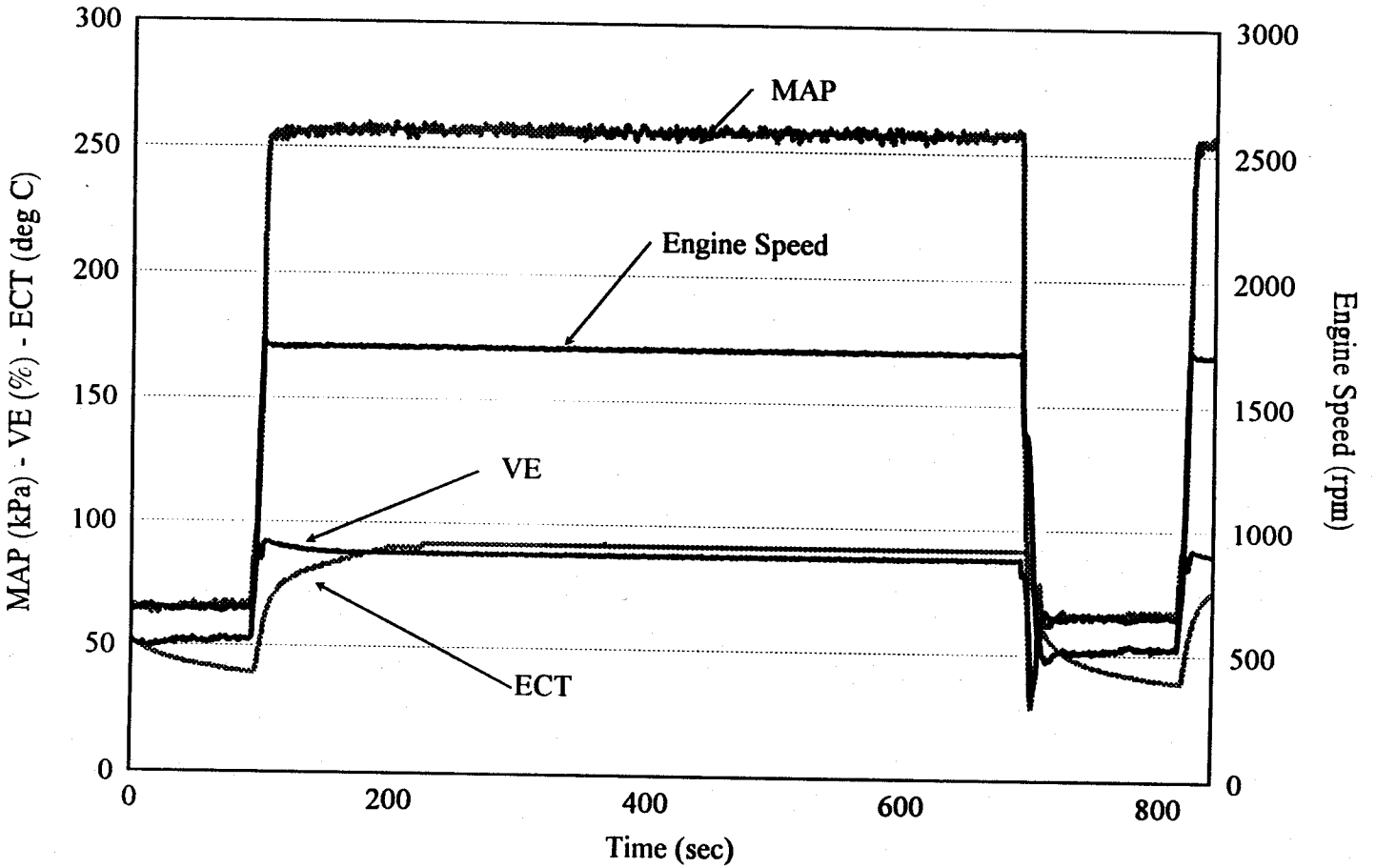
EMISSIONS RESULTS FOR TESTS AT 500 HOURS ON THE STC TEST



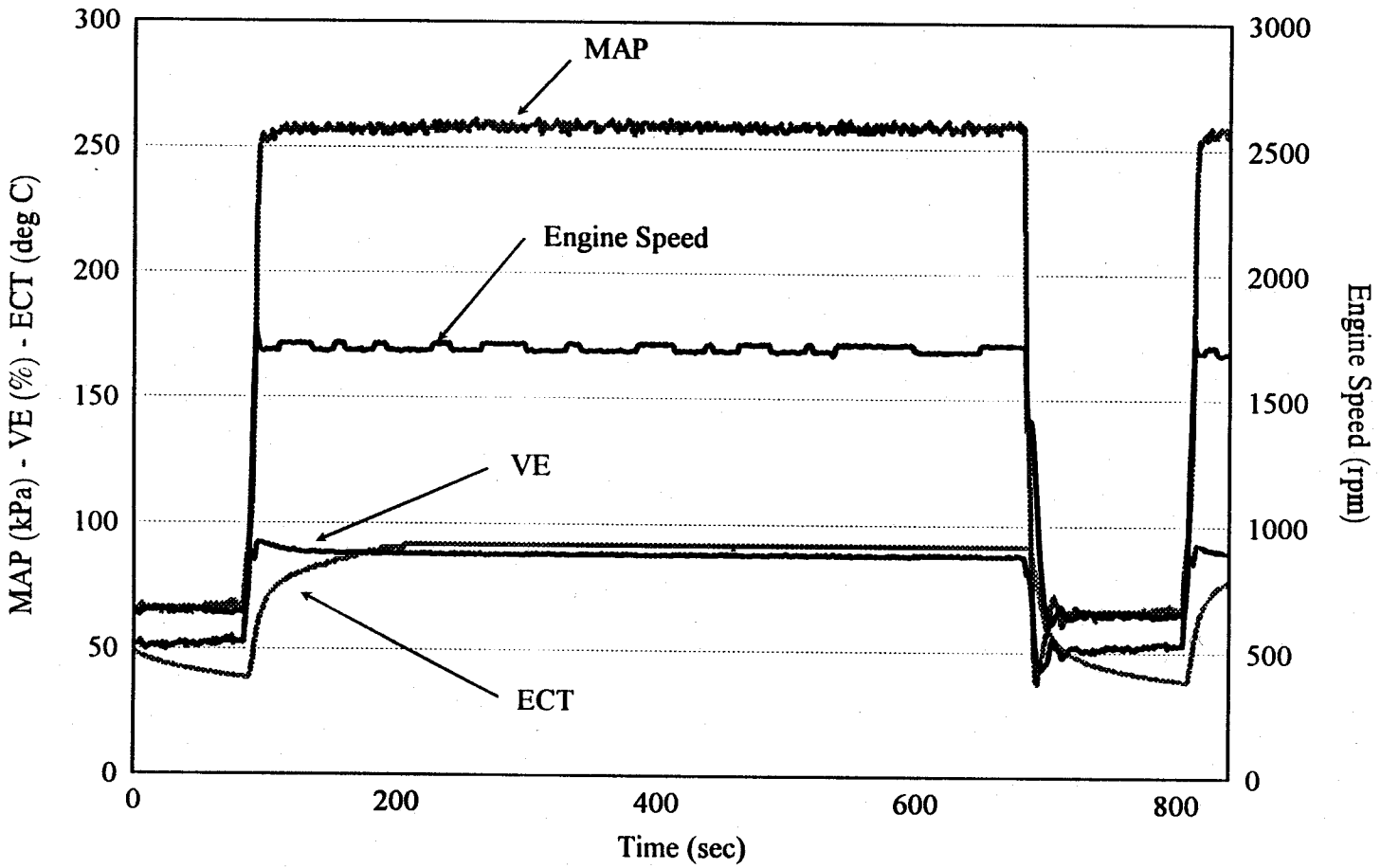
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 825 HOUR



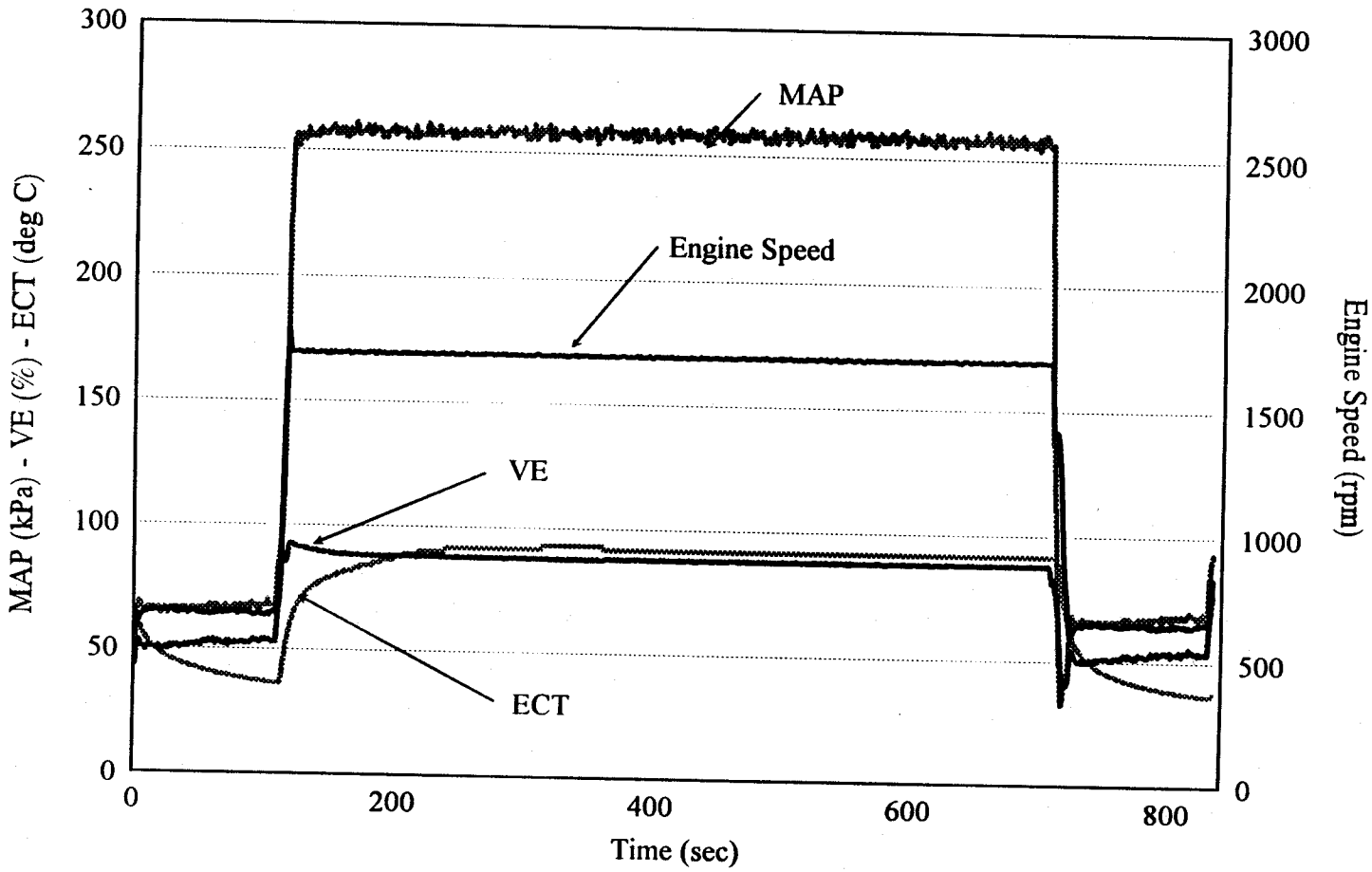
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 850 HOUR



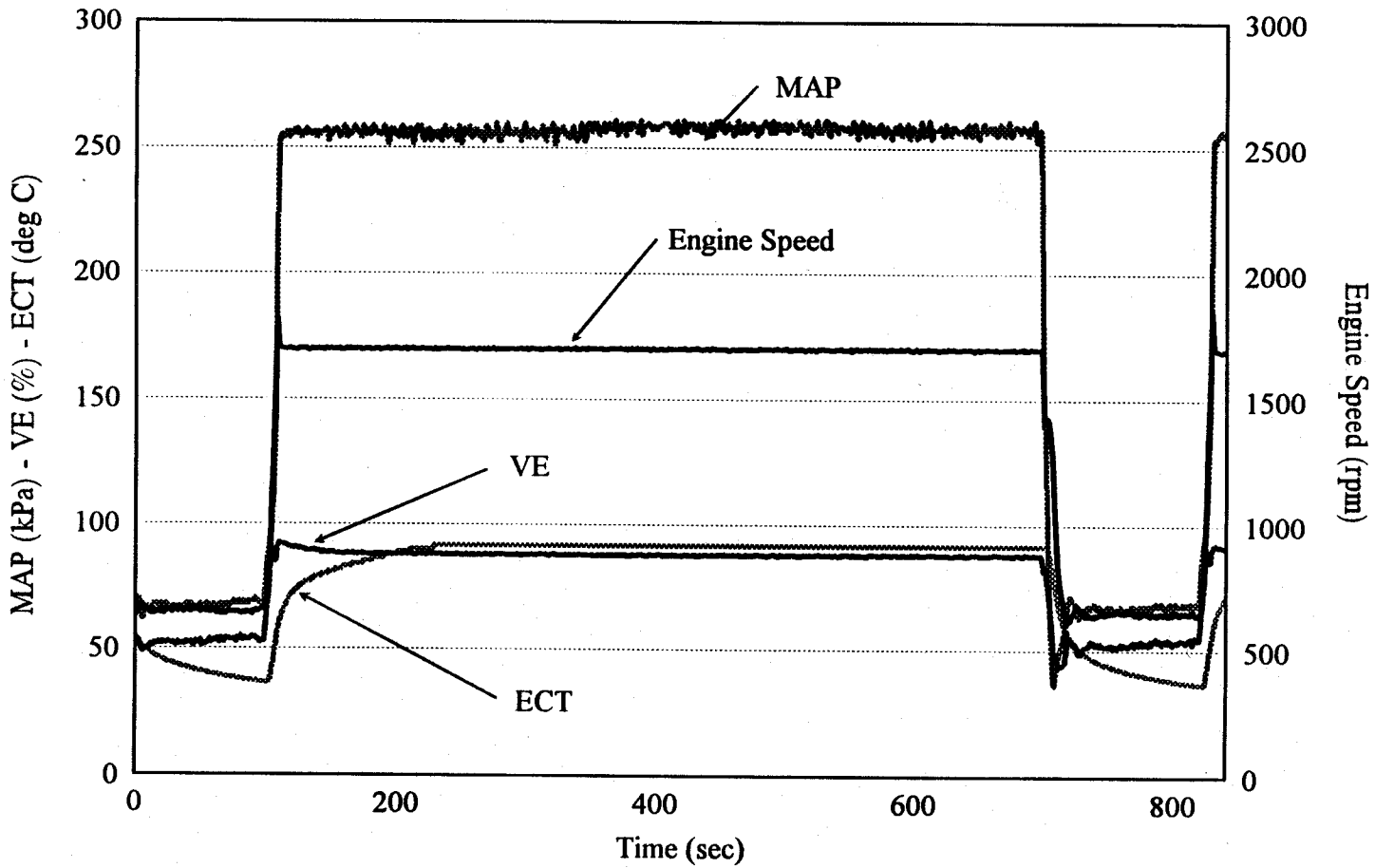
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 875 HOUR



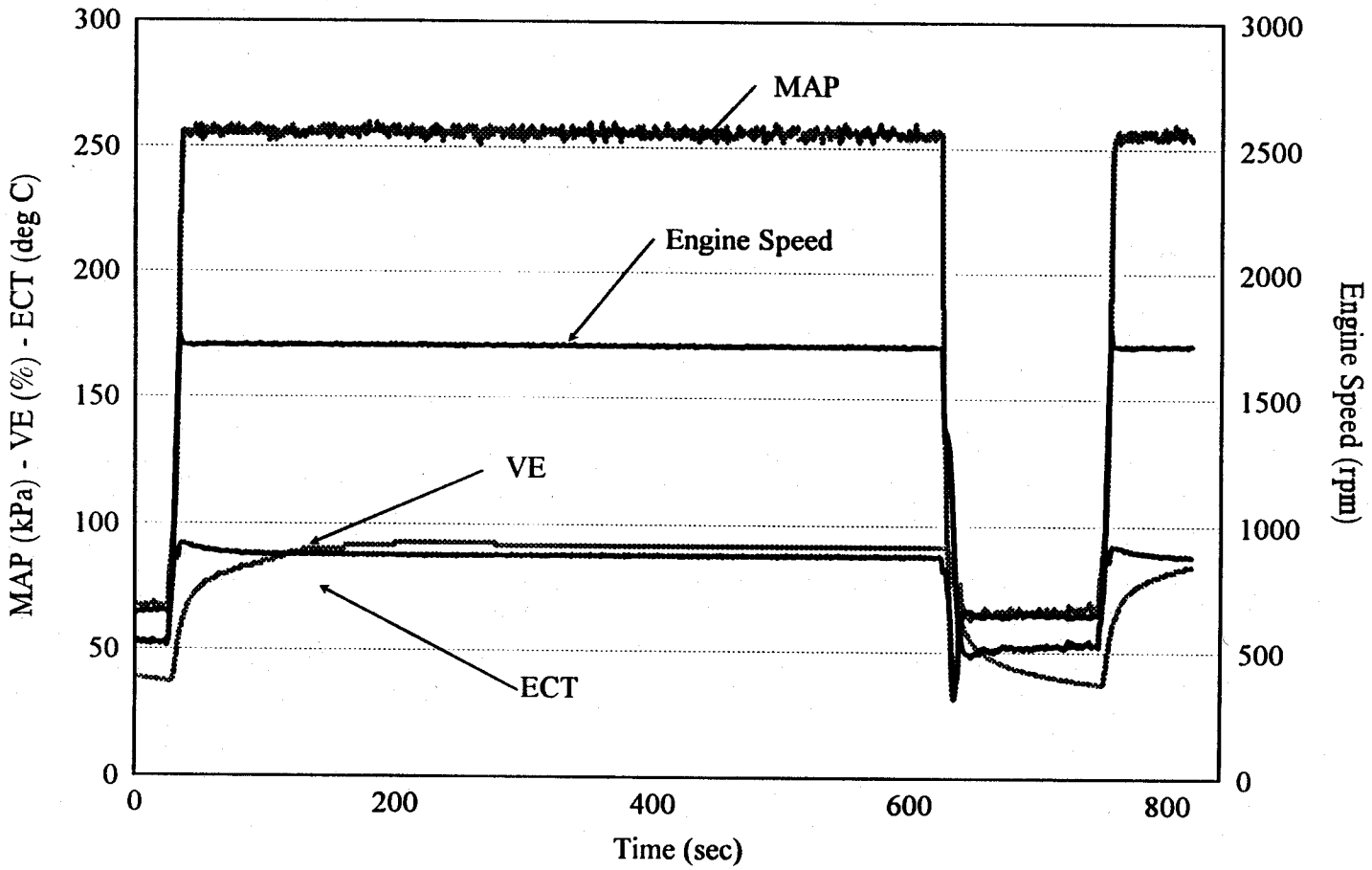
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 900 HOUR



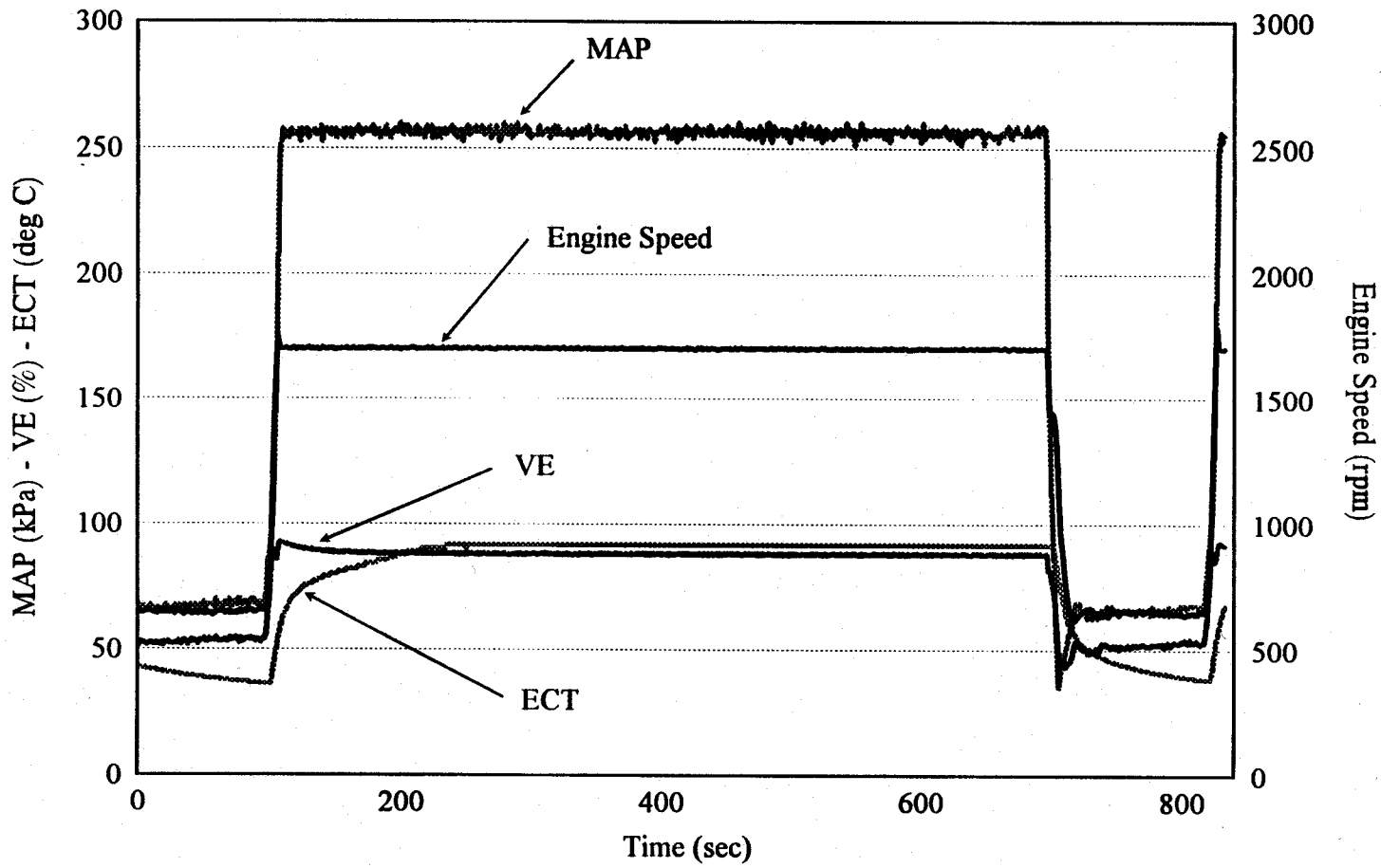
TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 925 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 950 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 975 HOUR



TRANSIENT DATA RECORDED FROM THE GEM SYSTEM FOR ONE FULL CYCLE AT 1000 HOUR

APPENDIX E

FINAL REPORT FOR

1000-HOUR SUPER THERMAL CYCLE TEST ON A MACK E-7 NATURAL GAS FUELED ENGINE

SwRI PROJECT NO. 03-1248

1000-HOUR SUPER THERMAL CYCLE DURABILITY TEST ON A MACK E-7 NATURAL GAS FUELED ENGINE

FINAL REPORT

SwRI Project No. 03-1248

Prepared for:

Mack Trucks, Inc.
13302 Pennsylvania Ave.
Hagerstown, MD 21742

Contract No. EXP144683

Prepared by:

James P. Chiu
Richard J. Branecky

December 1998

Approved:

Daniel W. Dickey, Director
Department of Engine Research

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EXECUTIVE SUMMARY

The goal of this task was to perform a 1000-hour Super Thermal Cycle (STC) Durability Test. The super thermal cycle consisted of two minutes at idle (unloaded stage) and 10 minutes at high speed and load (loaded stage). The engine was thermally "shocked" with 43°C (110°F) coolant at the unloaded stage and 99°C (210°F) coolant at the loaded stage to produce a 56°C (100°F) temperature difference. This was the second super thermal cycle test performed on this engine model. The first test had problems with a blowby filter failure and a piston cracking. Both of these items were redesigned for this test.

The 1000-hour Super Thermal Cycle Durability Test was successfully completed. Basic engine performance data were recorded every hour during the test, and more detailed performance data were recorded every 25 hours. Oil consumption was recorded every 50 hours. Valve stem heights, valve lash, spark plug gaps, cylinder compression, and cylinder leak down were recorded every 250 hours.

A borescope inspection of the pistons at 500, 750, and 1000 hours showed no signs of piston cracking. The blowby filter was still functioning properly at 1000 hours. The spark plugs were able to operate for 500 hours without maintenance during this test.

Major maintenance items before the start of the STC test included a rebuild of the front cylinder head, replacement of the UEGO sensor, and replacement of all injectors. Major maintenance items during the STC test included a misfire problem caused by noise on the mag pickup signal, replacement of the throttle, and replacement of two injectors.

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1.0 BACKGROUND

The goal of this project was to aid Mack Trucks, Inc. in expediting the development of a natural gas-fueled Mack E-7 engine and to perform part of the tests to determine an emissions deterioration factor for the engine. This report covers the second of two 1000-hour durability tests. The purpose of the first "1000-Hour Durability Test" was to verify the durability of the natural gas-related hardware, including the valve/valve seat combination and to verify acceptability of the engine control system. Based on the results from this test, it was recommended that additional testing be conducted to verify the durability of the suspect components, including the blowby filter element, the platinum-iridium tipped spark plugs, and the pistons used for the Mack E-7 natural gas-fueled engine. (SwRI Final Report, entitled "Task 2 - 1000-Hour Super Thermal Cycle Test", SwRI Project No. 03-7501-002, dated November 1996). An improved blowby filter design, a spark plug maintenance (regap) interval, and a redesigned piston were incorporated into this second test.

Funding for the testing, completed prior to the STC test, was provided by the "Mack LNG Vehicle Development" project conducted by SwRI for Mack Trucks. The STC durability test was conducted at SwRI's Engine and Vehicle Research Division, Department of Engine Research, Automotive Research Laboratory (443 Avenue C, Bldg. 69) and the results are reported herein.

2.0 TECHNICAL DISCUSSION

A 1000-hour Super Thermal Cycle (STC) Durability Test was conducted on a Mack E-7 natural gas fueled engine. The STC test cycle (as provided by Mack Trucks) consisted of two stages, including two minutes at idle (unloaded stage) and ten minutes at high speed and load (loaded stage), for a total cycle time of twelve minutes. The operating condition for engine coolant out temperature differed by a minimum of 56°C (100°F) between the loaded and unloaded stages. The following sections describe the test schedule, engine and test stand preparations, and test results.

2.1 Test Schedule

The test schedule for the STC durability test engine is shown in Table 1. The engine was used for previous work, including emissions and performance testing, prior to running the durability test. Total engine hours, as described in this report, refers to the total hours on the engine since the start of all testing. STC test hours refers to the hours of actual test time on the STC test.

Table 1. Test Schedule

Test	Time (hours)	Engine Speed (rpm)	Power (kW)
Break-In	125	1950	242
Emissions (12-mode) & Performance Tests	As needed	Various	Various
Miscellaneous testing	As needed	Various	Various
Transient Emissions	As needed	FTP Cycle	FTP Cycle
STC Durability Test	1000	STC Cycle	STC Cycle
Valve Rotation	As needed	1700 / 600	Minimum

The cycle for the STC test is shown in Table 2. On the unloaded stage, the engine is operated at idle speed with minimum load. The operating conditions for the loaded stage were selected by Mack Trucks as 1700 rpm and 110% load, based on a power curve provided by Renualt V.I. for an engine rated at 261 kW (350 hp) at 1900 rpm, to reach 290 kW at 1700 rpm. At the loaded stage, the equivalence ratio was at 0.65 and the ignition timing was set to MBT. Due to the high ambient temperature typical to San Antonio at the time of the year this test was performed, the specified coolant out temperature for the unloaded stage (idle) of 32°C (90°F) could not be obtained. Therefore, a coolant out temperature of 38-43°C (100-110°F) was specified for the unloaded stage and 99°C (210°F) for the loaded stage. These temperatures maintained a minimum of 56°C (100°F) differential between the loaded and unloaded stages during the test.

The schedule for engine data recording and engine maintenance, during the 1000-hour durability test, is shown in Table 3. Shutdowns were scheduled every 25 test hours.

Table 2. Super Thermal Cycle

Parameter	Unloaded	Loaded
Engine Speed (rpm)	600	1700
Power (kW)	4	290
Time (minutes)	2	10
Coolant Out Temperature (°C at end of cycle)	38-43	99

Table 3. Scheduled Data Recording And Maintenance

Description	Schedule
Oil Sample	At one hour after oil change
HP DAQ Hourly Data	Every hour
HP DAQ Snapshot Data	Every 25 hours
OH1 Transient Data	Every 25 hours
OH1 NGP Data	Every 25 hours
Oil Level Check (fill as needed)	Every 25 hours
Oil Sample	Every 50 hours
Oil Fill (record oil consumption)	Every 50 hours
Drain Blowby Filter Housing	Every 50 hours
Drain Gas Filter Housings	Every 50 hours
Replace Adsorption Filter Element	As needed
Measure Valve Stem Heights	Every 250 hours
Measure Valve Lash	Every 250 hours
Measure Spark Plug Gaps	Every 250 hours
Measure Cylinder Compression	Every 250 hours
Measure Cylinder Leak Down	Every 250 hours
Change Oil and Filters	At 500 hours
Replace Coalescing Fuel Filters	Every 500 hours
Measure Coolant Flow	Every 500 hours

2.2 Engine and Test Stand Preparations

The Mack E-7G engine (S/N 5N-1311), used for previous work including emissions (both steady-state and transient) and performance testing, was also used for the 1000-hour STC durability test. There were a total of 304.5 hours on the engine prior to the start of the durability test, including 160.5 hours for the break-in, steady-state emissions, and performance testing, 111.8 hours for the transient emissions tests, and 32.2 hours of miscellaneous time.

The pistons in this engine were redesigned and modified for this test, by Mack Trucks, based on the results of the first STC durability test (see Conclusions and Recommendations in SwRI Report 03-7501-002, dated November 1996). A redesigned blowby filter was also incorporated for this test. The engine specifications are shown in Table 4. Valve lash was reset to 0.41mm (0.016") for intake valves and 0.71 mm (0.028") for exhaust valves at the beginning of the STC test. The spark plugs were replaced with new plugs, with a date code of 2H6, and gaps were set to 0.25mm (0.010").

Table 4. Engine Specification

Engine Model	E7G-325
Engine Serial Number	5N1311
Engine Displacement (L)	12
Bore and Stroke (mm)	123.8 x 165.1
Piston	Modified Zollner Aluminum H Ring*
First Ring	P/N 349GC3105
Second Ring	P/N 349GC3106
Oil Rail	P/N 350GC342
Oil Expander	P/N 350GC341
Camshaft Timing	Standard gas timing
Ignition System Controller Supplier	Woodward
Ignition System Coil Supplier	Nippondenso
Ignition System Type	Inductive
Ignition System Timing Sensor	Bosch
Spark Plug Supplier	Champion
Mixer Type	Cast Annular with One 90° Bend
Number of Holes in Mixing Ring	9
Fuel Metering System Supplier	Woodward
Fuel Injector Type	Servojet SP021S1
Number of Injectors	8
Throttle Supplier	Woodward
Throttle Model	FLOWTECH, 68mm
Throttle Type	Electronic, Analog
UEGO Sensor	Honda

* Pistons were modified for the second 1000-Hour Durability Test, per the Conclusions and Recommendations of the first SwRI 1000-Hour Test Report, dated November 1996

After the break-in, steady-state emissions, and performance tests were conducted, the test stand cooling system was modified for the thermal "shock" of the engine on the STC durability test. Two coolant tanks were installed in the test cell to provide either hot coolant to the engine during the loaded stage or cold coolant during the unloaded stage. The hot tank was maintained at approximately 99°C (210°F) at the beginning of the loaded stage and the cold tank was controlled to approximately 38-43°C (100-110°F) near the end of the unloaded stage. A schematic of the coolant system for the STC test is shown in Figure 1. A mixture of Nalcool™ 2000 and demineralized water, at a ratio of 489 ml (16 ounces) of Nalcool™ to 15.2 l (4 gallons) of water, was added to the engine cooling system. The test stand was also equipped with an external electric motor to operate the engine water pump at a constant speed that was equivalent to the speed of the water pump at 2000 rpm (when the engine is in its normal configuration).

The oil and filters were changed prior to the start of the test. A closed crankcase ventilation system was installed, which included a blowby filter and canister provided by Mack Trucks and an in line blowby flow meter. The blowby was routed to the filter, then the in line flow meter, and finally to the inlet air system for the engine (between the laminar flow element and the turbocharger). New coalescing natural gas filters were installed. An adsorption filter and a low pressure coalescing filter (provided by Clean Air Partners, model number 616190-1) were added to the natural gas fuel supply line for the STC test stand. Figure 2 shows the schematic of the fuel filtering system with the two new filters installed.

2.3 Test Results

A total of 1326.0 hours were put on the engine since the beginning of all test work. A runtime history for the engine is shown in Table 5. Maintenance performed on the engine prior to the STC test is shown in Table 6. Results of the STC test program including the HP DAQ data, Woodward OH1 data, oil consumption, valve lash and recession measurements, spark plug maintenance, cylinder compression and leak down measurements, coolant flow measurements, and unscheduled shutdowns/maintenance are presented in the following sections.

2.3.1 HP DAQ Data

Hourly and snapshot engine data were recorded by the HP Data Acquisition System (DAQ) during the STC test. Hourly data were recorded, by an average of two points, with a target of recording data within 30 seconds of the end of each stage. Snapshot data were recorded for one full 12-minute cycle, in approximately 15 second intervals, every 25 test hours. There were a total of 2000 hourly readings and 2296 snapshot readings recorded during the course of the 1000-hour STC test. The hourly readings at 238 and 761 test hours were inadvertently missed by the engine operator. The hourly readings at 657 and 668 test hours were recorded incorrectly (during engine ramp) due to an HP DAQ system problem. Extra readings were recorded at 709 test hours due an engine operator error. A listing of all HP DAQ run numbers recorded during the STC test, with corresponding test hours and data type, is included in Appendix A.

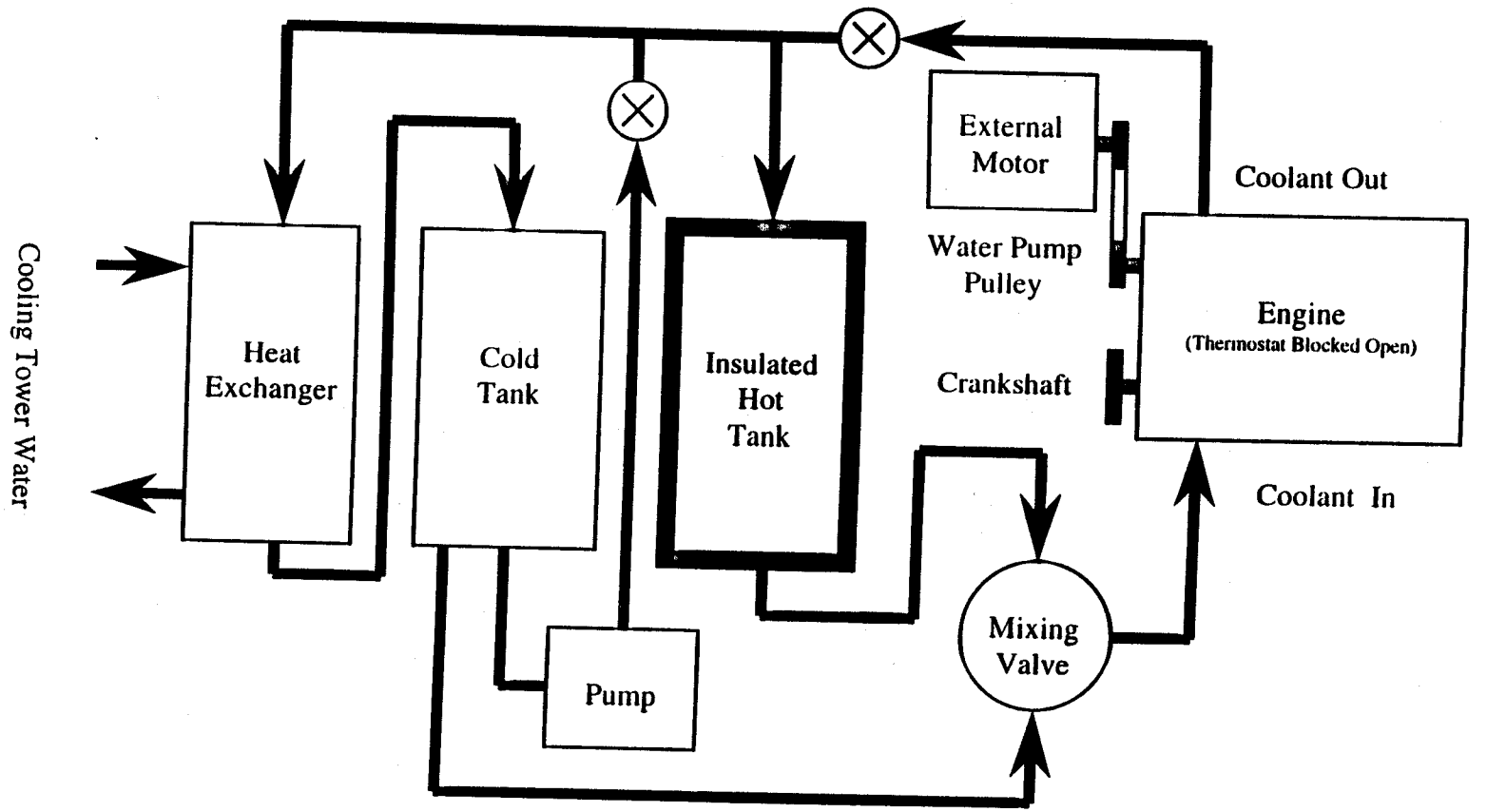

Figure 1. Super Thermal Cycle (STC) Test Stand Configuration

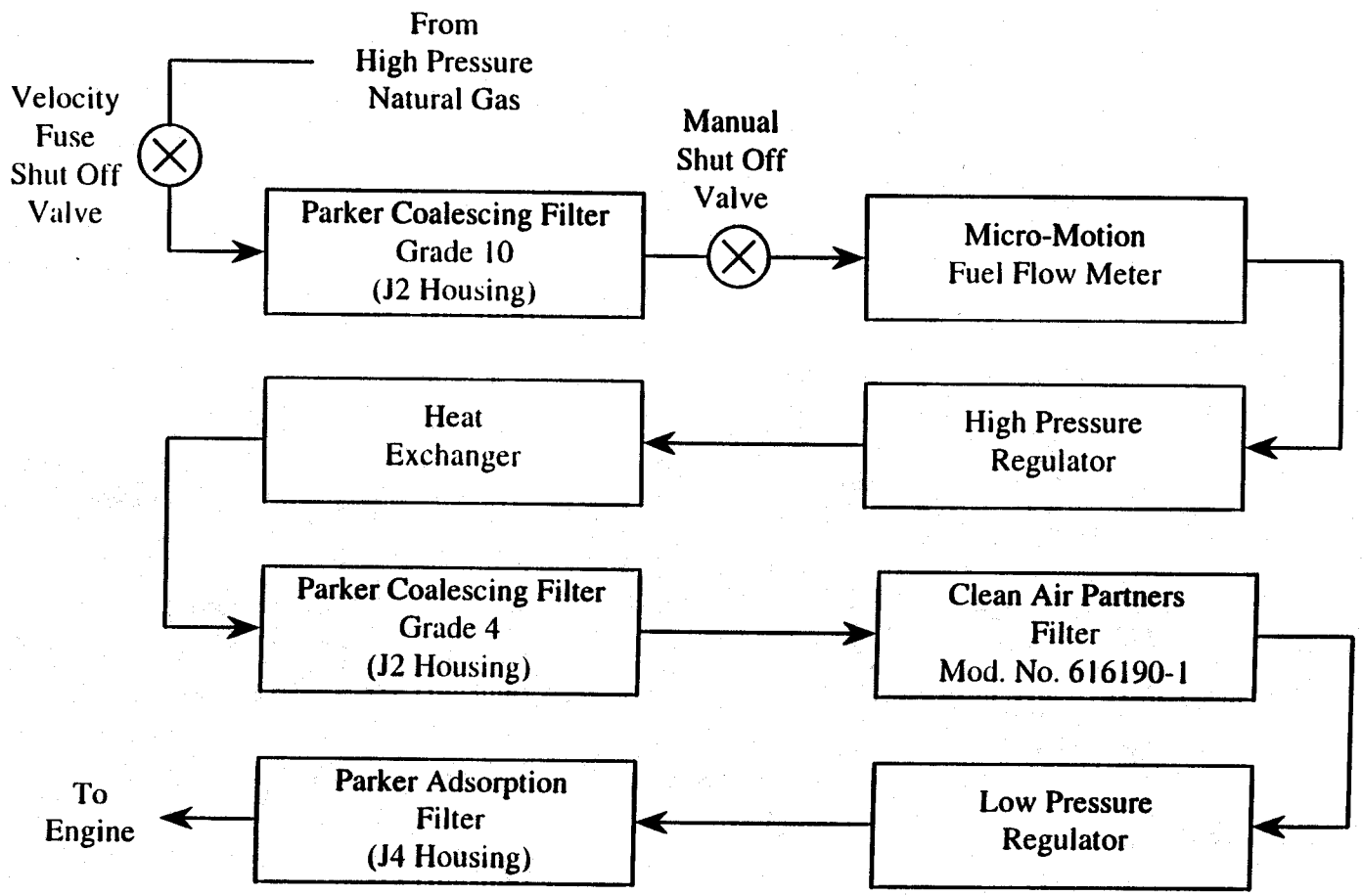

Figure 2. Fuel Filter Size and Location for the STC Test Stand

Table 5. Runtime History of Engine

Test Type	Test Time (Hours)	Miscellaneous Time (Hours)	Total Engine Time (Hours)
Break-In	125.0	35.5	160.5
Miscellaneous Tests	--	15.8	176.3
Transient Emissions	--	111.8	288.1
STC Test	0.0	16.4	304.5
STC Test	250.0	5.8	560.3
STC Test	500.0	3.4	813.7
STC Test	750.0	3.2	1066.9
STC Test	1000.0	5.5	1322.4
Valve Rotation Tests	--	3.6	1326.0

Table 6. Maintenance History Prior to STC Test

Date	Total Engine Time (Hours)	Description
12/2/97	0.1	Replaced one bad Injector.
12/15/97	51.8	Replaced NGP Sensor.
12/16/97	64.4	Replaced UEGO (O_2) Sensor.
12/19/97	64.7	Replaced Air Compressor.
12/19/97	117.6	Replaced Ignition Control Box.
12/23/97	161.4	Rebuilt No. 3 Cyl. Head (replaced exhaust valve on exhaust manifold side) and replaced Piston. Replaced Air Compressor.
1/26/98	163.7	Installed new ICM (from Woodward).
6/9/98	232.2	Replaced all 8 Fuel Injectors.
7/2/98	288.1	Installed a gasket between Turbocharger and Exhaust Manifold Flanges (gasket was missing).
7/20/98	294.2	Replaced all Spark Plugs and set gaps to 0.010 inches (used Champion RX501PYP/2H6 Spark Plugs).

2.3.2 OH1 System Data

Data from the Woodward OH1 gas engine management system were recorded every 25 hours. Transient data were recorded for one full cycle in one second intervals for engine speed, manifold air pressure (MAP), volumetric efficiency (VE), and engine coolant temperature (ECT). Figure 3 shows the average readings from 1 to 1000 hours from the transient data. There were 40 sets of data recorded. Data at 275 hours were recorded but inadvertently erased and the ECT data at 825 hours were not recorded due to operator error. Figures 4 through 7 show the average for each parameter along with a band of one standard deviation. Figures for individual reading are included in Appendix B.

Data from the OH1 system for injector block leak down were recorded every 25 hours. Data were recorded for two minutes at one second intervals by starting the data acquisition with the ignition key turned off, then turning the ignition key on (without starting the engine) within five seconds after starting the data acquisition. Turning the key on energizes the solenoid in the injector block to allow fuel to pressurize the injector block. When the OH1 system does not receive a signal that the engine has started, it de-energizes the solenoid, and the OH1 system records the pressure in the injector block as it leaks down. The static pressure to the injector block (setting of the low pressure regulator) is set to maintain at least 690 kPa (100 psia) when the engine is in the loaded stage. Figure 8 shows the leak down rates calculated during the STC test. There were several leak down rates of zero kPa/s. A manual shut off valve was closed to verify that the solenoid valve on the injector block was fully closed. There was no indication that the pressure sensor was reading incorrectly. Almost all of the injectors operated for approximately 71 million cycles by the end of the test. However, two injectors were replaced during the course of the test, one at 555 test hours (approx. 615 hours of service, 41 million cycles) and another at 693 test hours (approx. 755 hours of service, 51 million cycles). Further details can be found in the unscheduled maintenance section of this report.

2.3.3 Oil Consumption

Dryden experimental natural gas oil was used for the first 500 hours of the STC durability test. Oil samples were taken every 50 test hours and sent directly to Dryden Oil for analysis. Ethyl experimental natural gas oil was used for the second 500 hours of the test. Oil samples were taken, again every 50 test hours, and the analysis was conducted at SwRI (by the Dept. Of Petroleum Products Research, Automotive Products and Emissions Research Division). The results were forwarded to Ethyl and can also be found in Appendix E.

Oil was added and oil consumption was recorded every 50 hours during the STC test. In addition, the level was checked at 25 hour intervals (after each oil add), and oil was added only as needed. The procedure used for recording oil consumption was as follows:

1. While engine is idling, take a small discard sample from the engine and record weight.
2. After taking discard sample, take an oil sample from engine and record weight.
3. After engine is stopped, drain oil from blowby filter housing and record weight.
4. After engine is stopped, record weight of all oil leakage.
5. After the engine has soaked for 10 minutes, fill with oil until level is at the full mark on the dip stick and record weight of oil added.

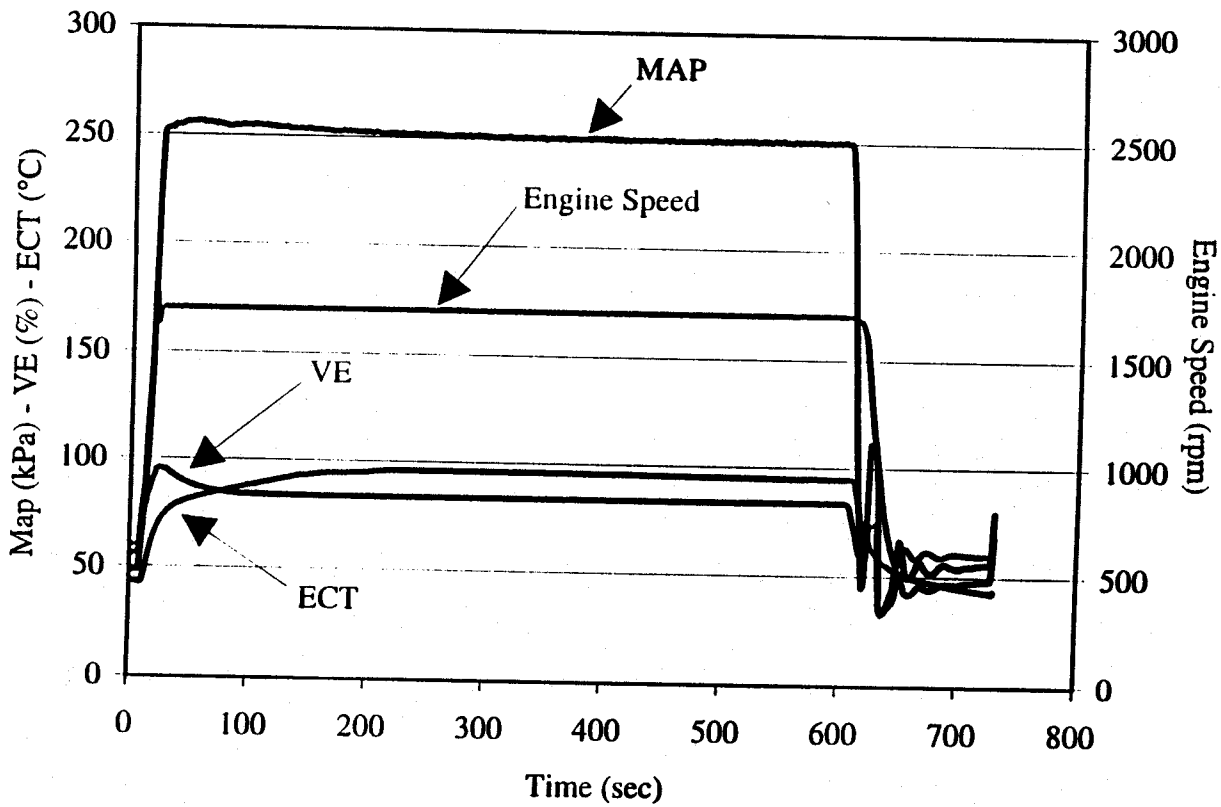

Figure 3. Average of 40 Readings Recorded Between 1 and 1000 Test Hours From the Woodward OH1 During the STC Test

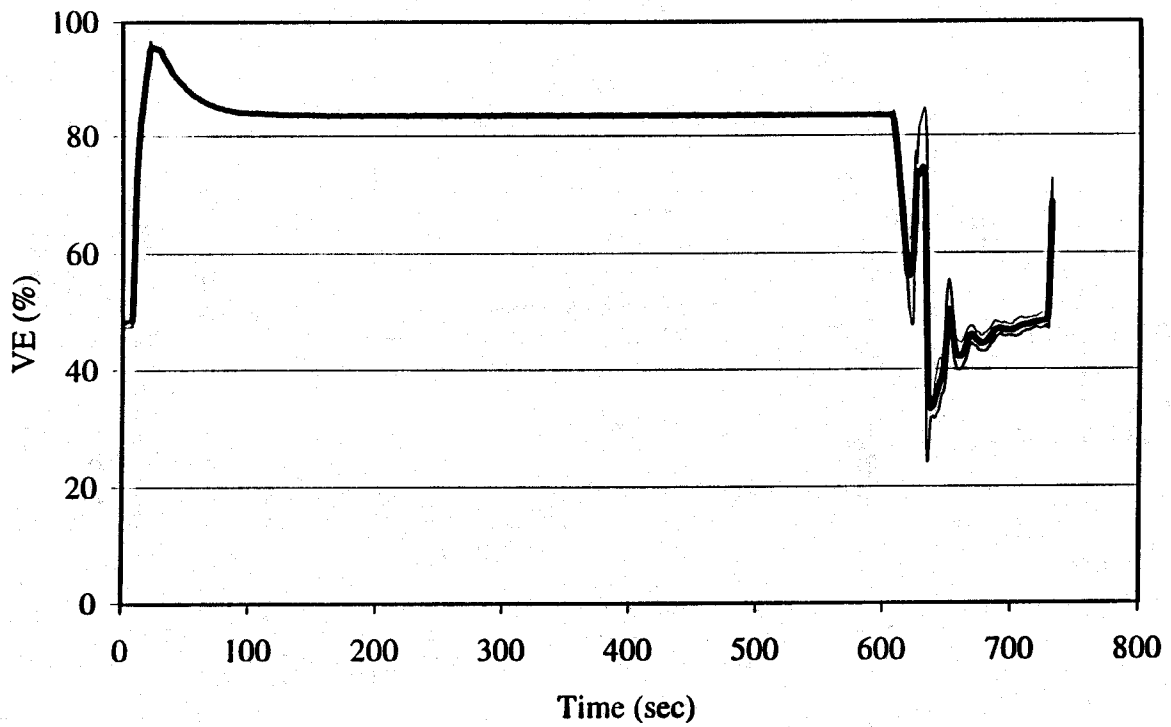

Figure 4. Average of 40 Readings and +/- One Standard Deviation For VE Recorded Between 1 and 1000 Test Hours From the Woodward OH1 During the STC Test

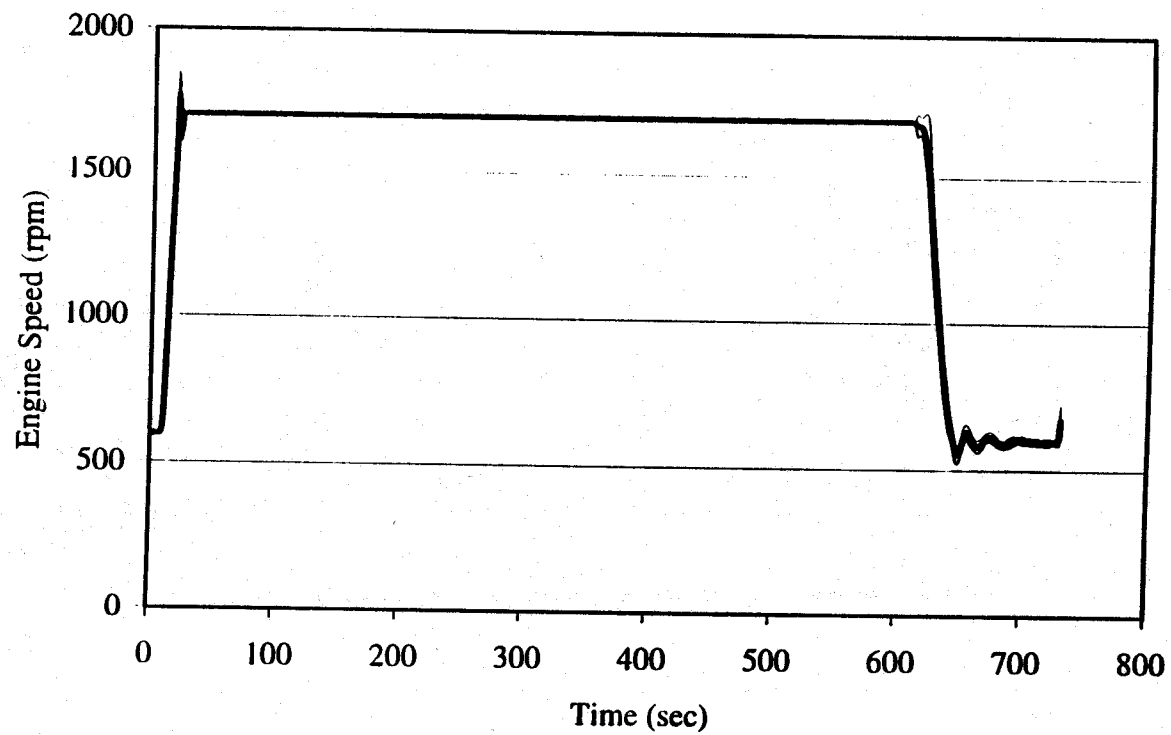

Figure 5. Average of 40 Readings and +/- One Standard Deviation For Engine Speed Recorded Between 1 and 1000 Test Hours From the Woodward OH1 During the STC Test

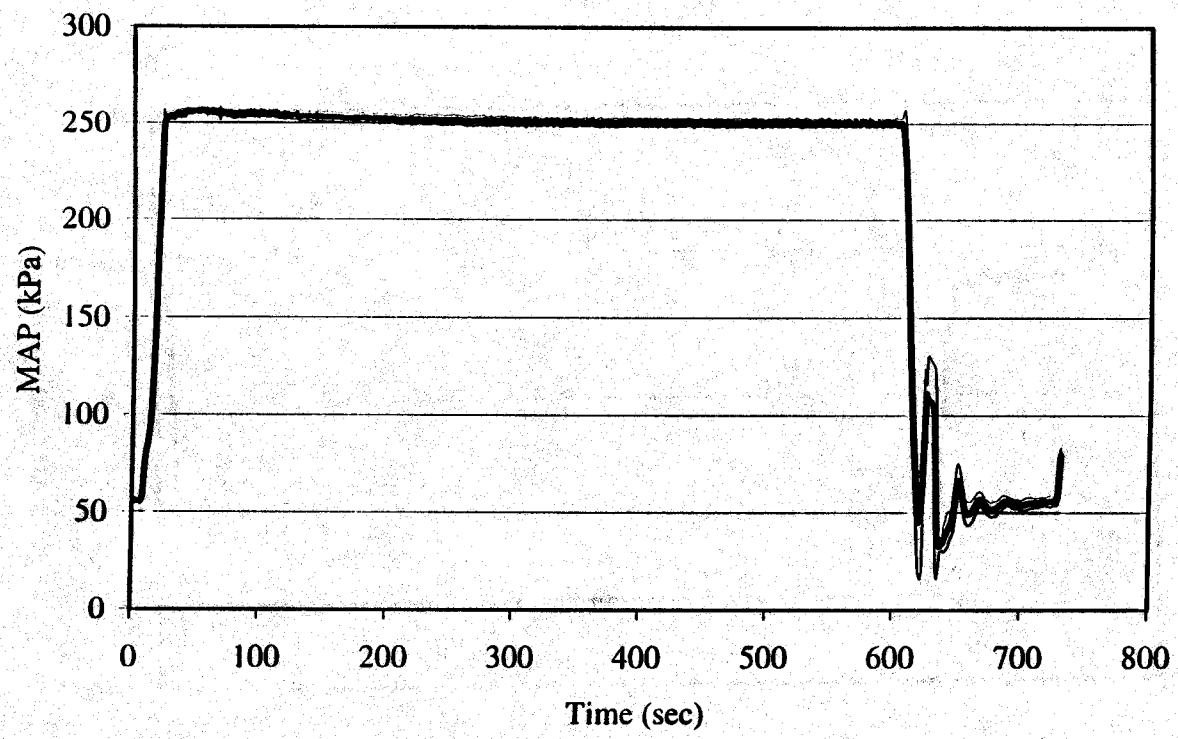

Figure 6. Average of 40 Readings and +/- One Standard Deviation For MAP Recorded Between 1 and 1000 Test Hours From the Woodward OH1 During the STC Test

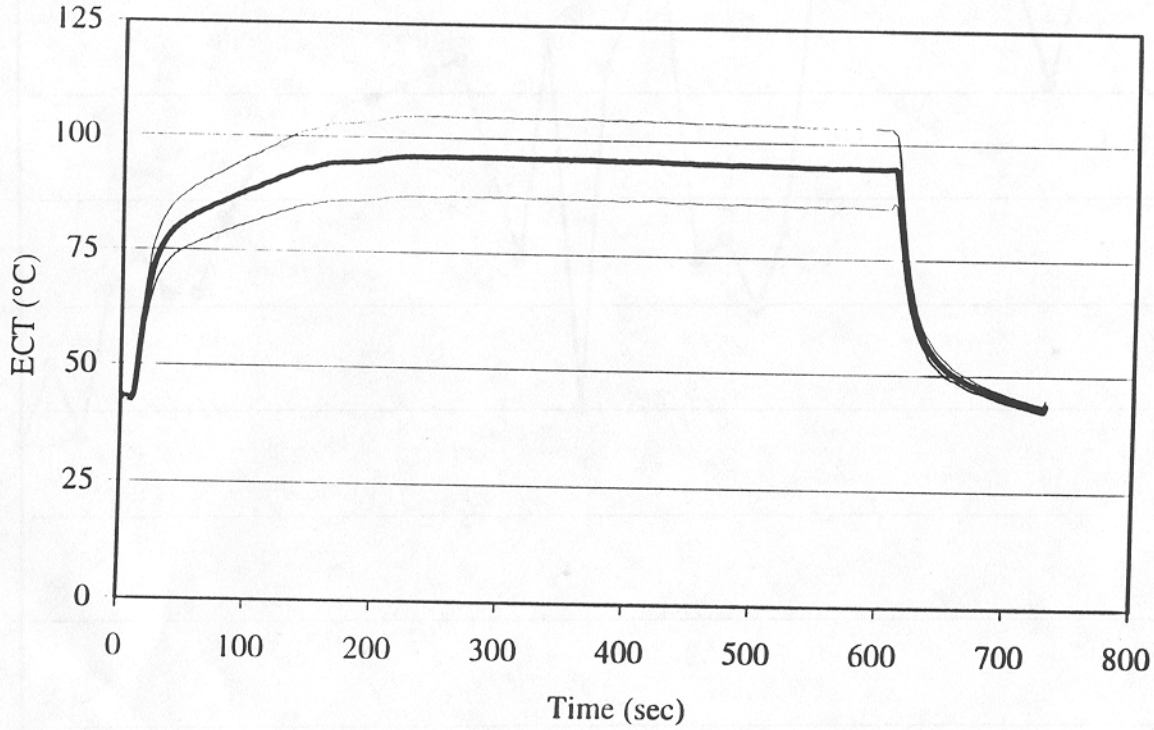

Figure 7. Average of 40 Readings and +/- One Standard Deviation For ECT Recorded Between 1 and 1000 Test Hours From the Woodward OH1 During the STC Test

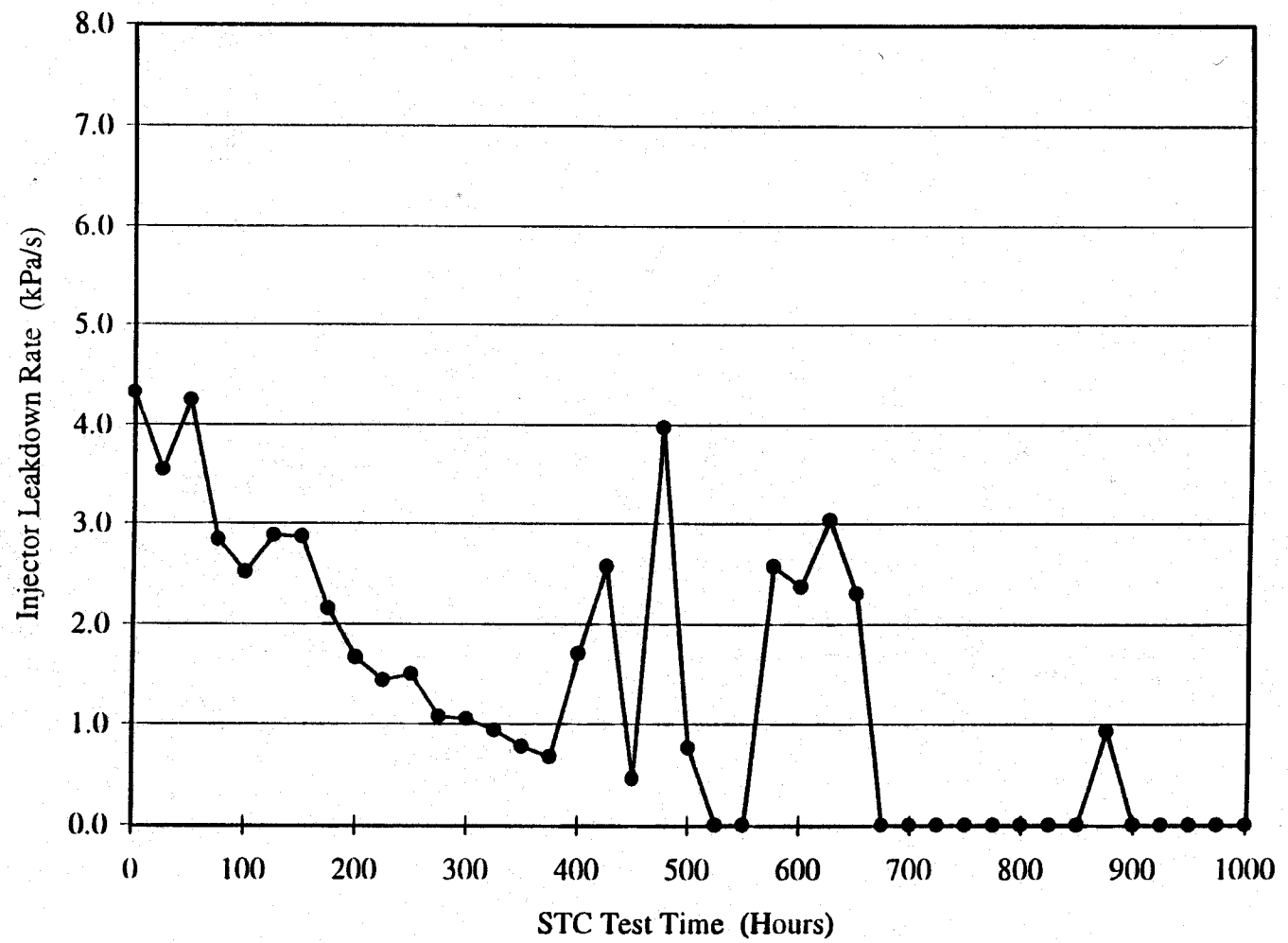

Figure 8. Injector Block Leak Down Rate During the STC Test

6. Calculate oil consumption from the amount of oil added in step 5, plus the amount of oil added at the 25 hour oil level check (if any), minus the amount of oil drained in steps 1-4, minus any other oil drains during the 50 hours.

The estimated accuracy of the oil adds is approximately ± 100 grams. Oil adds and drains are shown in Table 7, and the calculated oil consumption are shown in Table 8 along with the average blowby for each interval. At 100 test hours, the oil added appears abnormally high and may not have been recorded correctly. Therefore, the oil consumption calculation at 100 test hours is probably incorrect. A graph of the oil consumption trend from the STC durability test is shown in Figure 9.

Table 7. Oil Adds and Drains

Test Hour	Oil Add (grams)	Oil Drained for Discard (grams)	Oil Drained for Sample (grams)	Oil Drained from Leakage (grams)	Oil Drained from Blowby (grams)
1	--	19	142	--	--
50	1583	39	149	5	61
100	(3181)	46	141	2	64
150	1213	32	142	0	49
200	1089	91	146	4	63
250	1780	35	144	7	52
300	1487	34	150	4	54
350	930	26	149	6	56
400	1020	28	141	4	61
450	1493	34	143	5	62
500	1425	34	145	8	54
501	--	58	214	--	--
550	2137	34	207	4	70
600	1683	68	210	4	75
650	1686	58	217	5	77
700	1057	25	213	3	75
750	2390	61	209	2	74
800	1315	24	217	4	76
850	1231	19	214	6	105
900	2528	42	228	5	62
950	1350	25	216	9	84
1000	1827	24	216	7	53

Table 8. Oil Consumption

Test Hour	Oil Consumption (grams)	Oil Consumption (g/kW-hr)	Average Blowby for 600 rpm Operation (l/min)	Average Blowby for 1700 rpm Operation (l/min)
0-50	1168	0.099	5.35	147.7
50-100	2928	0.249	5.17	143.4
100-150	990	0.084	5.66	142.4
150-200	785	0.067	6.01	141.8
200-250	1542	0.131	6.20	144.1
250-300	1245	0.107	6.29	146.1
300-350	693	0.060	6.68	146.4
350-400	786	0.068	6.61	148.2
400-450	1249	0.106	7.39	145.0
450-500	1184	0.101	8.61	142.3
500-550	1550	0.133	7.50	149.8
550-600	1326	0.114	6.80	150.1
600-650	1329	0.116	6.54	151.9
650-700	741	0.064	5.62	153.9
700-750	2044	0.172	5.53	148.1
750-800	994	0.084	6.74	154.1
800-850	887	0.075	6.59	158.6
850-900	2191	0.186	7.61	161.2
900-950	1016	0.087	8.42	156.9
950-1000	1527	0.133	8.43	163.1
0-1000	26,175	0.112	6.69	149.8

2.3.4 Valve Measurements

Valve lash and valve stem heights were measured before, during, and after the STC durability test. Results of the intake and exhaust valve stem height measurements or valve recession data are shown in Figures 10 and 11, respectively. Data for the valve stem height measurements are also included in Appendix F. Valve lash measurements are shown in Table 9.

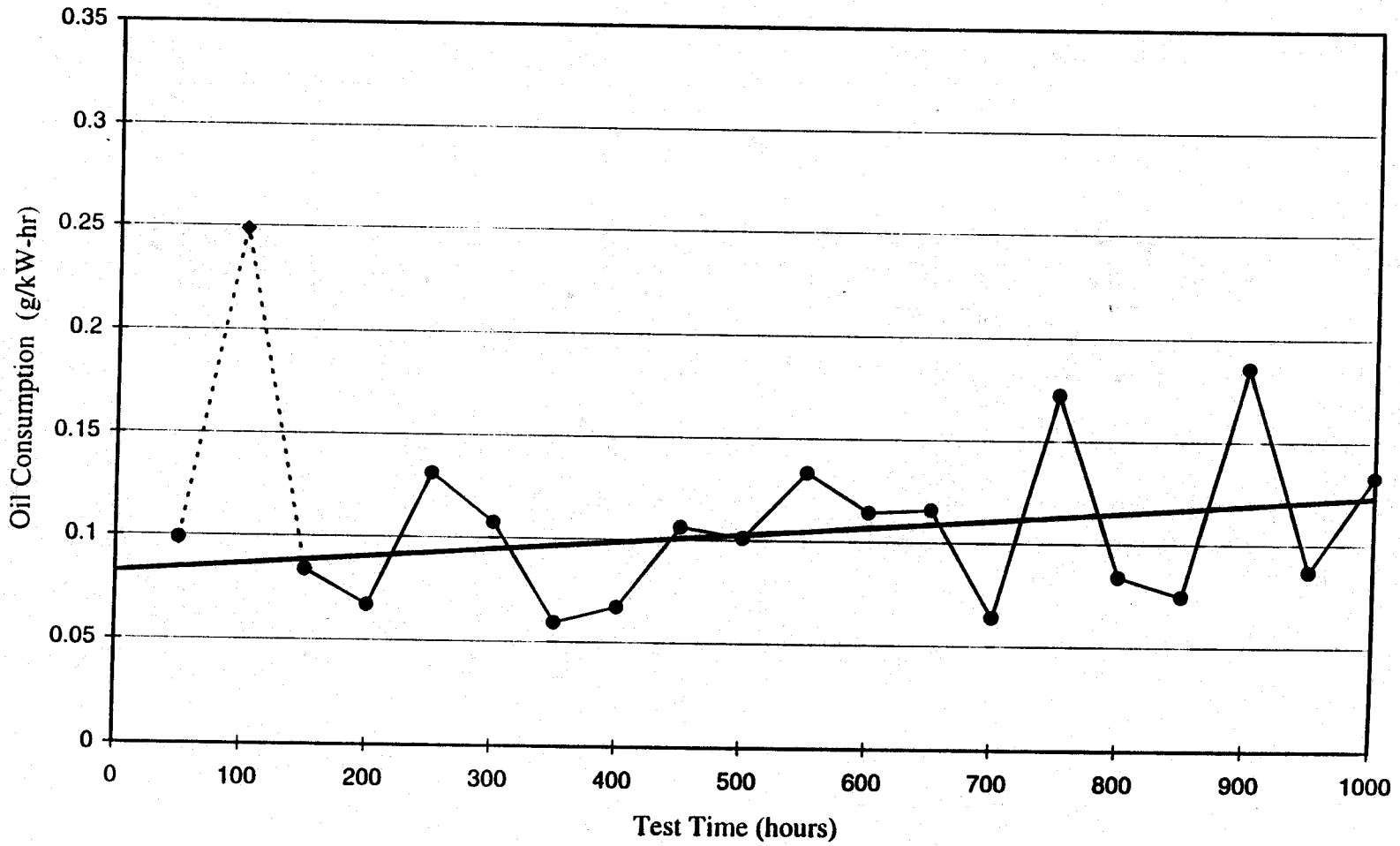

Figure 9. Oil Consumption Trend

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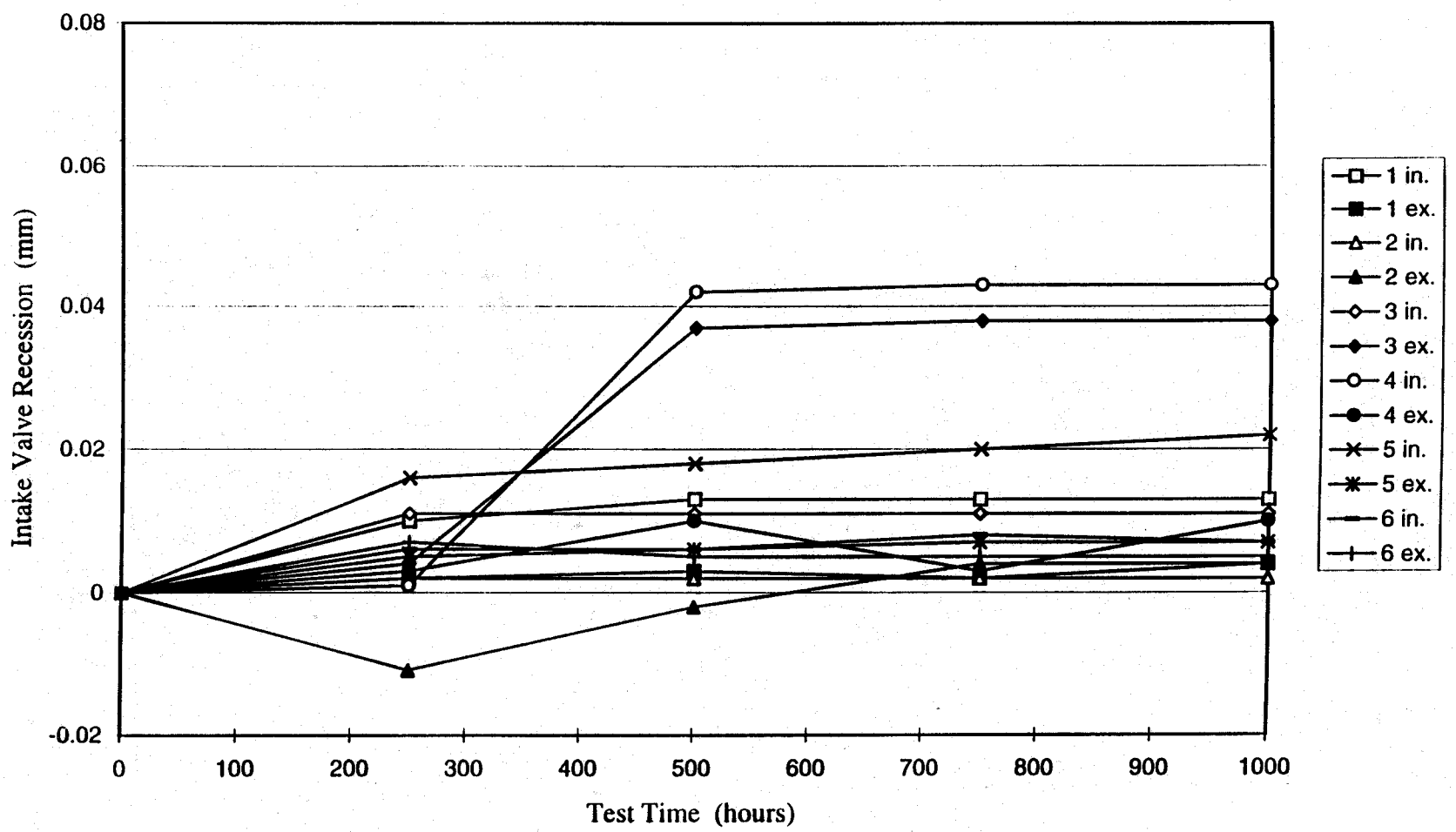


Figure 10. Intake Valve Recession

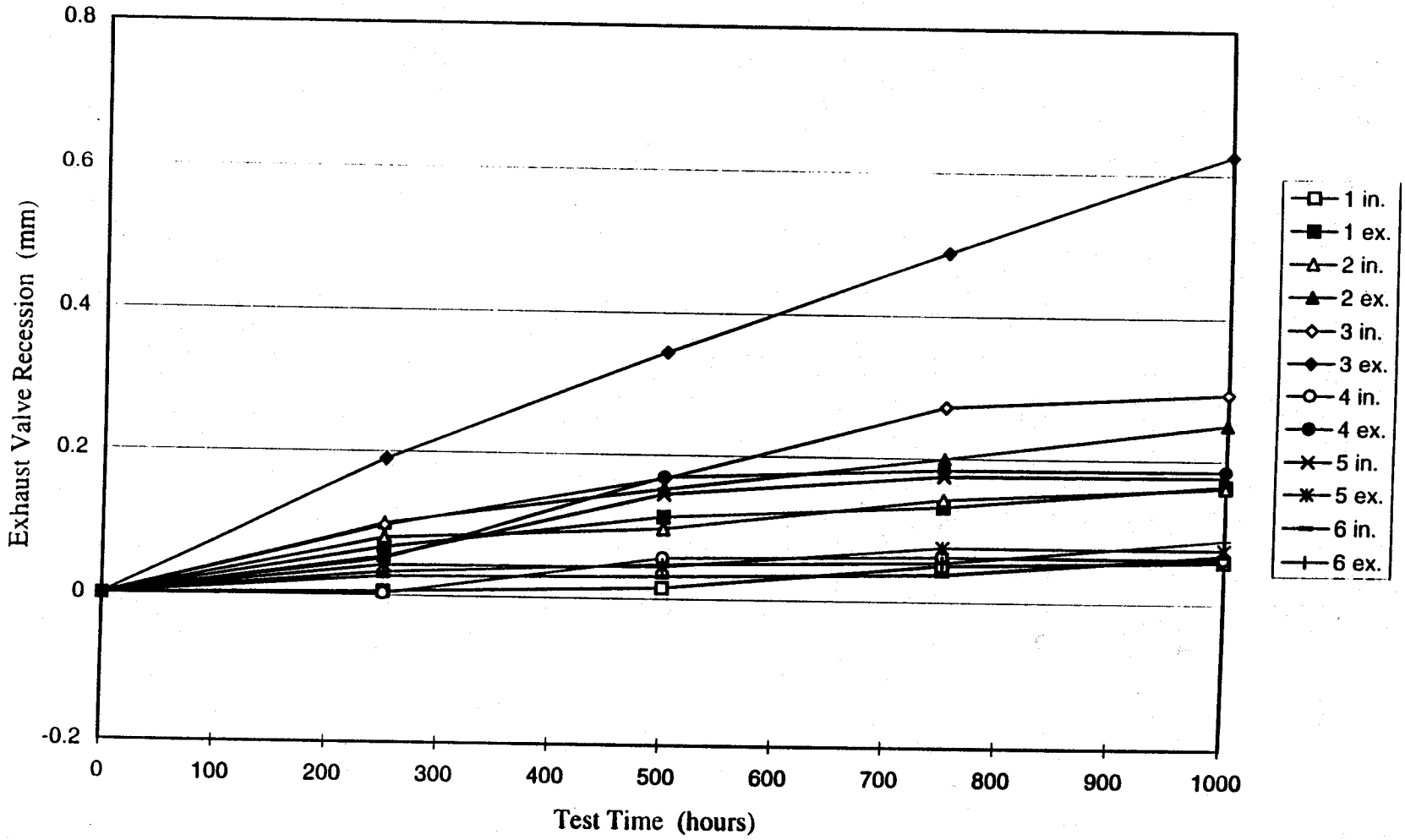


Figure 11. Exhaust Valve Recession

Table 9. Valve Lash Measurements

Cylinder	Valve	Valve Lash (mm) @ STC Test Hours				
		0.0	250.0	500.0	750.0	1000.0
1	in.	0.41	0.38	0.38	0.38	0.41
2	in.	0.41	0.41	0.41	0.41	0.41
3	in.	0.41	0.38	0.38	0.38	0.38
4	in.	0.41	0.41	0.41	0.41	0.38
5	in.	0.41	0.41	0.43	0.41	0.43
6	in.	0.41	0.43	0.43	0.43	0.43
1	ex.	0.71	0.66	0.64	0.64	0.61
2	ex.	0.71	0.61	0.58	0.53	0.51
3	ex.	0.71	0.58	0.48*	0.61	0.48
4	ex.	0.71	0.69	0.64	0.61	0.61
5	ex.	0.71	0.69	0.66	0.64	0.61
6	ex.	0.71	0.66	0.66	0.66	0.64

* Reset Exhaust Valve Lash to Specifications (0.71 mm)

2.3.5 Spark Plugs Maintenance

Champion spark plugs were used for the STC durability test. New spark plugs were installed in the engine before the start of the test. All new spark plugs installed in the engine were initially gapped to 0.25 mm (0.010"). The spark plug gaps were measured every 250 test hours and the gap growth rate can be seen in Figure 12. The gaps were reset to 0.25 mm (0.010") at 500 test hours.

2.3.6 Cylinder Compression and Leak Down Measurements

Cylinder compression and leak down measurements were recorded every 250 test hours on the STC cycle. The results are shown in Tables 10 and 11, respectively. Cylinder leak down was performed by regulating air upstream of a 1.02 mm (0.040") orifice at 690 kPa_{gage} (100 psig) and measuring the pressure downstream of the orifice (cylinder pressure). The percent leak down is the difference between the upstream and downstream pressure normalized by the upstream pressure.

C:\Excel\Mack_data\Spark_Gap.xls

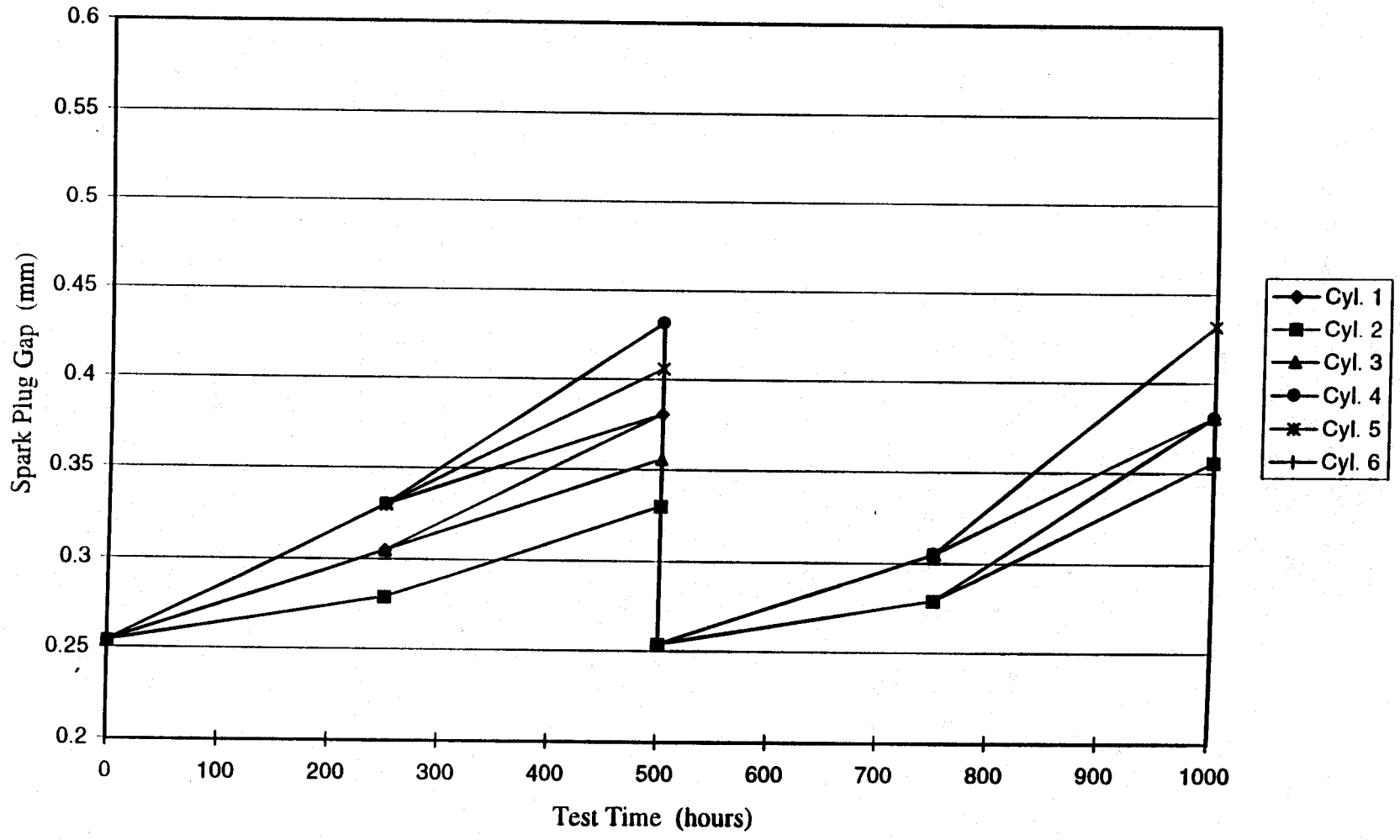


Figure 12. Spark Plug Gap Growth

Table 10. Cylinder Compression Pressures

Compression @ ~250 rpm (KPa_{gage})					
Total Engine Hours	**291.5**	**560.8**	**814.5**	**1067.4**	**1322.4**
Hours on STC Test	**0.0**	**250.0**	**500.0**	**750.0**	**1000.0**
Cylinder No. 1	1987	1918	1945	1904	1891
Cylinder No. 2	1960	1987	2001	1960	1946
Cylinder No. 3	1973	2015	2015	1953	1967
Cylinder No. 4	1987	2036	2036	1973	1973
Cylinder No. 5	1973	2042	2029	1987	1980
Cylinder No. 6	2001	2029	2029	1987	1967

Table 11. Cylinder Pressure Leak down

Leak Down (%)					
Total Engine Hours	**291.5**	**560.8**	**814.5**	**1067.4**	**1322.4**
Hours on STC Test	**0.0**	**250.0**	**500.0**	**750.0**	**1000.0**
Cylinder No. 1	48	52	56	35	57
Cylinder No. 2	27	10	12	7	8
Cylinder No. 3	5	14	8	4	4
Cylinder No. 4	33	20	17	13	22
Cylinder No. 5	20	10	18	7	6
Cylinder No. 6	20	8	5	4	8

2.3.7 Coolant Flow Measurements

Coolant flow was measured every 500 hours on the STC cycle. A turbine flow meter was installed in the coolant line between the outlet of the engine and the gate valve for the thermal "shock test setup. Coolant flow was measured at a typical valve position during the unloaded and loaded stages of the cycle. The results are shown in Table 12.

Table 12. Coolant Flow Measurements

Hours on STC Test	Coolant Flow at Unloaded Stage (l/m)	Coolant Flow at Loaded Stage (l/m)
0.0	321	362
500.0	314	365
1000.0	313	366

2.3.8 Maintenance/ Unscheduled Shutdowns

Major maintenance items before the start of the STC test included a rebuild of the front cylinder head, at 161.4 total engine hours, due to an exhaust valve failure on the number three cylinder. Also included were the replacement of the UEGO sensor, at 64.4 total engine hours, due to an incorrect equivalence ratio readings and the replacement of the injectors, at 232.2 total engine hours, due to slow reacting injectors.

Major maintenance items during the STC test included a misfire problem caused by noise on the mag pickup signal. The mag pickup was shimmed out by 0.020 inches. The throttle was replaced at 871.8 total engine hours due to a "sticking" problem. Two injectors were replaced at 871 and 1010 total engine hours due to "sticking".

Shutdowns for the engine, during the STC test were scheduled for every 25 test hours. Unscheduled and/or extended shutdowns, along with unscheduled maintenance events, are shown in Table 13.

Table 13. Unscheduled Shutdowns/Maintenance During STC Test

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
7/22/98	311.7	7.2	"AL_Lim" low fault on OH1. Noted occasional misfire.
7/23/98	322.4	17.9	Engine running erratic. Stopped engine and found broken wire to fuel metering block shut-off valve. Repaired wire and restarted engine.
7/24/98	332.6	27.2	Idle speed high at unloaded stage (~1100 rpm). Stopped engine. No faults or problems found. Restarted engine.
7/25/98	335.3	39.4	Idle speed erratic. No faults found. Stopped and restarted engine. Idle speed still erratic.

Table 13. Unscheduled Shutdowns/Maintenance During STC Test - Cont'd

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
7/25/98	350.9	45.0	Idle speed erratic. Found pinched and/or shorted wire (RPM_targ_def). Repaired wire (w/engine running).
7/25/98	354.9	49.0	Engine over-speeds/surges during ramp to loaded stage. "Inj DutyCycle" fault noted. Also occasional "NGP Exp" low fault noted. Cleared faults and continued test.
7/26/98	382.4	76.0	Idle speed high (~700 rpm). Reset by turning ignition key off and back on at idle stage.
7/27/98	392.9	86.5	Multiple faults noted including "NGP Exp" low, "Boost Exp" low, "PTP Active", and Inj DutyCycle. Also an occasional "Control Closed Loop". Reset and continue.
7/27/98	400.5	94.1	Stopped engine to repair broken mounting bolt. Adjust ramp rates due to over-speed condition. Also adjust OH1 System controller due to continuous faults. Restarted engine.
7/27/98	413.2	106.2	Boost hose failure (Lab). Stopped engine and replaced boost hose. Restarted engine.
7/28/98	427.4	120.1	Stopped engine to repair water pump/drive motor belt guard (Lab). Restarted engine.
7/28/98	428.3	120.7	Engine stopped. "NGP Exp" low fault noted. Repaired broken wire to injector block solenoid. Restarted engine.
7/29/98	436.9	129.0	Stopped engine due to repair broken mounting bolt. Replaced bolt and restarted engine.
7/29/98	440.2	132.0	Idle speed High (~1000 rpm). Reset by turning ignition key off and back on at idle stage.
7/30/98	458.4	150.0	Scheduled shutdown - Found broken mounting bolt. Replaced all mount bolts, repaired engine mount, and realigned w/dyno. Also replaced wire harness w/new one.
7/30/98	461.6	152.7	Intermittent misfires. Stopped engine to troubleshoot. Replaced ignition harness and changed ignition timing to MBT at 22 deg BTDC (3 deg retard). Restarted engine.

Table 13. Unscheduled Shutdowns/Maintenance During STC Test - Cont'd

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
7/31/98	484.5	175.0	Scheduled shutdown - Changed to new Blowby cannister assembly (supplied by Mack). Reinstalled original ignition harness. Inserted 0.020" shims under cam gear speed sensor due to false pulses causing misfires.
8/3/98	543.3	233.2	Boost hose leaking (Lab). Stopped engine and replaced boost hose. Restarted engine.
8/3/98	546.2	236.0	Idle speed high (~750 rpm). Reset by turning ignition key off and back on at idle stage.
8/4/98	560.8	250.0	Scheduled shutdown - Replaced CNG metering block shut-off solenoid. Also replaced turbocharger wastegate actuator due to leaking diaphragm.
8/10/98	701.7	390.0	Stopped engine to investigate misfire problem (per Mack's request). Removed shims under cam sensor and observe engine. Misfires occurred w/o shims. Reinstall shims and restarted engine.
8/13/98	766.4	453.1	Stopped engine to run engine on adjacent test stand.
8/14/98	788.4	475.0	Scheduled shutdown - Left engine shutdown to run engine on adjacent test stand.
8/17/98	813.7	500.0	Scheduled shutdown - Replaced rear head valve cover gasket due to leak (discolored, burnt, brittle from heat). Reset spark plug gaps to 0.010" and reset Cyl. No. 3 exhaust lash from 0.019" to 0.028". Also inspected pistons for cracks (per Mack's request) using a bore scope with video camera to document piston conditions.
8/19/98	839.6	525.0	Scheduled shutdown - Installed valve before CNG metering block to verify injector leak down rate data.
8/20/98	859.9	545.1	Engine did not ramp up to loaded condition. "TPS Exp" low and "Boost Exp" low faults were noted. Reset by turning ignition key off and back on at idle. Resumed test. Faults continued intermittently.
8/20/98	864.8	550.0	Scheduled shutdown - Removed throttle unit for inspection due to possible binding/sticking. Cleaned and reinstalled unit. Restarted engine.

Table 13. Unscheduled Shutdowns/Maintenance During STC Test - Cont'd

Date	Total Engine Time (Hours)	STC Test Time (Hours)	Description
8/21/98	870.8	555.4	Engine stopped. Found bad injector (stuck open). Replaced w/new injector (m/n SP021S1). Restarted engine.
8/21/98	871.8	556.1	Engine not ramping down/hanging up. Stopped engine. Found throttle unit sticking again. Replaced w/new throttle unit (p/n 8535-124). Restarted engine.
8/27/98	1009.9	693.4	Engine erratic w/misfires. Stopped engine. Found bad injector (slow response). Replaced w/new injector (m/n SP021S1). Restarted engine.
8/31/98	1066.9	750.0	Scheduled shutdown - Changed adsorption filter element on fuel system due to oil/water drained. Also inspect pistons for cracks using bore scope with video camera.
9/4/98	1153.1	835.3	Lab off-line due to power failure. Stopped engine. Reset hardware and restarted engine.
9/4/98	1167.8	850.0	Scheduled shutdown - Left engine down for Holiday weekend. Restated engine on 9/8/98.
9/9/98	1204.1	885.7	Dyno case temperature safety tripped (Lab). Reset and brought engine back up to loaded stage. Resumed test.
9/11/98	1231.5	912.8	Stopped engine due to operator shift change arrived late. Restarted engine.
9/11/98	1254.1	935.0	Stopped engine for Lab weekend shutdown. Restarted engine on 9/14/98.
9/14/98	1272.0	950.6	Engine not ramping up to loaded condition. "Boost Exp" low fault. Turned ignition key off and on. Resumed test.
9/14/98	1276.7	955.3	Engine not ramping up to loaded condition. "Boost Exp" low fault. Turned ignition key off and on. Resumed test.
9/15/98	1300.5	979.0	Idle speed high (~750 rpm). "FPP" fault noted. Turned ignition key off and on to reset. Resumed test.

3.0 CONCLUSIONS & RECOMMENDATIONS

A 1000 hour durability test was successfully completed. Several conclusions regarding the technical content of the program were made.

1. The number three exhaust valve on the exhaust side showed high valve recession. This may be due to a problem caused by the rebuild of the cylinder heads when this exhaust valve was bent.

2. Injector block leak down rates were measured at zero kPa/sec during the test. Tests were conducted which confirmed the zero leak down rate. A zero leak down rate indicates no leakage through the injectors. Normally, there is a small amount of leakage through the injectors when they are closed.

3. Two injectors were replaced during the STC test. The injectors were "sticking" where the injectors were not fully closing. Further investigation into this problem should be conducted to avoid problems in the field.

4. The spark plugs gap growth showed that a regap interval of 500 hours was possible during the STC test.

5. A borescope was used to inspect the pistons for cracks at 500, 750, and 1000 test hours. No indications of piston cracking were noted.

6. The blowby filter showed no signs of degradation during the 1000 hour STC test.

7. An investigation of the high exhaust valve recession on the number three cylinder on the exhaust side should be conducted.

APPENDIX A

LISTING OF HP DAQ RECORDS

HP DAQ RECORDS FROM STC DURABILITY TEST

Run # From	Run # To	Test Hours From	Test Hours To	Hourly Data	Snapshot Data	Comments
392	393	0	0	x		
394	449	0	0		x	
450	483	1	17	x		
484	484	18	18	x		Engine stopped, reading aborted
485	498	18	24	x		
499	554	25	25		x	
555	556	25	25	x		
557	604	26	49	x		
605	660	50	50		x	
661	662	50	50	x		
663	710	51	74	x		
711	766	75	75		x	
767	768	75	75	x		
769	816	76	99	x		
817	872	100	100		x	
873	874	100	100	x		
875	922	101	124	x		
923	978	125	125		x	
979	980	125	125	x		
981	1028	126	149	x		
1029	1084	150	150		x	
1085	1086	150	150	x		
1087	1134	151	174	x		
1135	1190	175	175		x	
1191	1192	175	175	x		
1193	1240	176	199	x		
1241	1296	200	200		x	
1297	1298	200	200	x		
1299	1346	201	224	x		
1347	1402	225	225		x	
1403	1404	225	225	x		
1405	1428	226	237	x		
		238	238	x		Missed reading
1429	1450	239	249	x		
1451	1506	250	250		x	
1507	1508	250	250	x		
1509	1556	251	274	x		
1557	1612	275	275		x	
1613	1614	275	275	x		
1615	1662	276	299	x		
1663	1718	300	300		x	
1719	1720	300	300	x		
1721	1768	301	324	x		
1769	1824	325	325		x	
1825	1826	325	325	x		
1827	1874	326	349	x		
1875	1930	350	350		x	
1931	1932	350	350	x		

HP DAQ RECORDS FROM STC DURABILITY TEST

Run # From	Run # To	Test Hours From	Test Hours To	Hourly Data	Snapshot Data	Comments
1933	1980	351	374	x		
1981	2036	375	375		x	
2037	2038	375	375	x		
2039	2086	376	399	x		
2087	2142	400	400		x	
2143	2144	400	400	x		
2145	2192	401	424	x		
2193	2248	425	425		x	
2249	2250	425	425	x		
2251	2298	426	449	x		
2299	2354	450	450		x	
2355	2356	450	450	x		
2357	2404	451	474	x		
2405	2460	475	475		x	
2461	2462	475	475	x		
2463	2510	476	499	x		
2511	2566	500	500		x	
2567	2568	500	500	x		
2569	2616	501	524	x		
2617	2672	525	525		x	
2673	2674	525	525	x		
2675	2722	526	549	x		
2723	2778	550	550		x	
2779	2780	550	550	x		
2781	2828	551	574	x		
2829	2884	575	575		x	
2885	2886	575	575	x		
2887	2934	576	599	x		
2935	2990	600	600		x	
2991	2992	600	600	x		
2993	3040	601	624	x		
3041	3096	625	625		x	
3097	3098	625	625	x		
3099	3146	626	649	x		
3147	3202	650	650		x	
3203	3204	650	650	x		
3205	3216	651	656	x		
3217	3218	657	657	x		Bad reading. recorded incorrectly
3219	3238	658	667	x		
3239	3240	668	668	x		Bad reading. recorded incorrectly
3241	3252	669	674	x		
3253	3308	675	675		x	
3309	3310	675	675	x		
3311	3358	676	699	x		
3359	3414	700	700		x	
3415	3416	700	700	x		
3417	3434	701	709	x		
3435	3436	709	709	x		Extra reading. [illegible] recorded

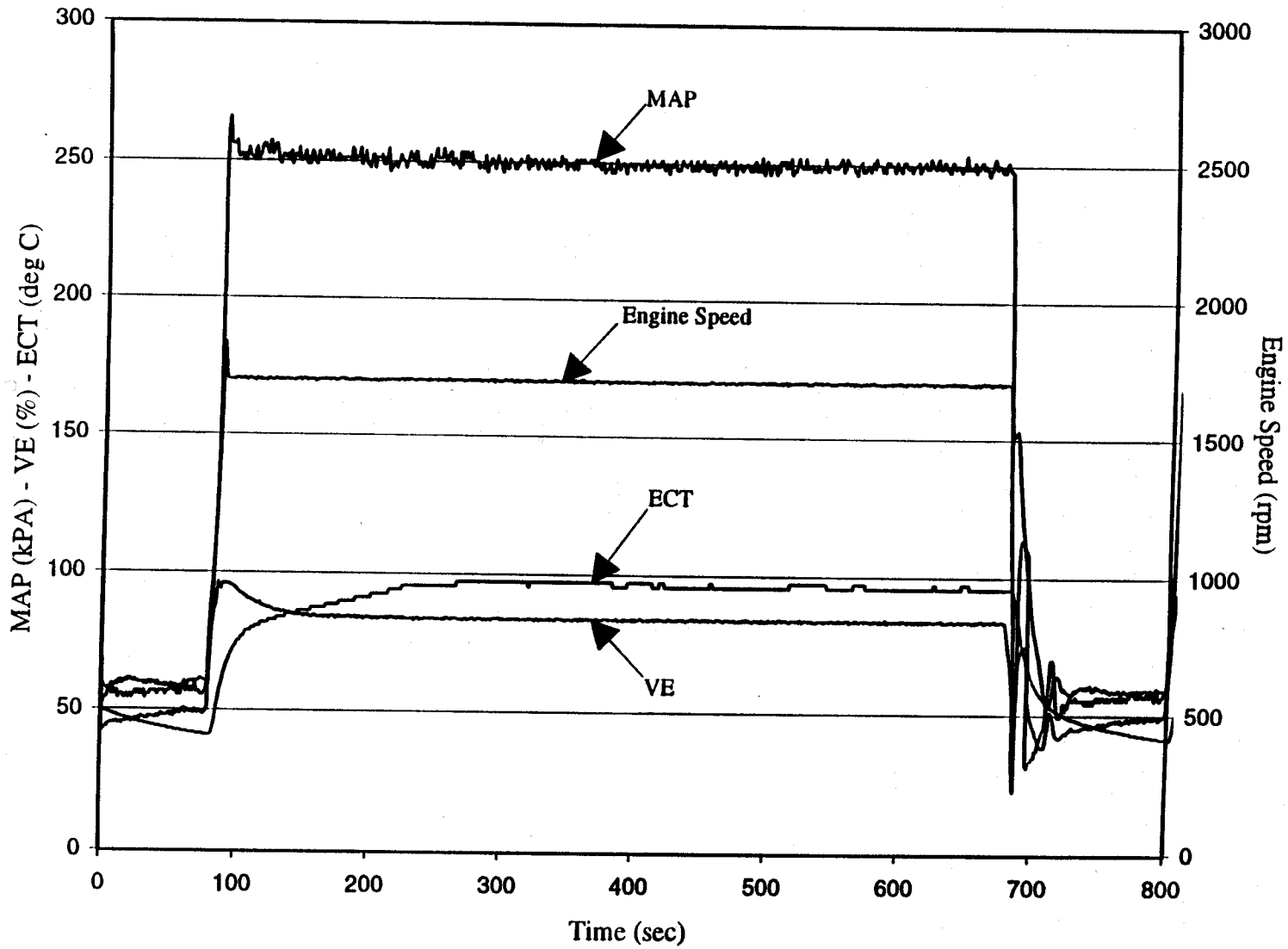
HP DAQ RECORDS FROM STC DURABILITY TEST

Run # From	Run # To	Test Hours From	Test Hours To	Hourly Data	Snapshot Data	Comments
3437	3466	710	724	x		
3467	3522	725	725		x	
3523	3524	725	725	x		
3525	3572	726	749	x		
3573	3628	750	750		x	
3629	3630	750	750	x		
3631	3650	751	760	x		
		761	761	x		Missed reading
3651	3676	762	774	x		
3677	3732	775	775		x	
3733	3734	775	775	x		
3735	3782	776	799	x		
3783	3838	800	800		x	
3839	3940	800	800	x		
3841	3888	801	824	x		
3889	3944	825	825		x	
3945	3946	825	825	x		
3947	3994	826	849	x		
3995	4050	850	850		x	
4051	4052	850	850	x		
4053	4100	851	874	x		
4101	4156	875	875		x	
4157	4158	875	875	x		
4159	4206	876	899	x		
4207	4262	900	900		x	
4263	4264	900	900	x		
4265	4312	901	924	x		
4313	4368	925	925		x	
4369	4370	925	925	x		
4371	4418	926	949	x		
4419	4474	950	950		x	
4475	4476	950	950	x		
4477	4524	951	974	x		
4525	4580	975	975		x	
4581	4582	975	975	x		
4583	4630	976	999	x		
4631	4686	1000	1000		x	
4687	4688	1000	1000	x		

APPENDIX B

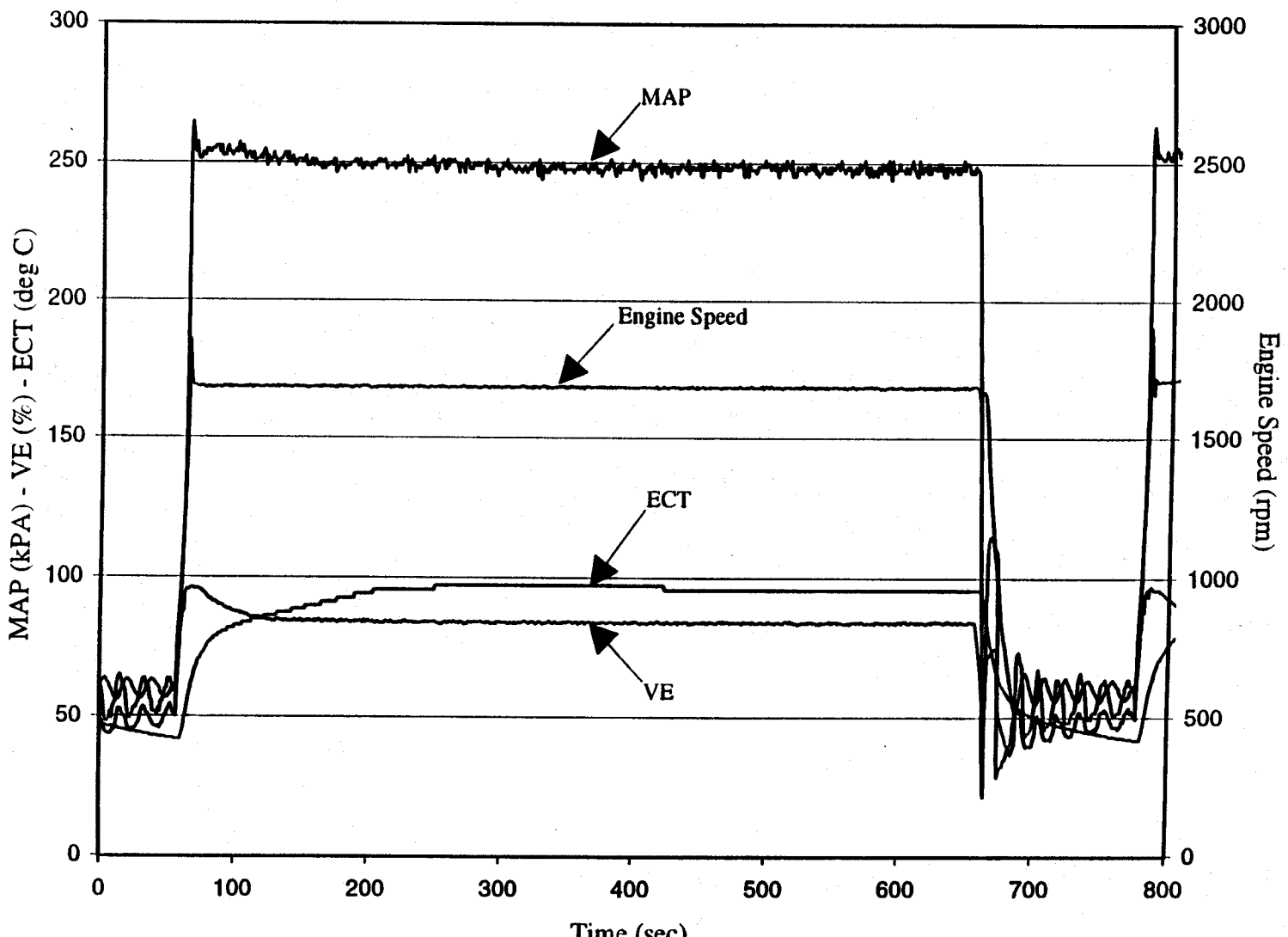
OH1 TRANSIENT DATA

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 0 TEST HOURS



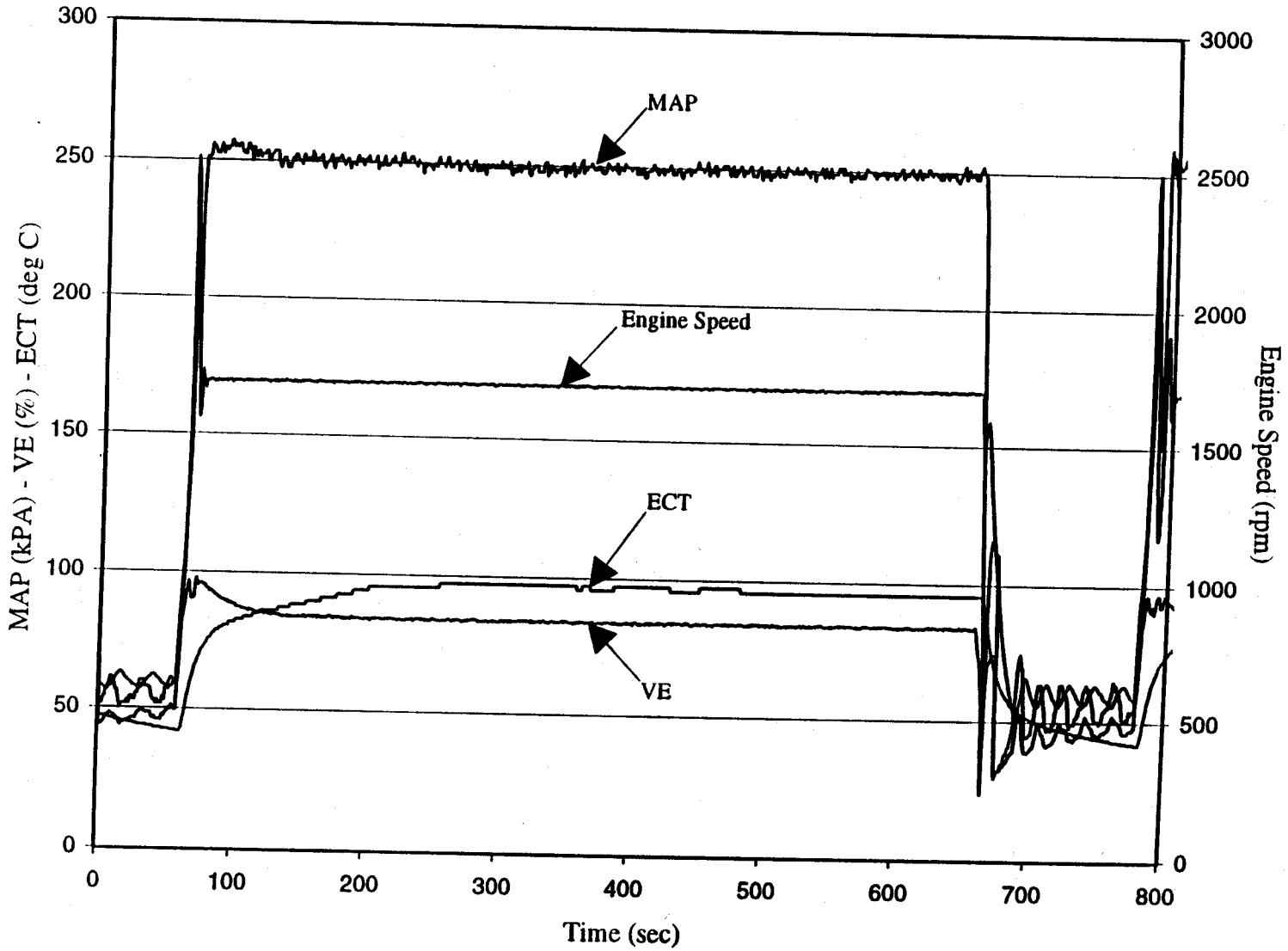
C:\Excel\Mack_data\0.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 25 TEST HOURS



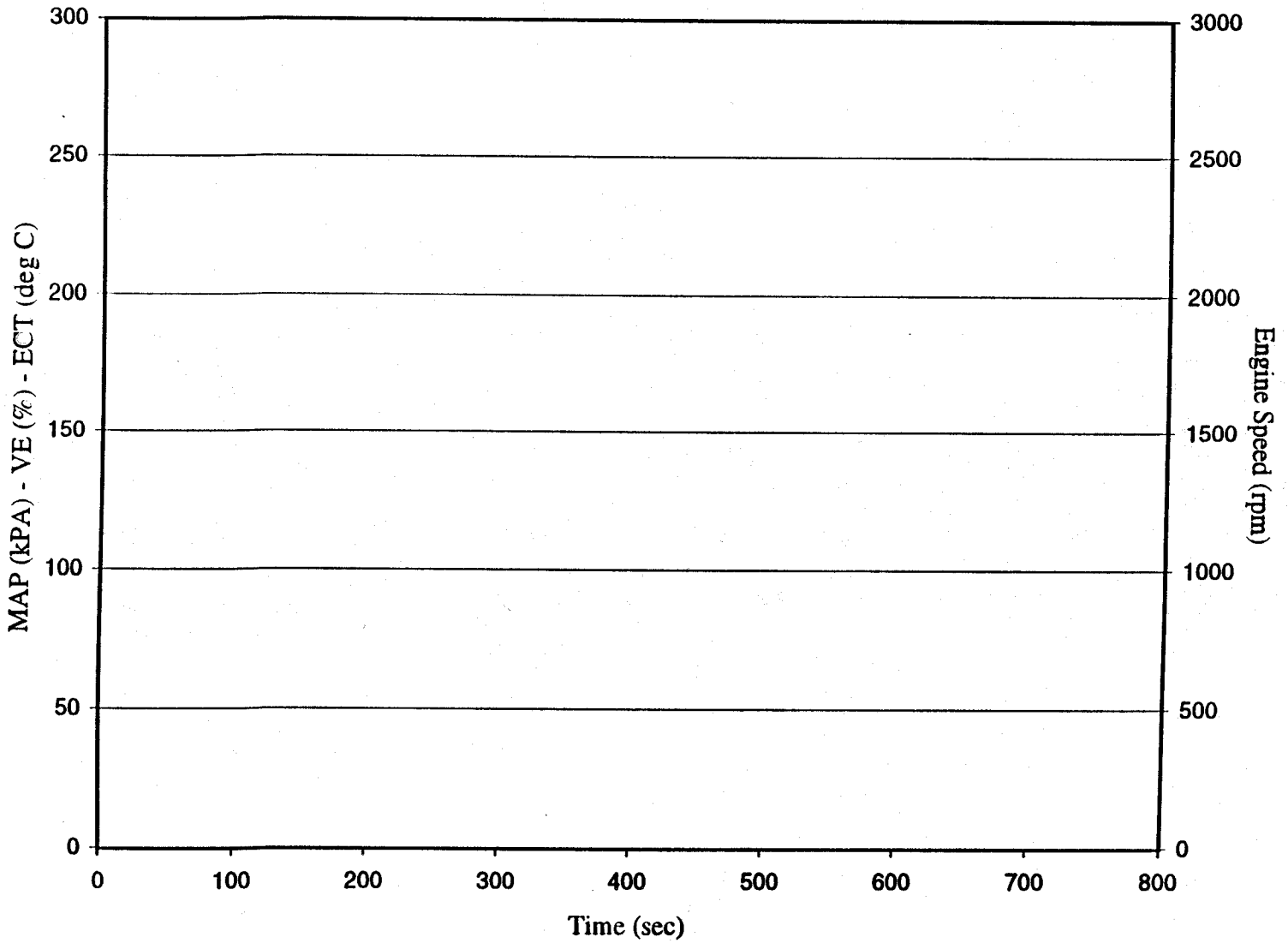
C:\Excel\Mack_data\25.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 50 TEST HOURS



C:\Excel\Mack_data\50.dat

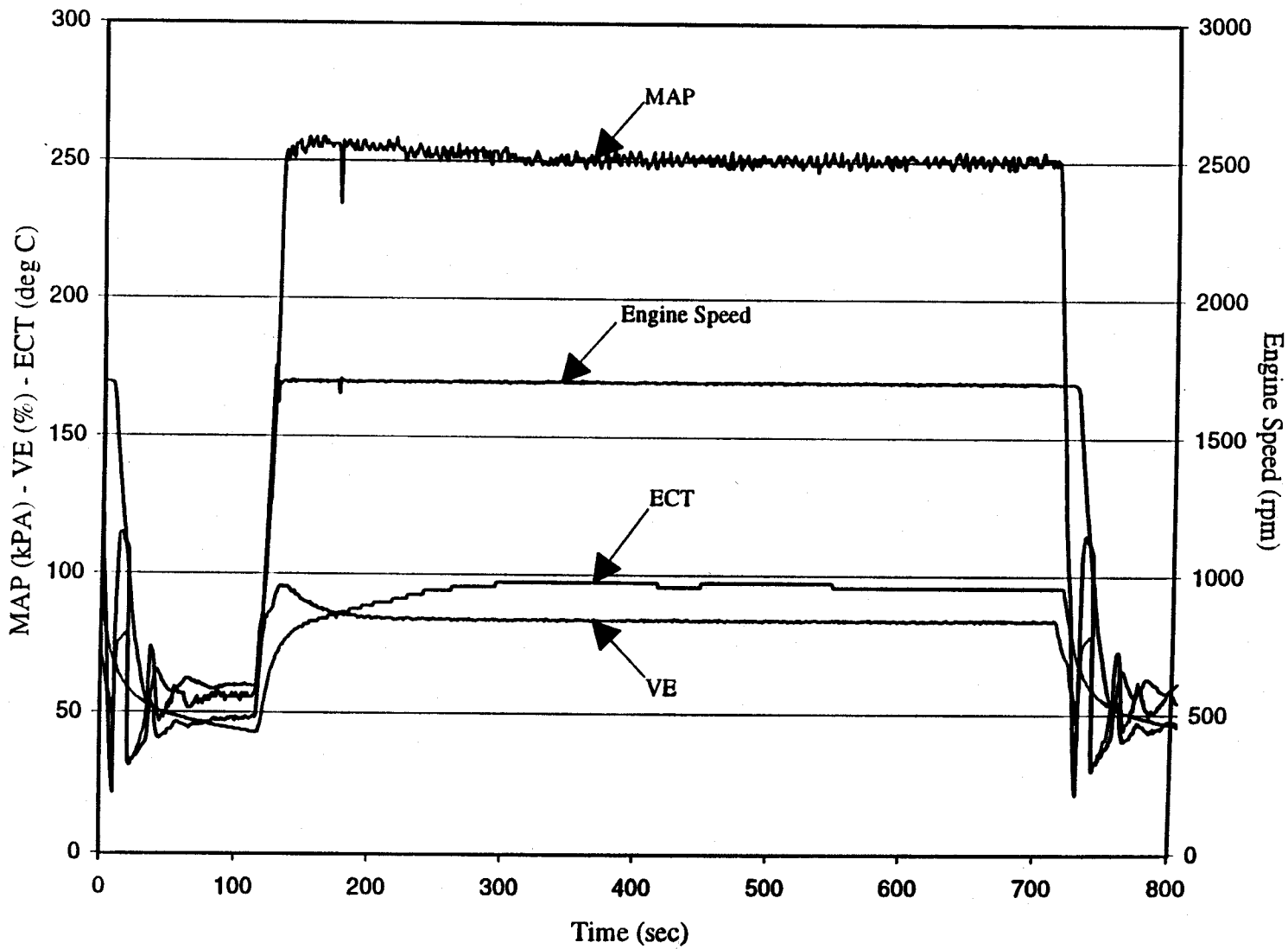
TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 75 TEST HOURS



NOTE: Data was taken but file was inadvertantly erased

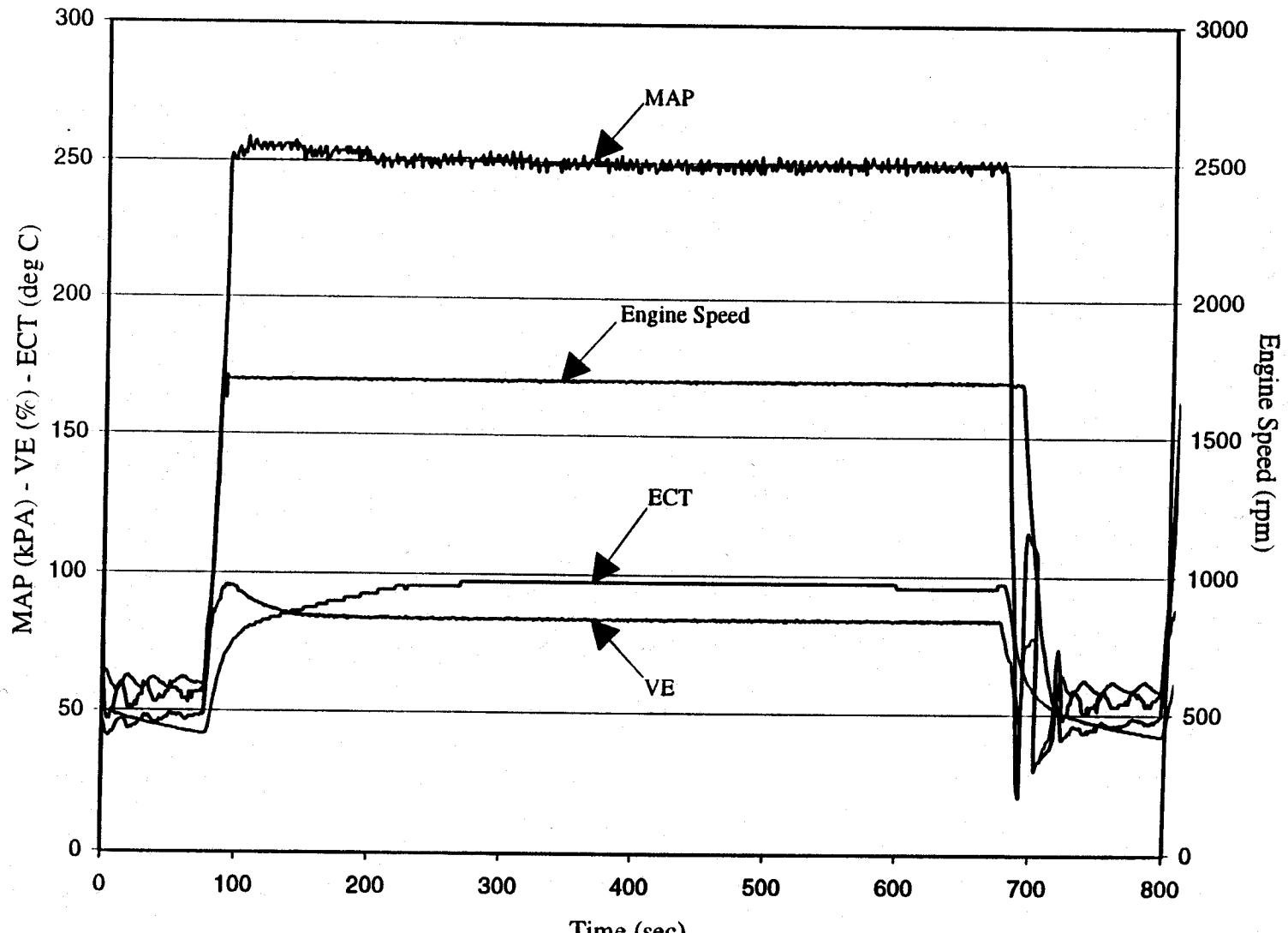
C:\Excel\Mack_data\75.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 100 TEST HOURS



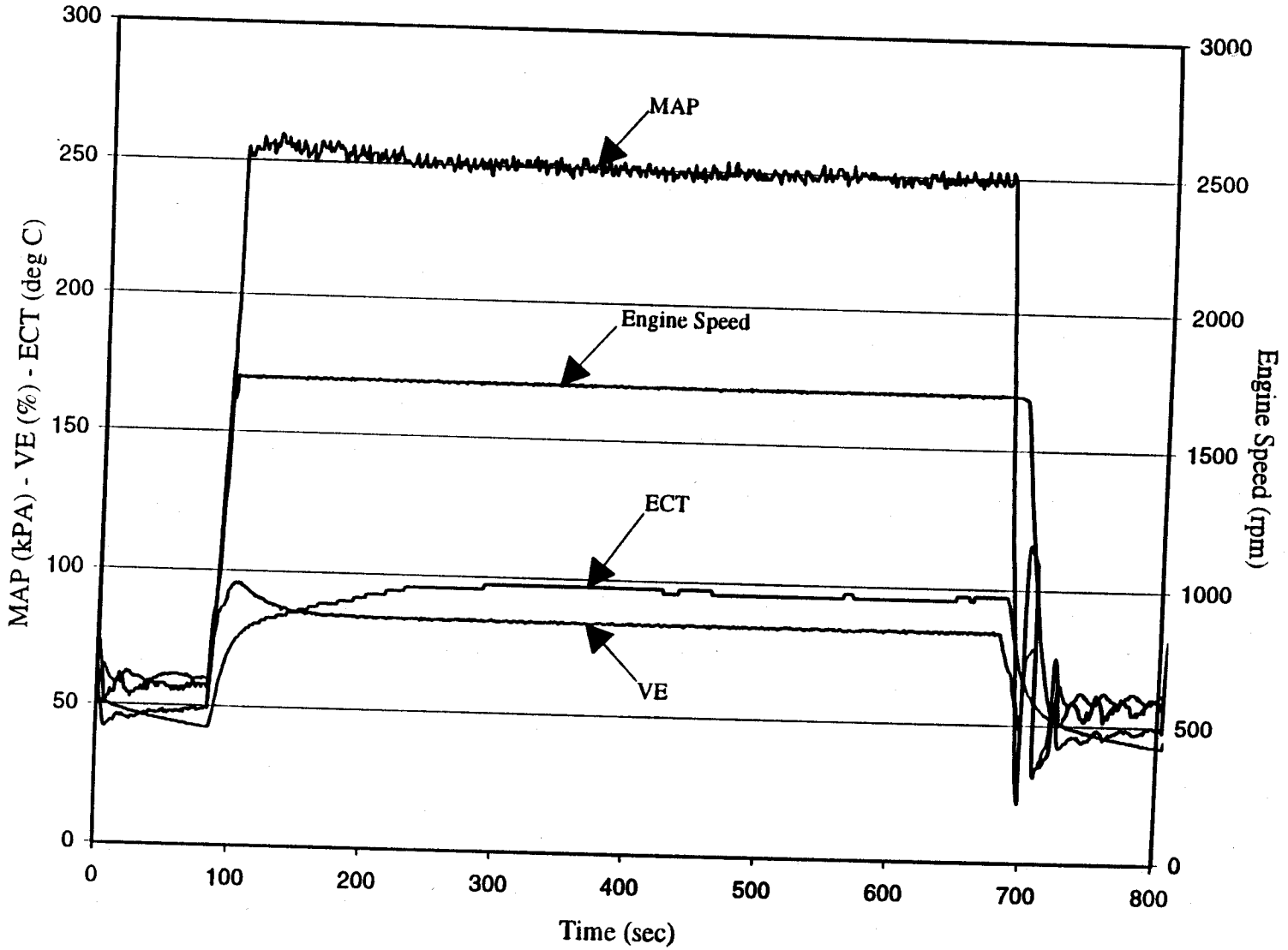
C:\Excel\Mack_data\100.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 125 TEST HOURS



C:\Excel\Mack_data\125.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 150 TEST HOURS



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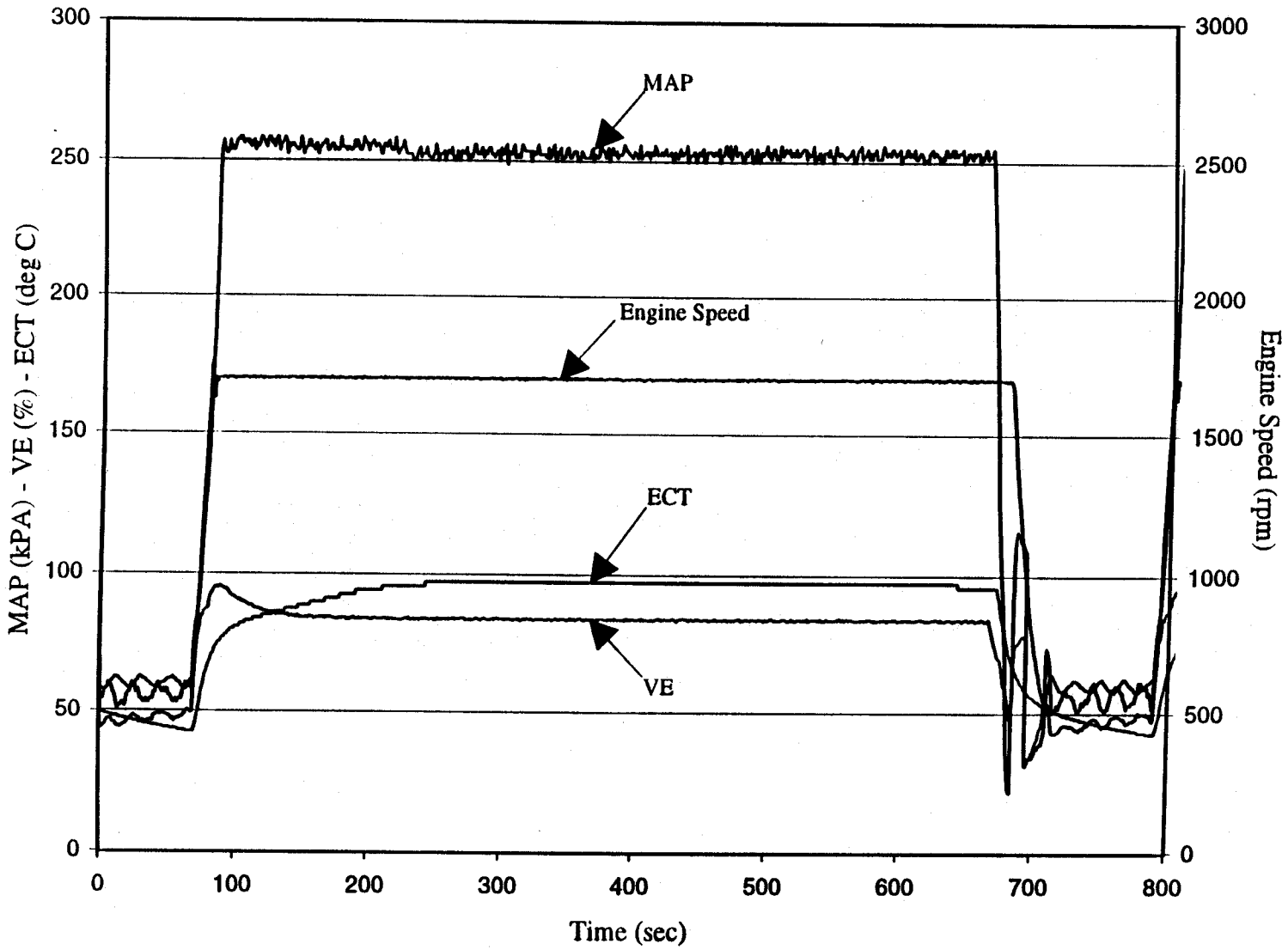
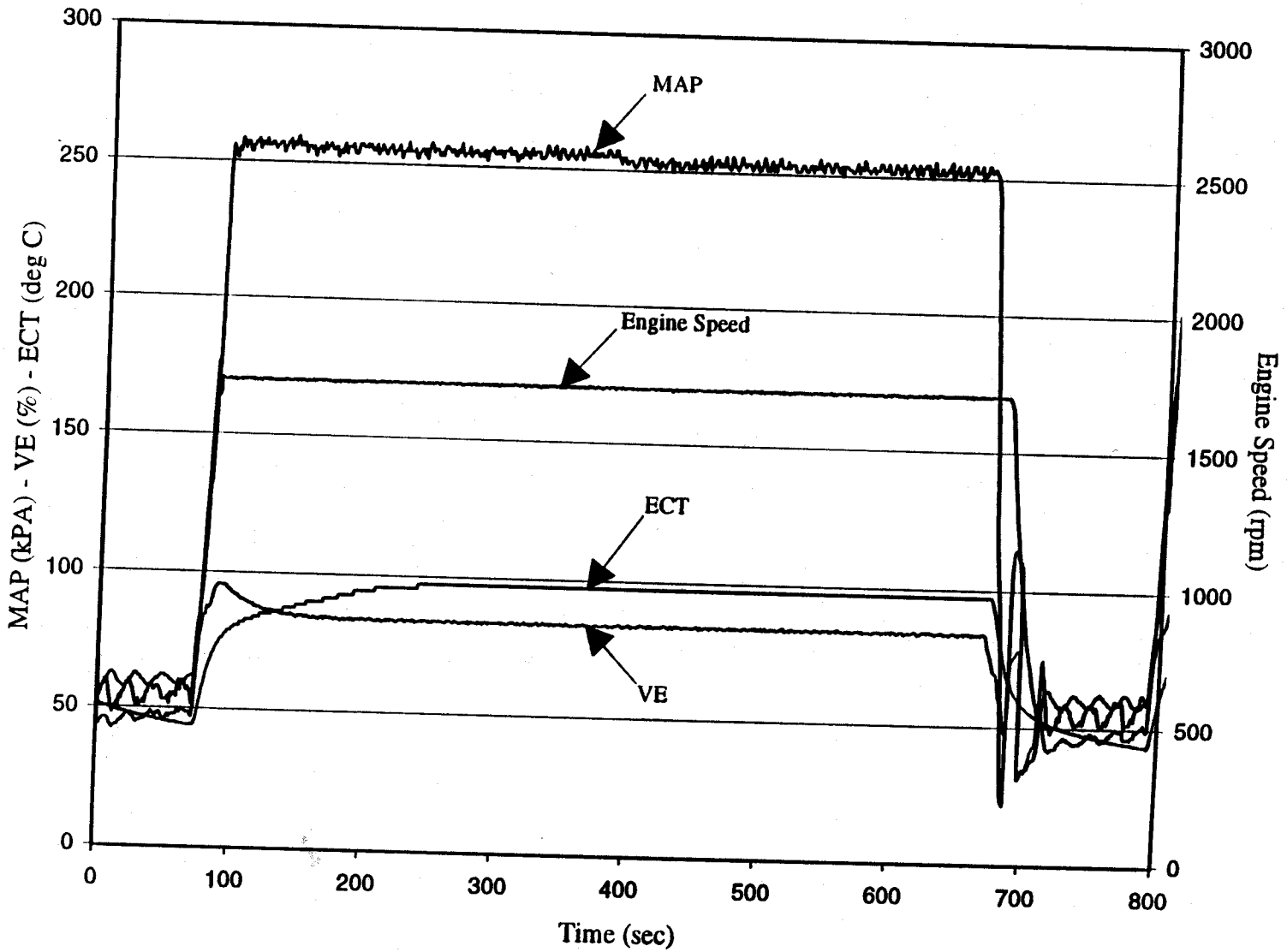
TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 175 TEST HOURS



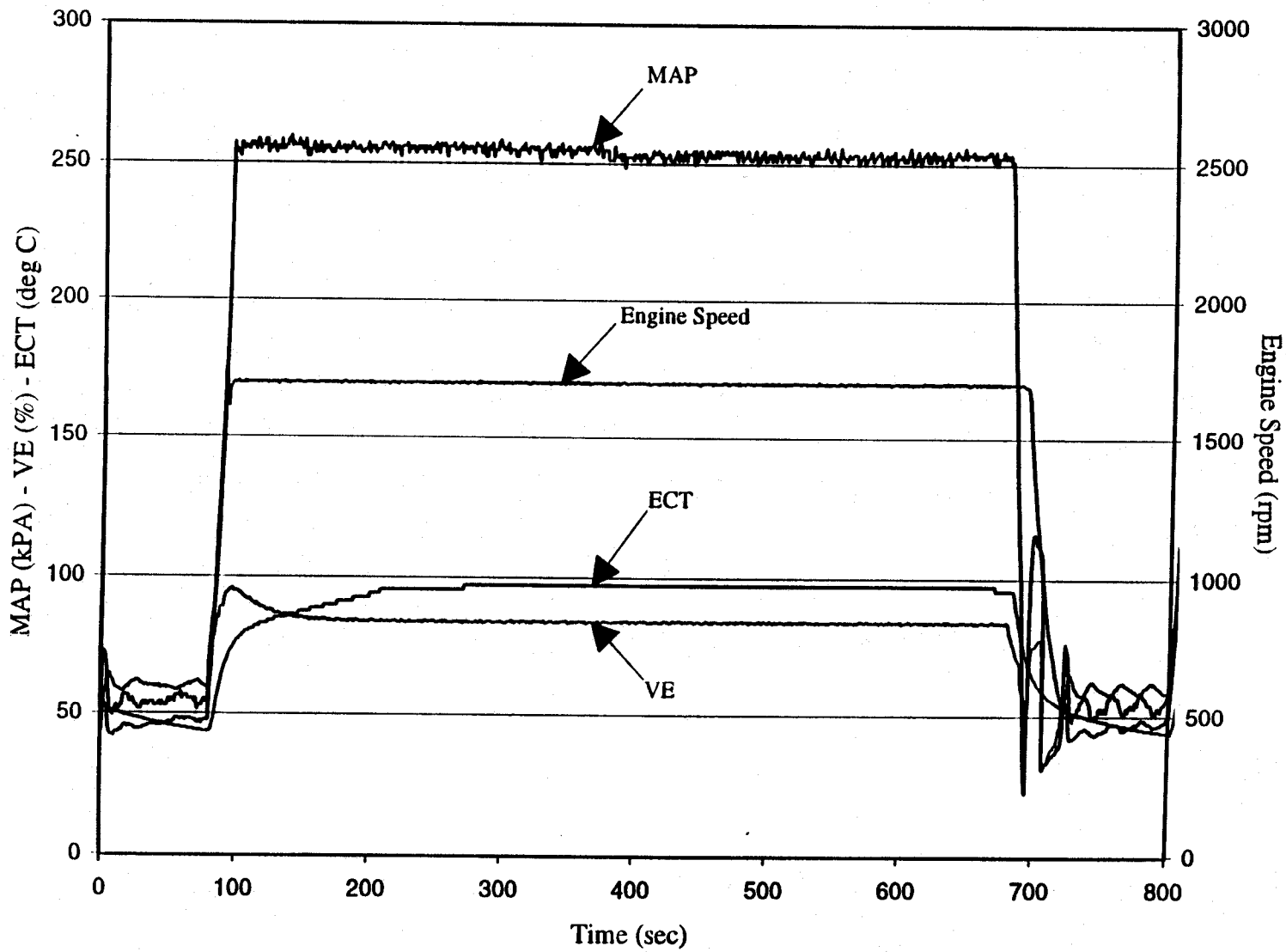
C:\Excel\Mack_data\175.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 200 TEST HOURS



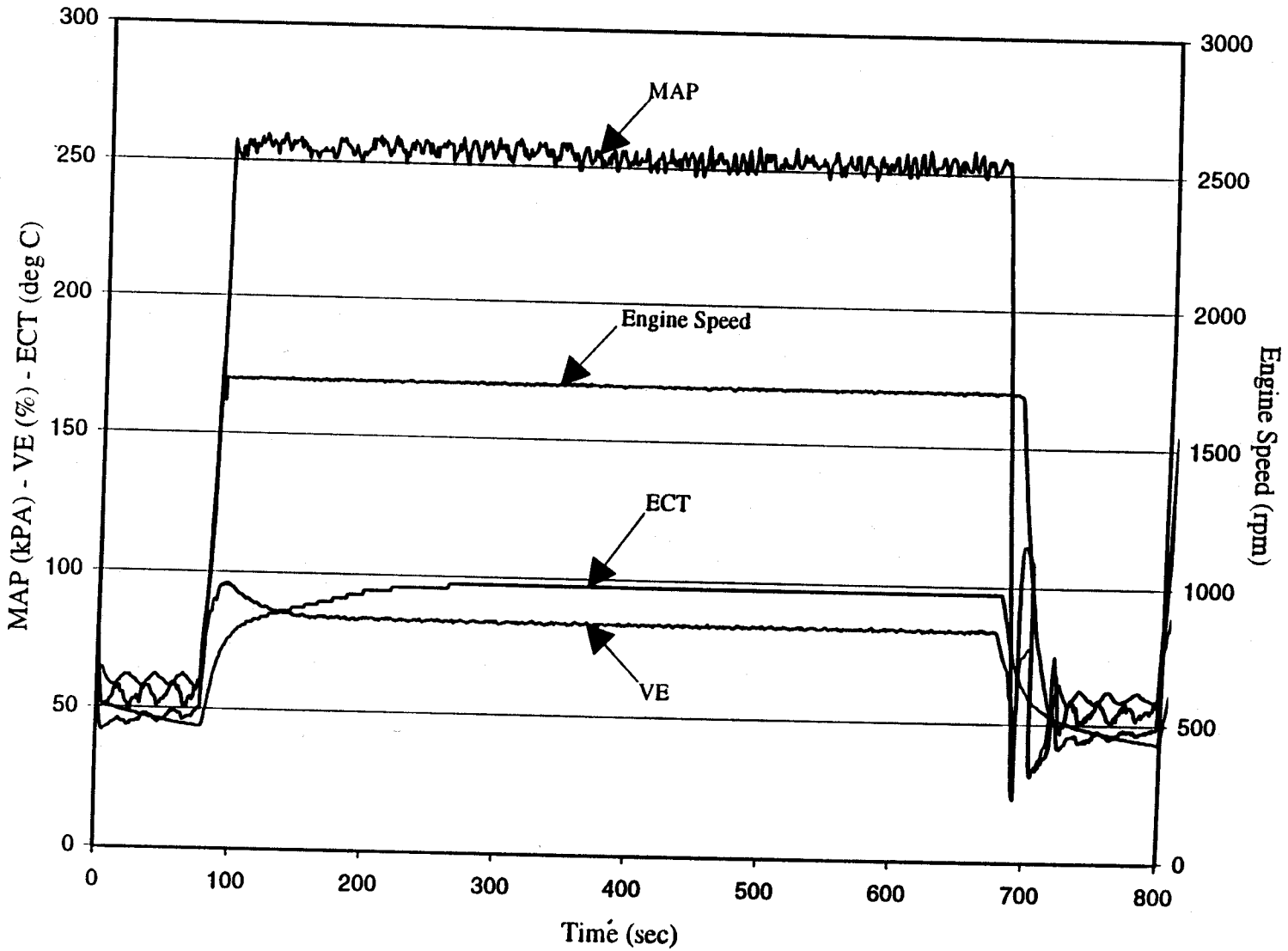
C:\Excel\Mack_data\200.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 225 TEST HOURS



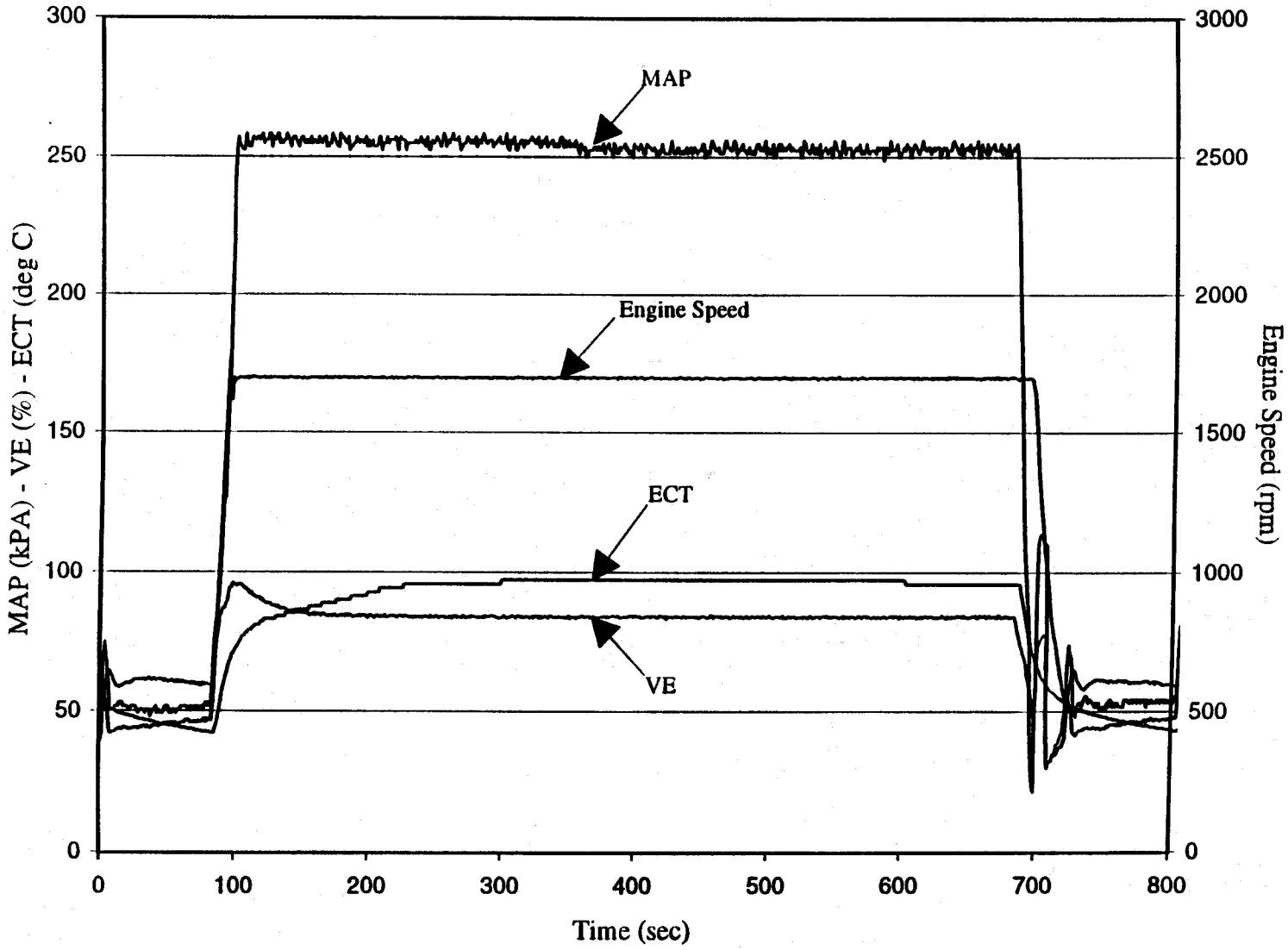
C:\Excel\Mack_data\225.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 250 TEST HOURS



C:\Excel\Mack_data\250.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 250 TEST HOURS



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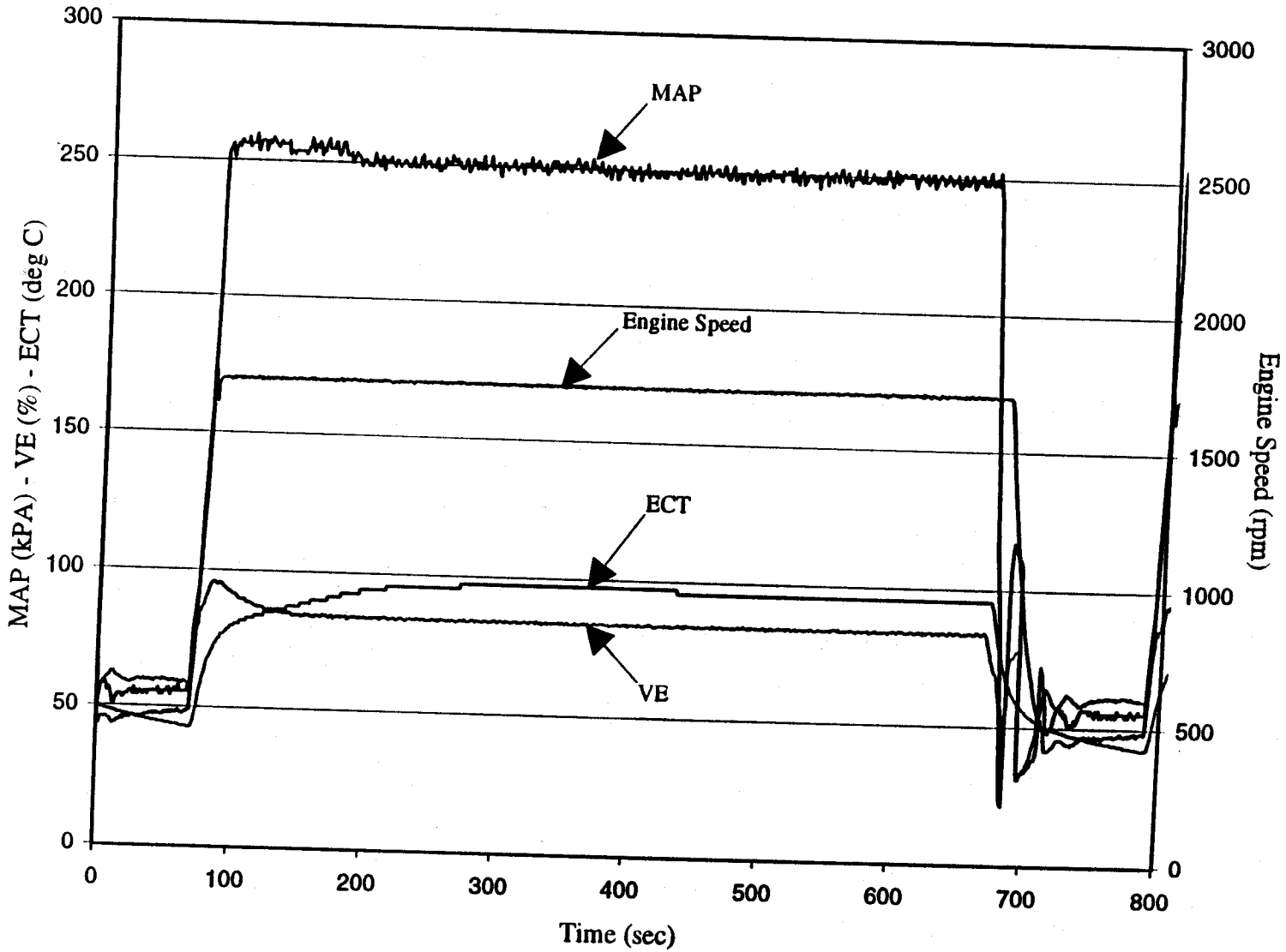
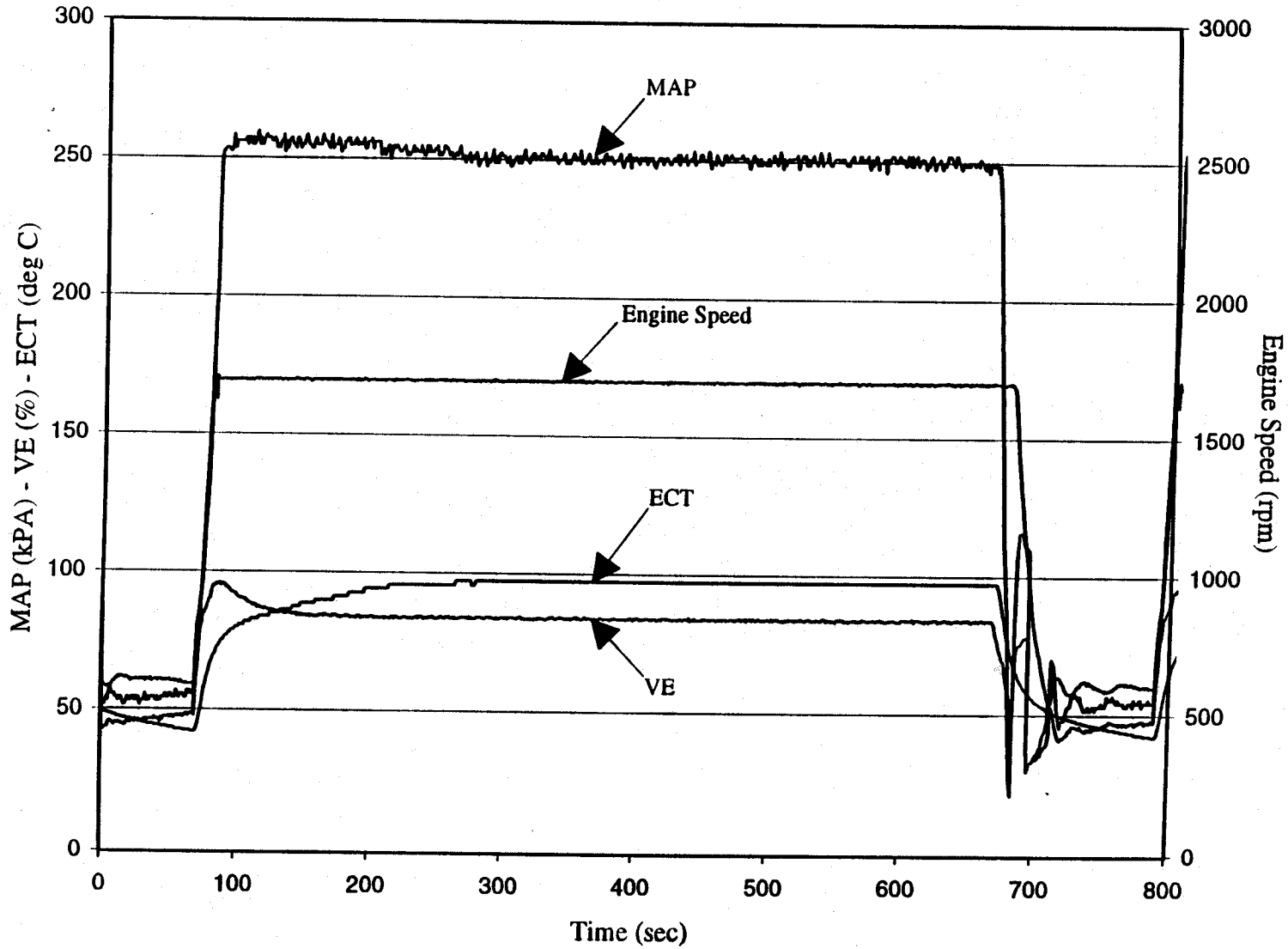
TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 275 TEST HOURS



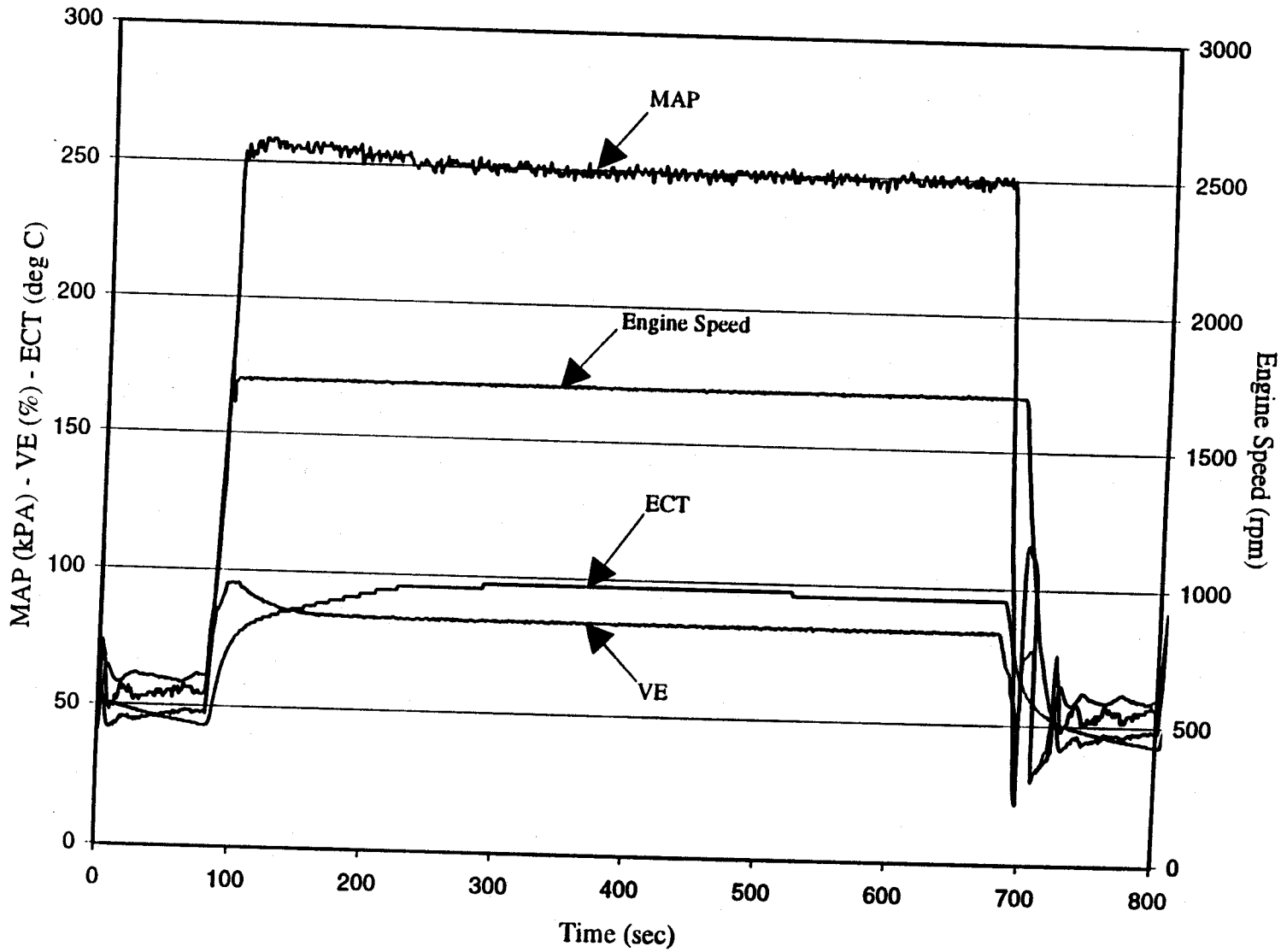
C:\Excel\Mack_data\275.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 300 TEST HOURS



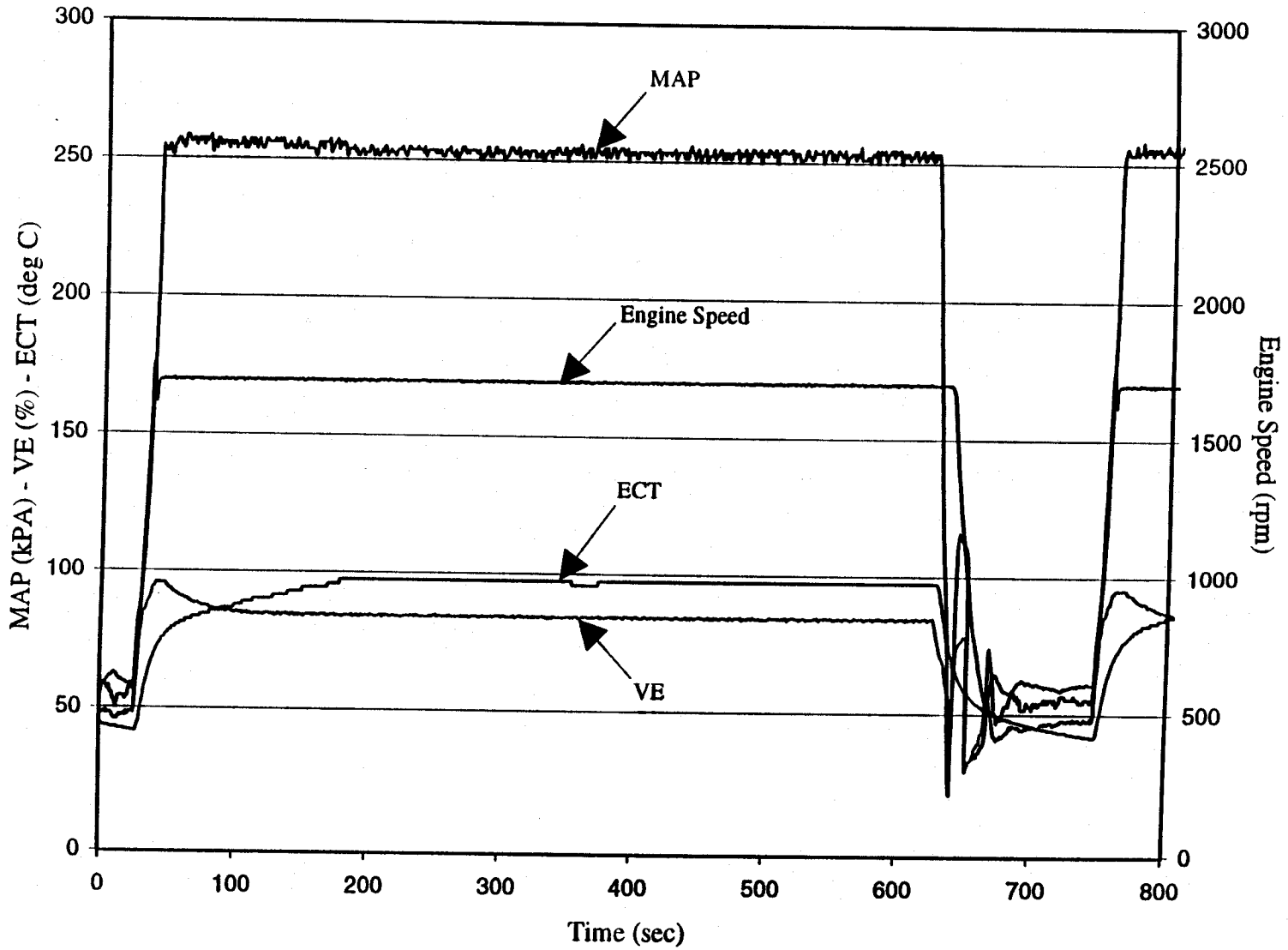
C:\Excel\Mack_data\300.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 325 TEST HOURS



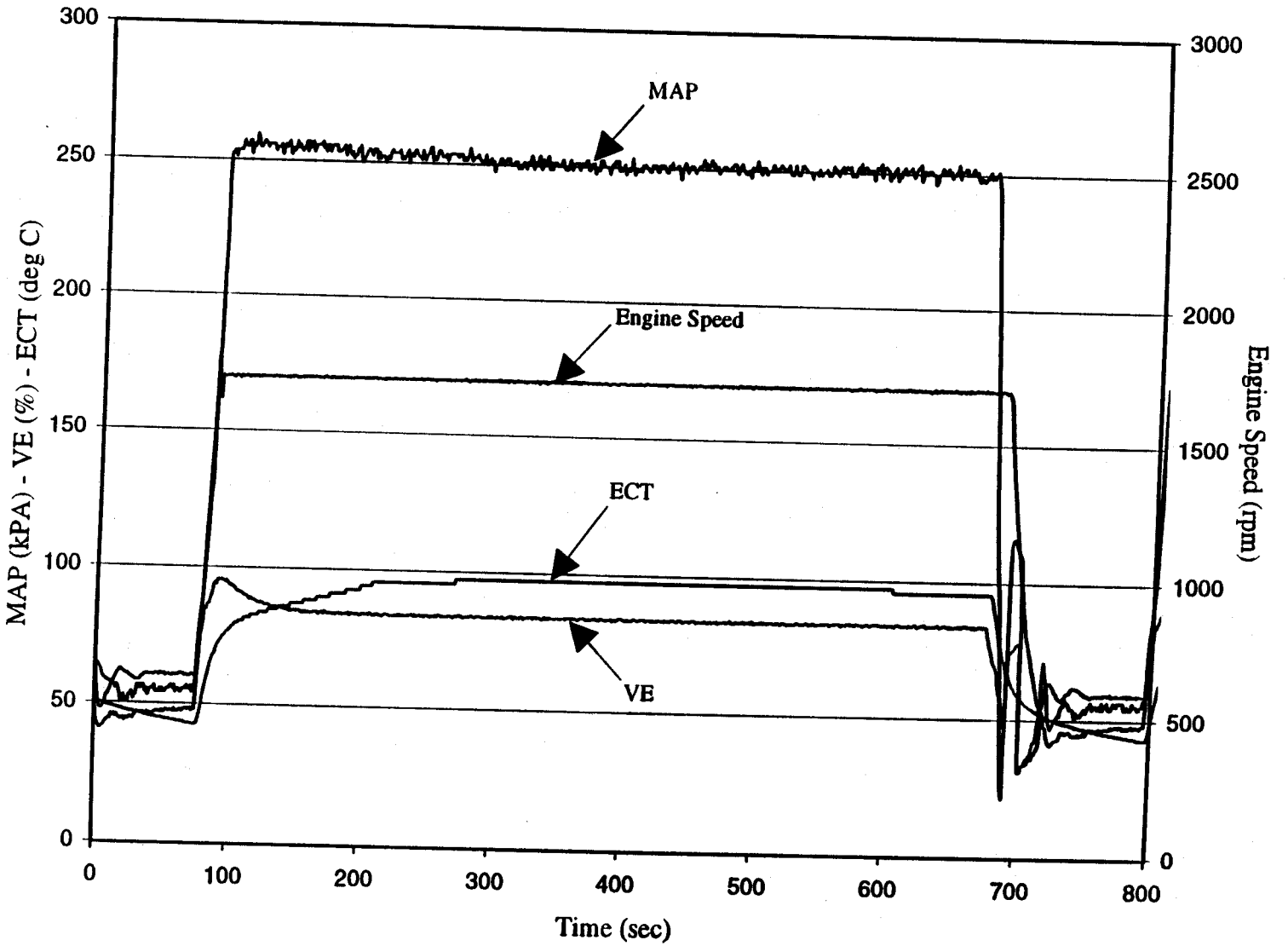
C:\Excel\Mack_data\325.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 350 TEST HOURS



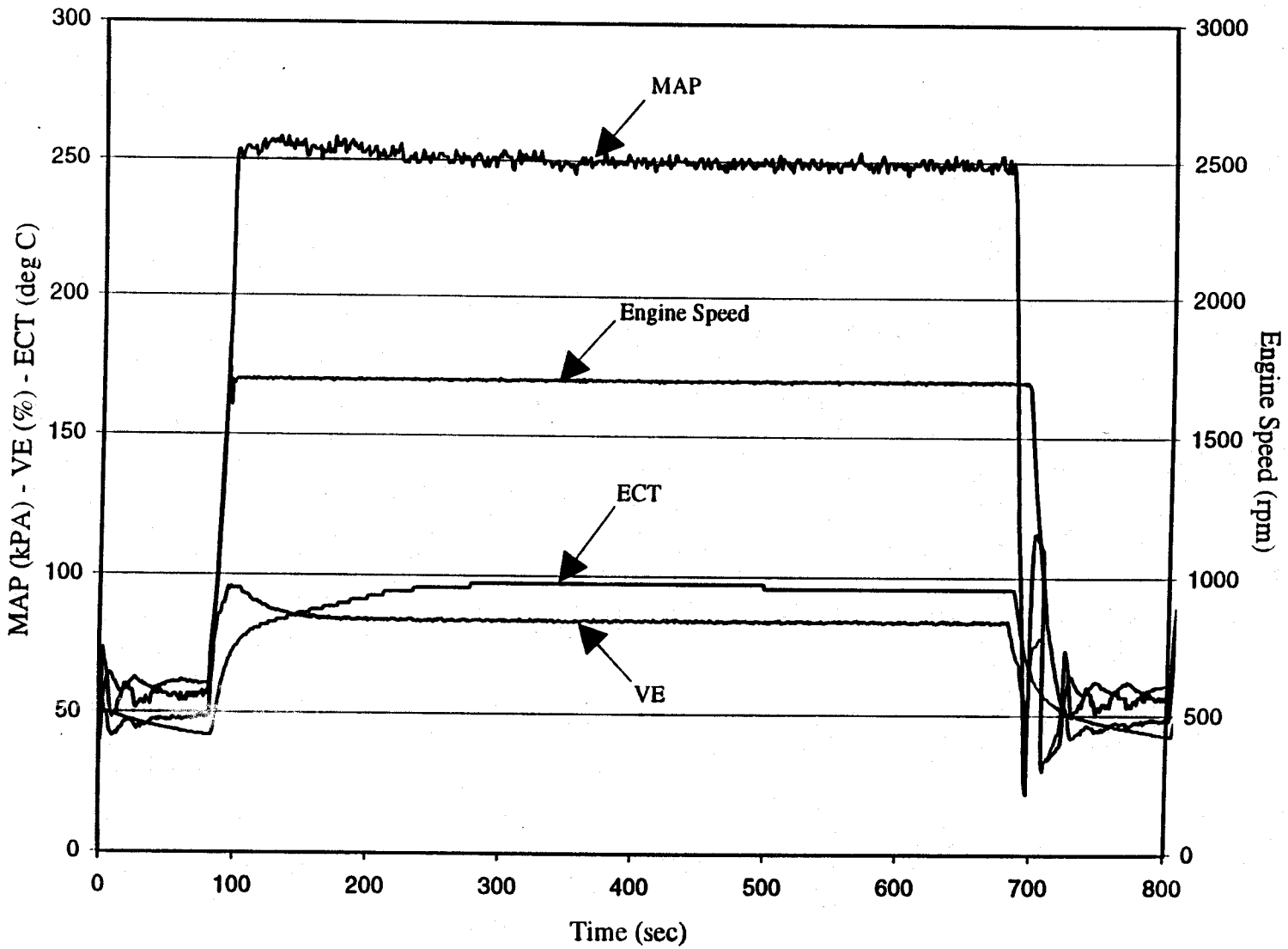
C:\Excel\Mack_data\350.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 375 TEST HOURS



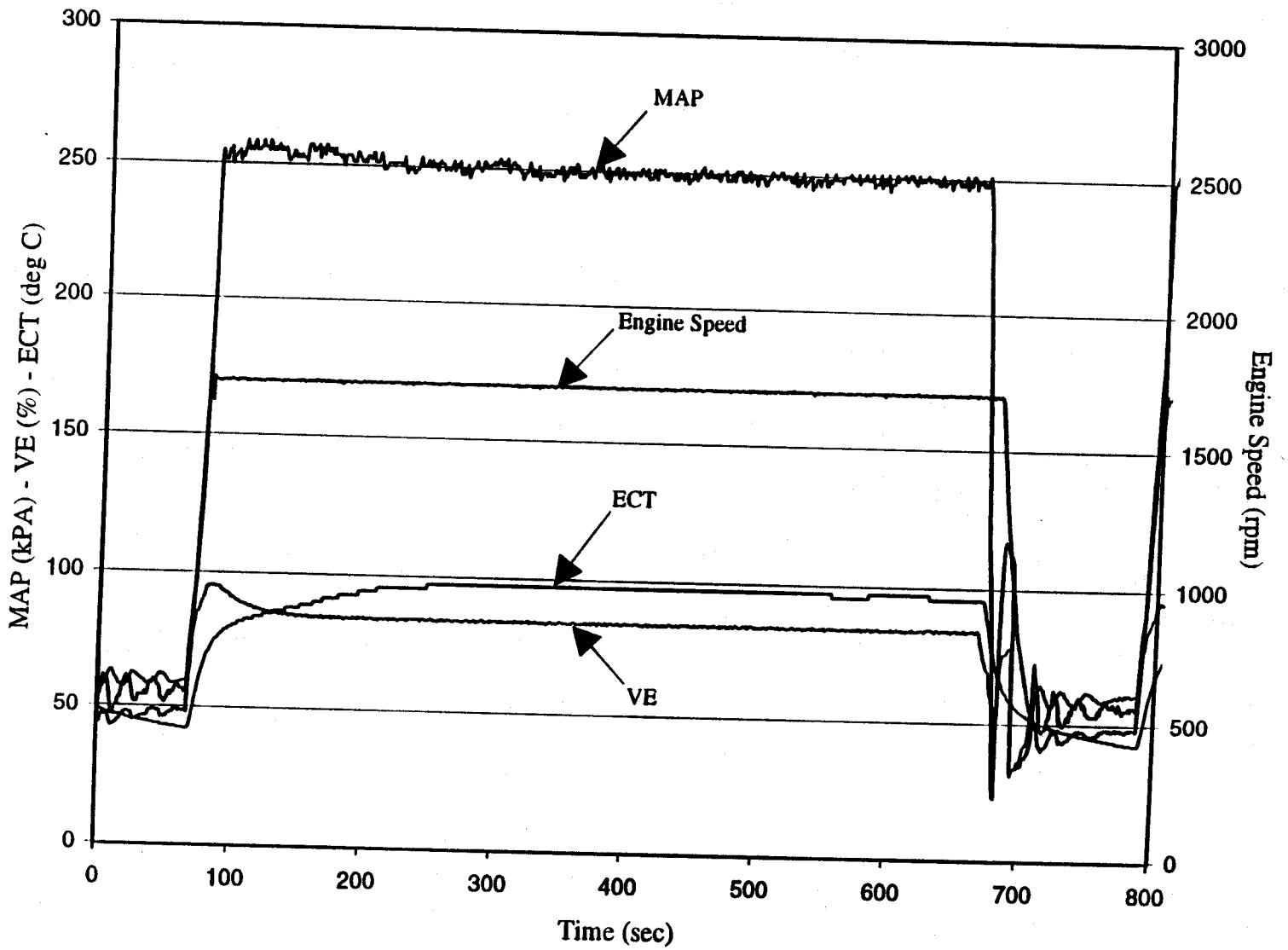
C:\Excel\Mack_data\375.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 400 TEST HOURS



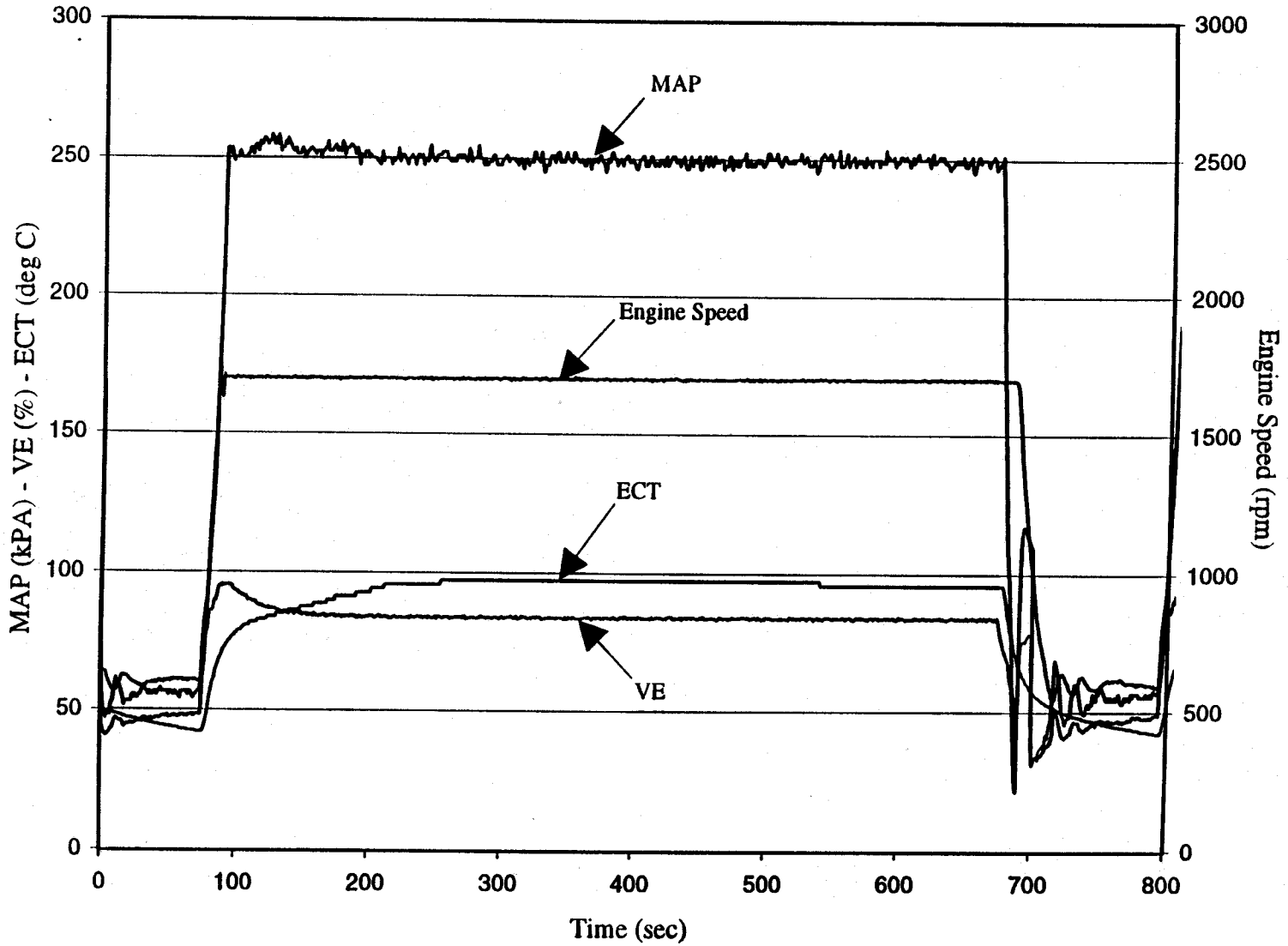
C:\Excel\Mack_data\400.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 425 TEST HOURS



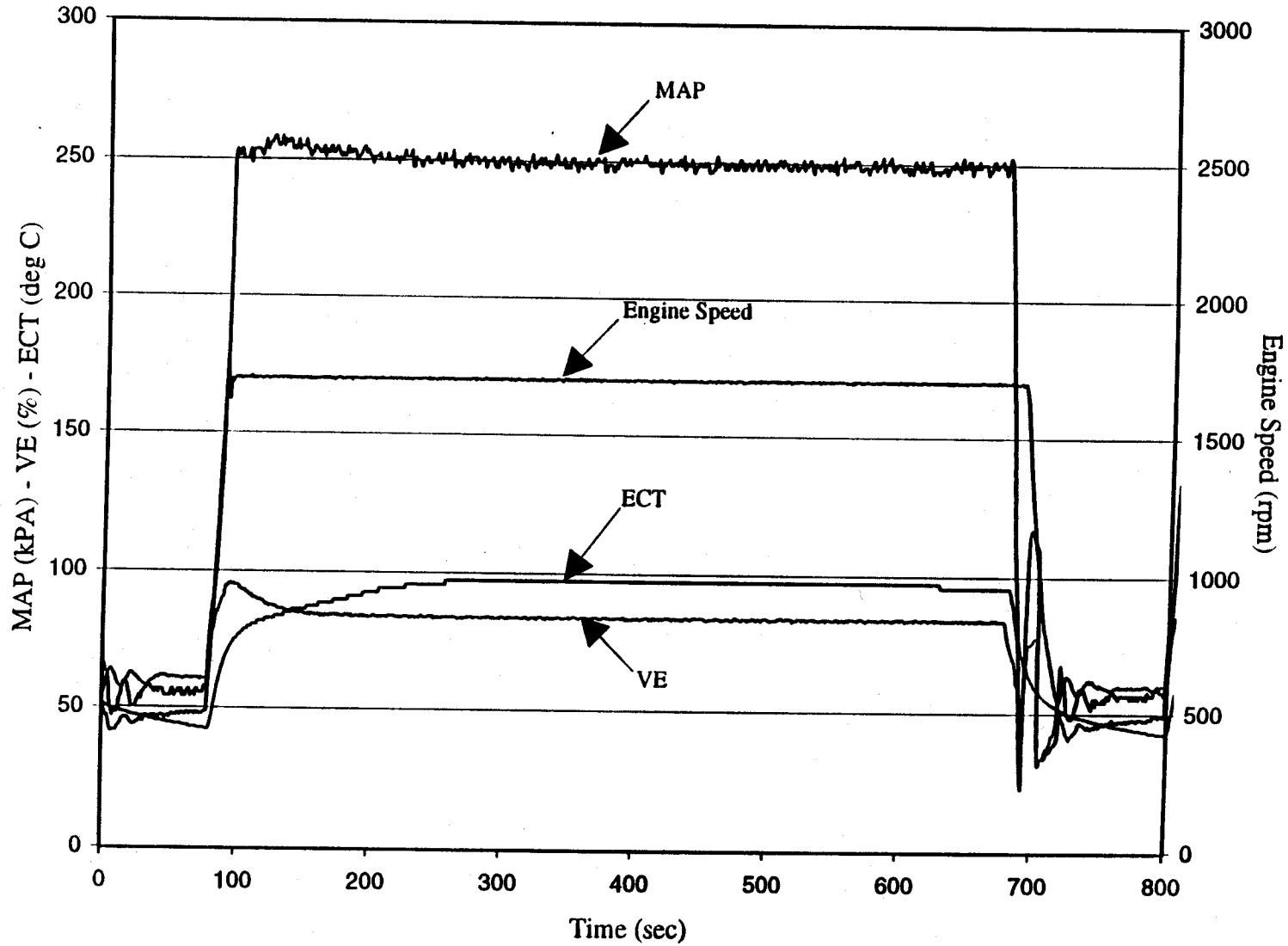
C:\Excel\Mack_data\425.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 450 TEST HOURS



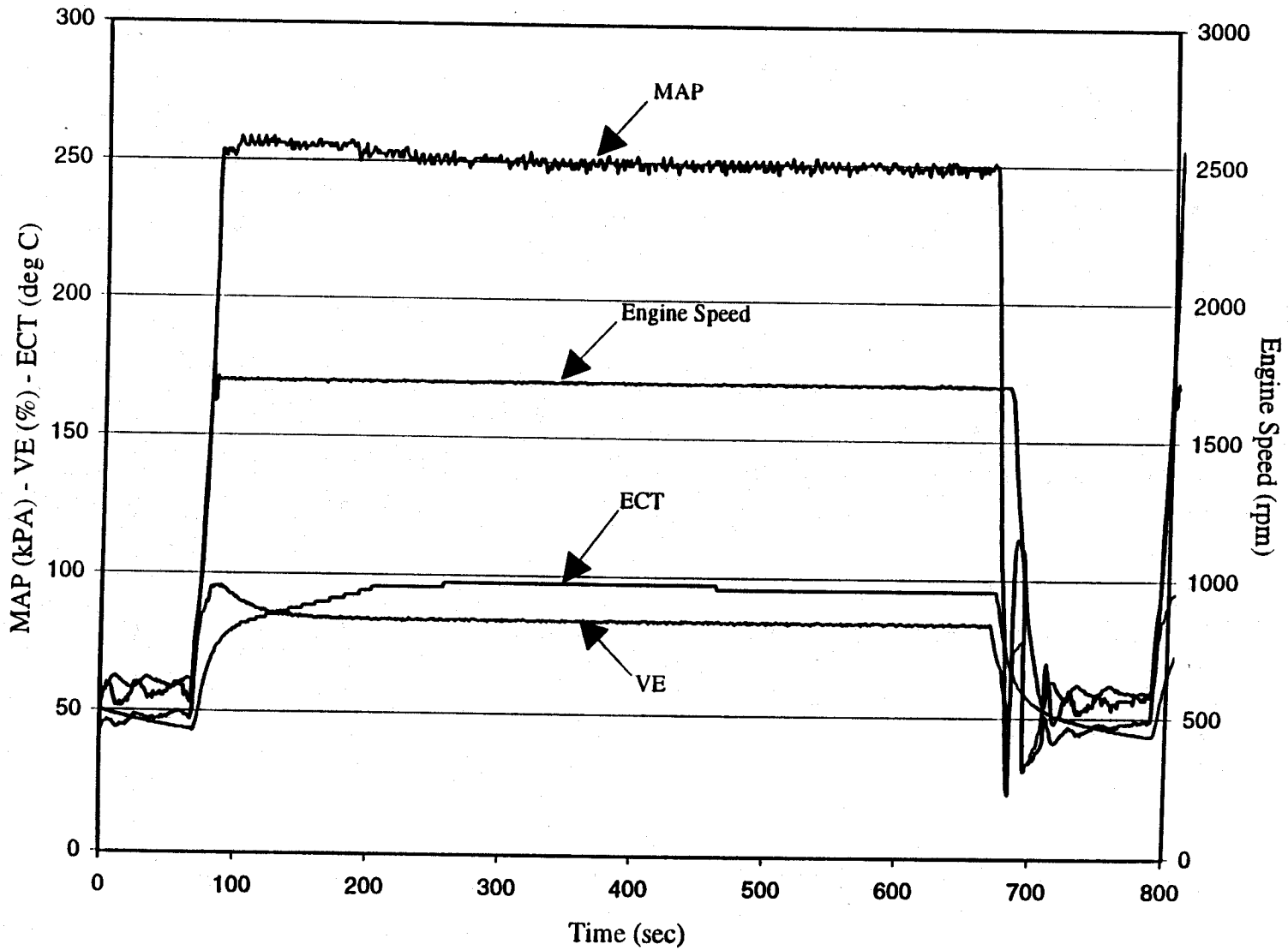
C:\Excel\Mack_data\450.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 475 TEST HOURS



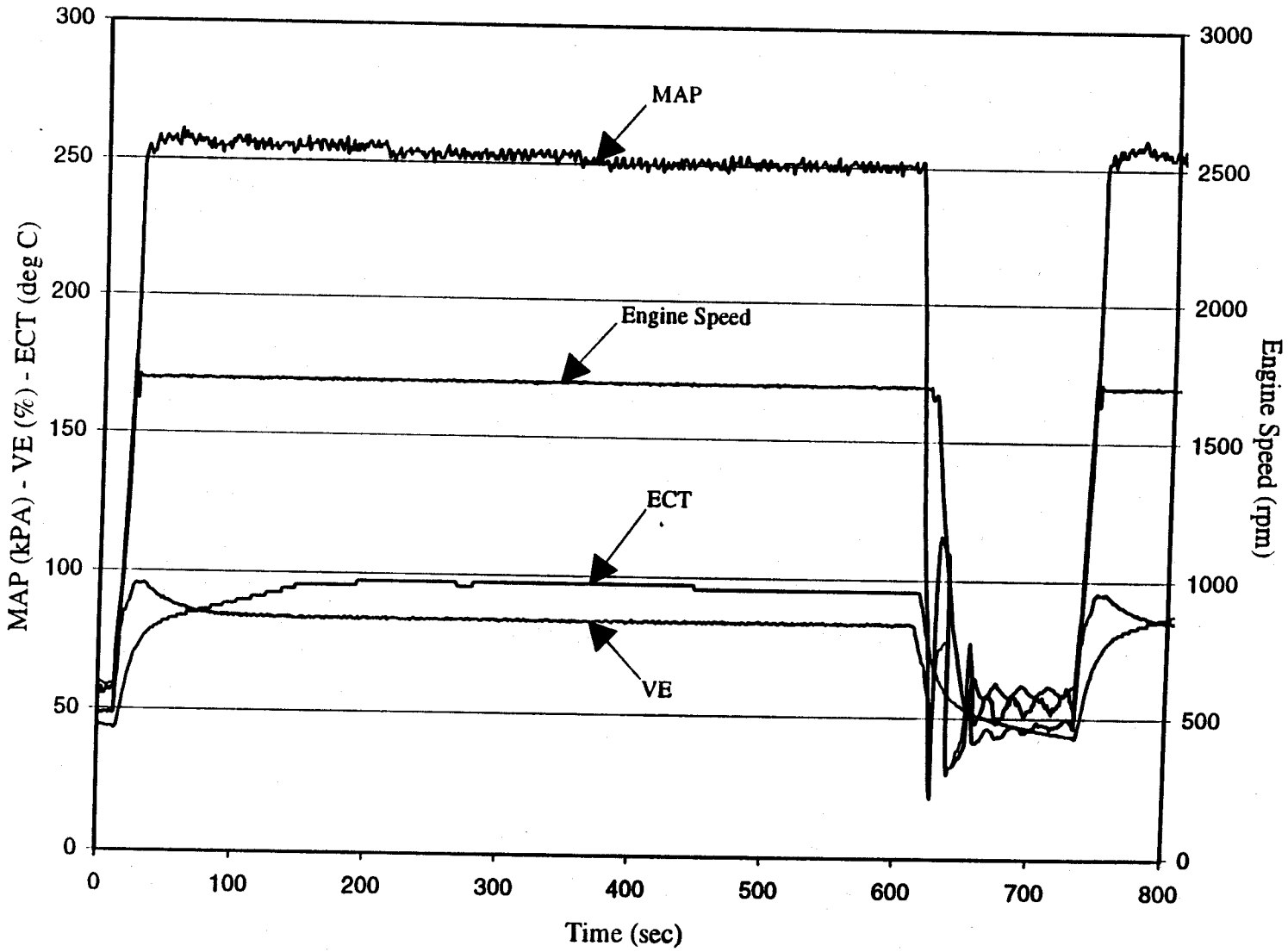
C:\Excel\Mack_data\475.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 500 TEST HOURS



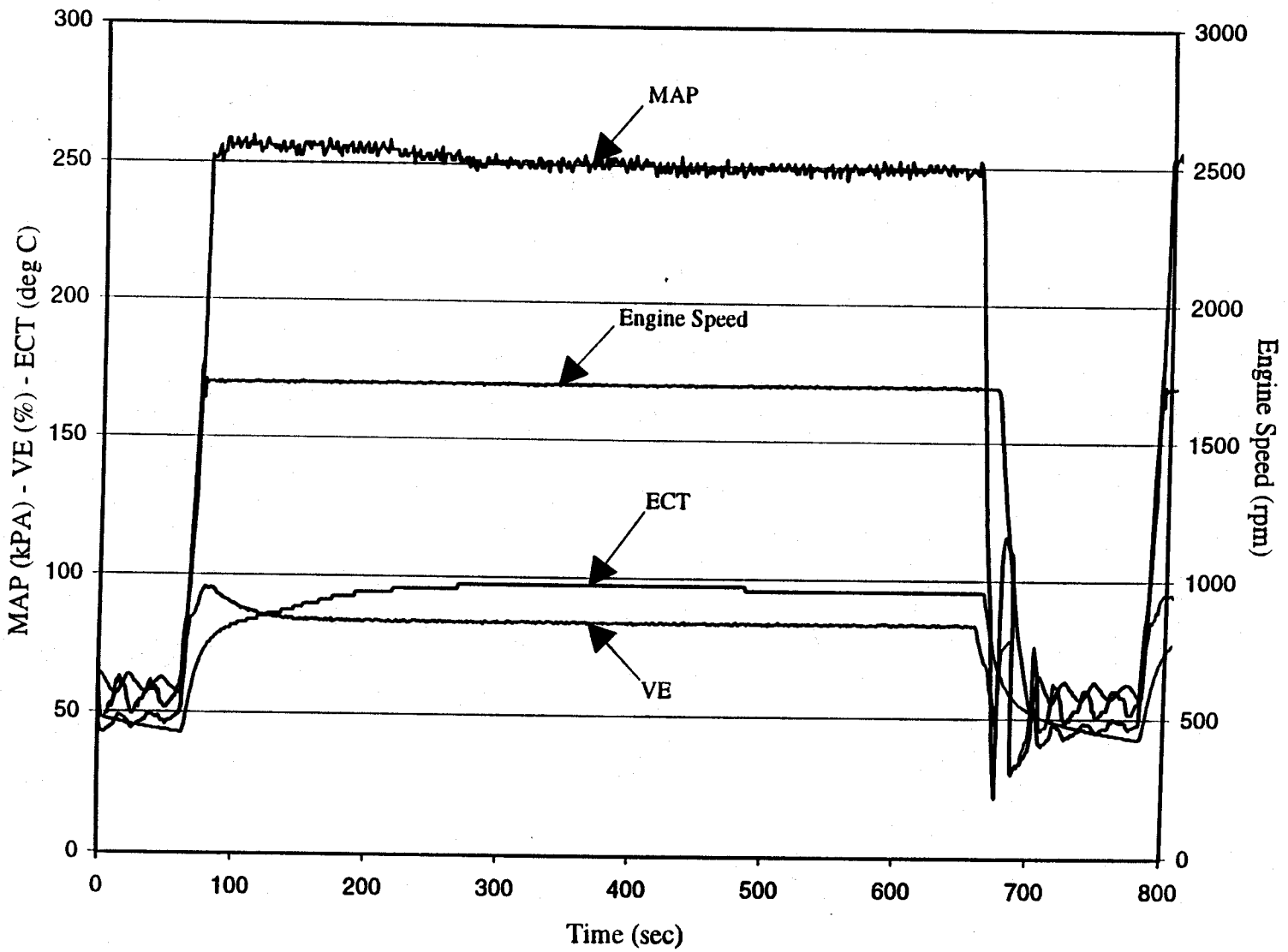
C:\Excel\Mack_data\500.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 525 TEST HOURS



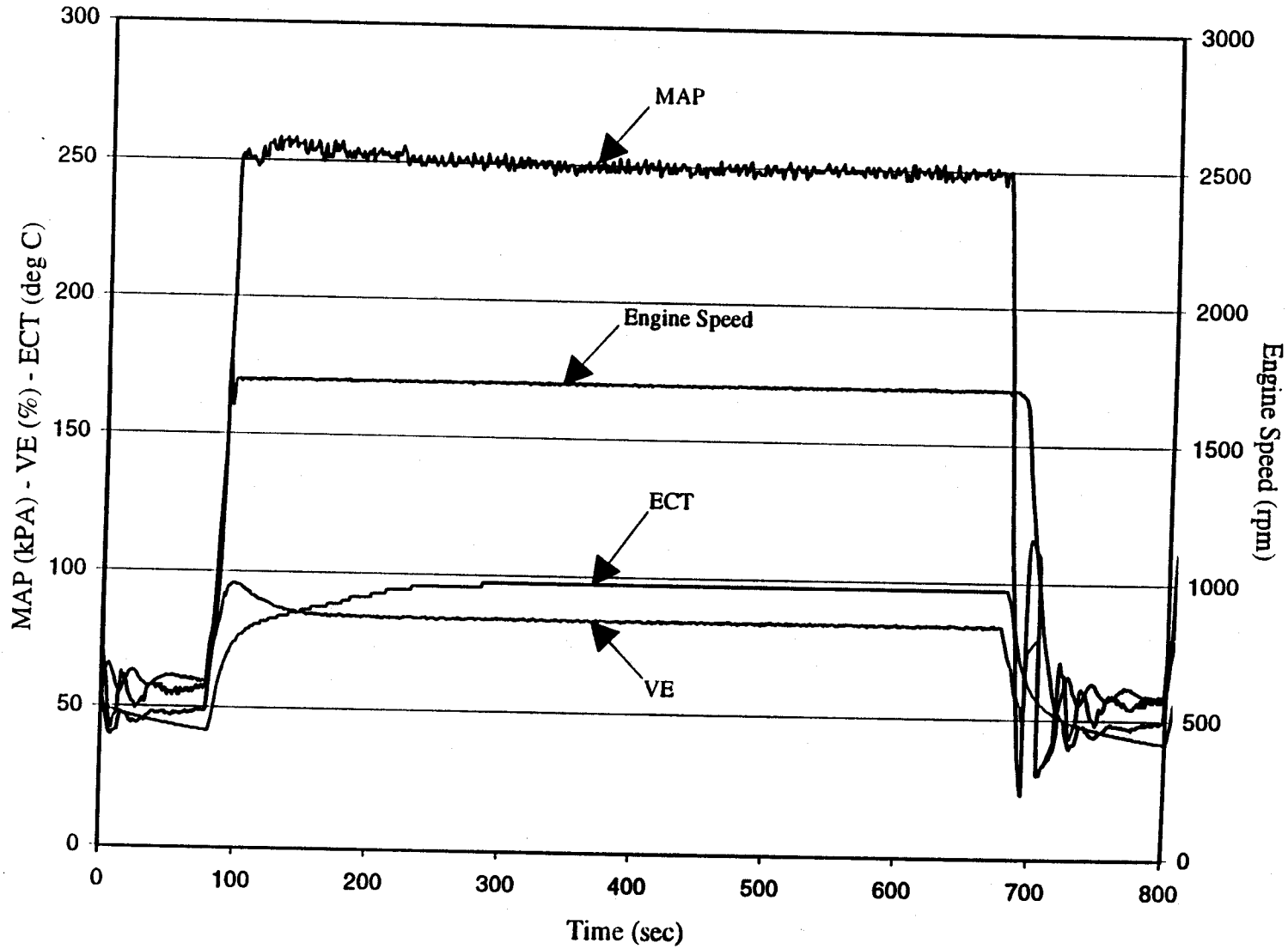
C:\Excel\Mack_data\525.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 550 TEST HOURS



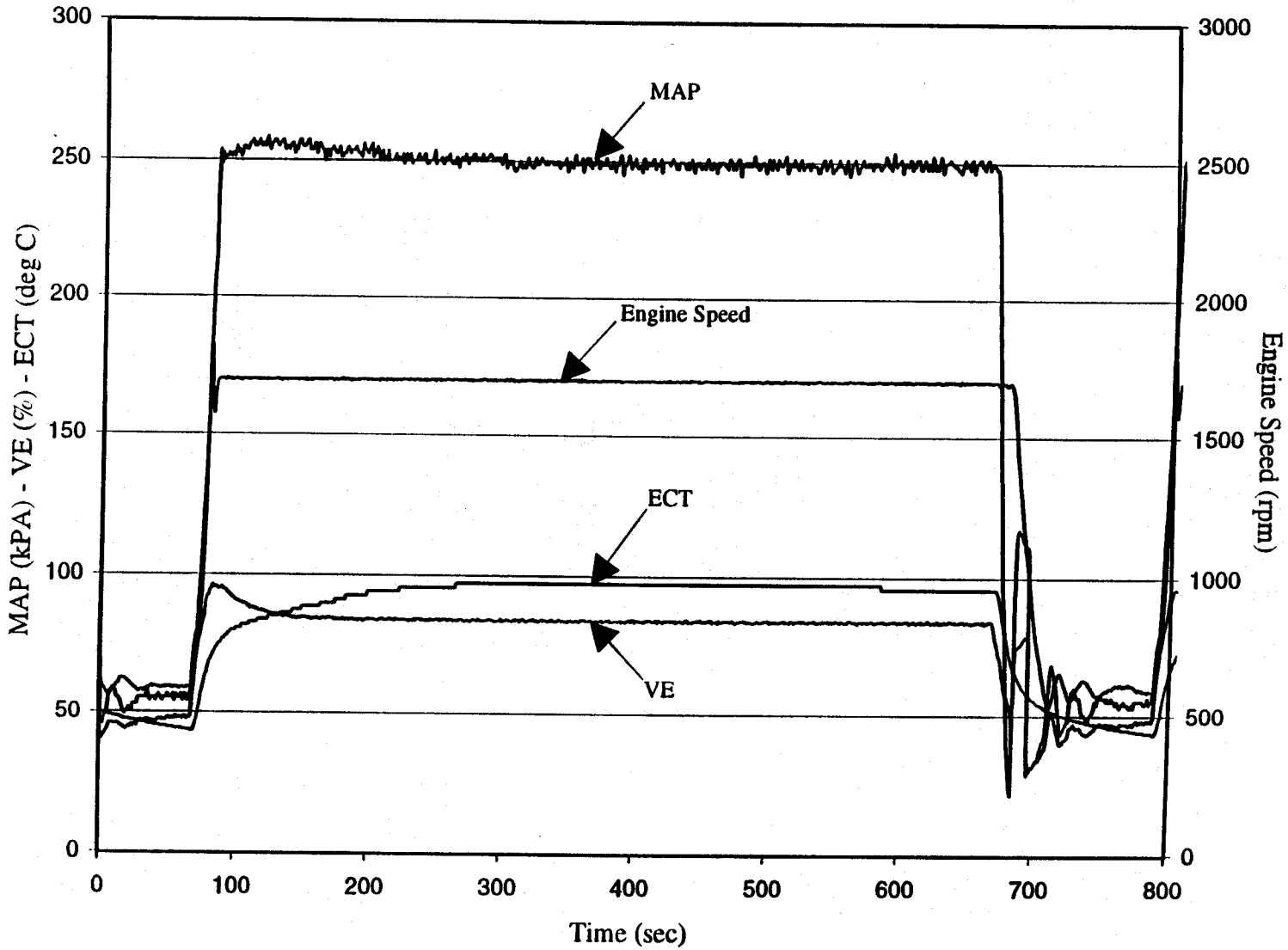
C:\Excel\Mack_data\550.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 575 TEST HOURS



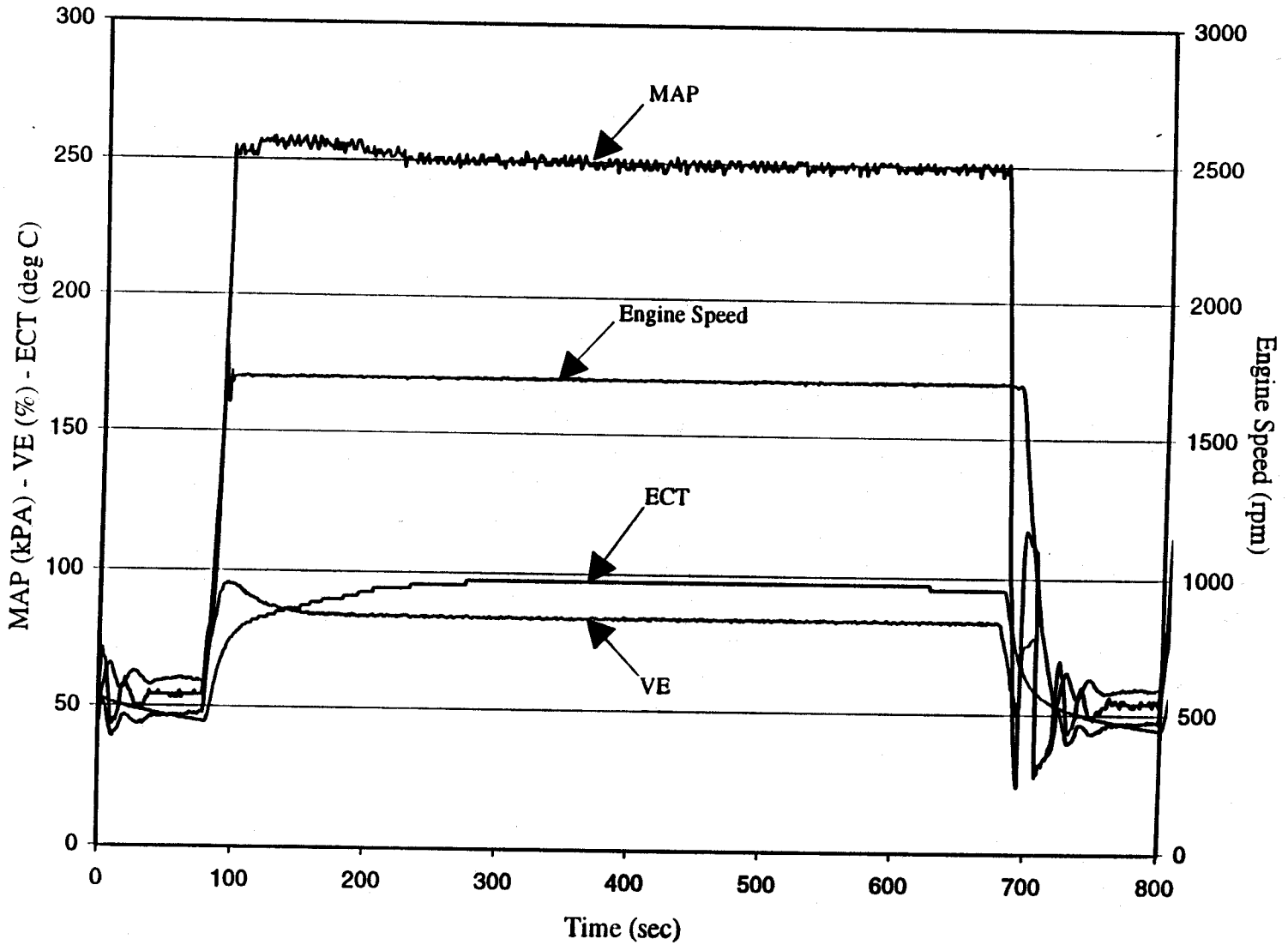
C:\Excel\Mack_data\575.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 600 TEST HOURS



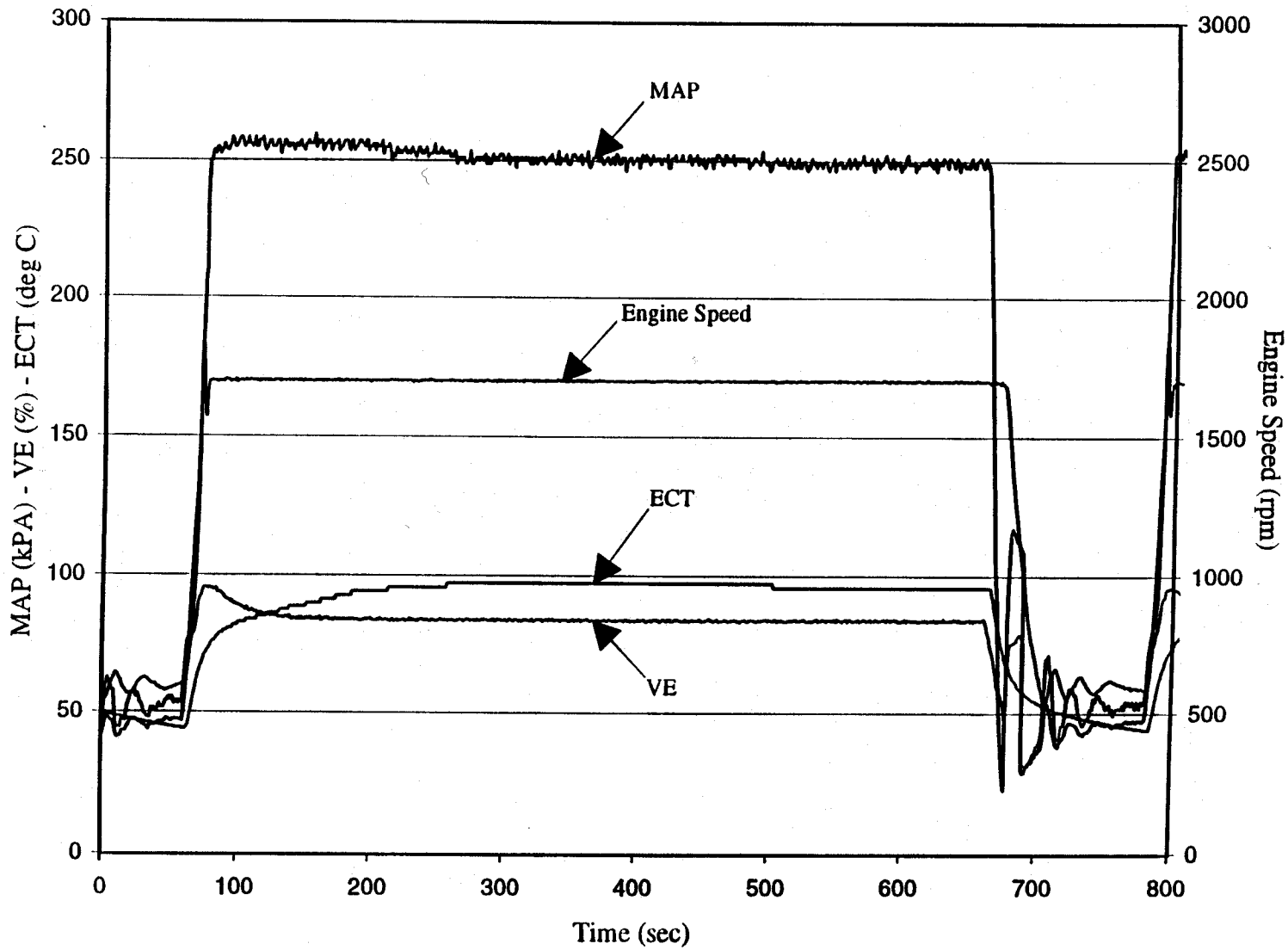
C:\Excel\Mack_data\600.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 625 TEST HOURS



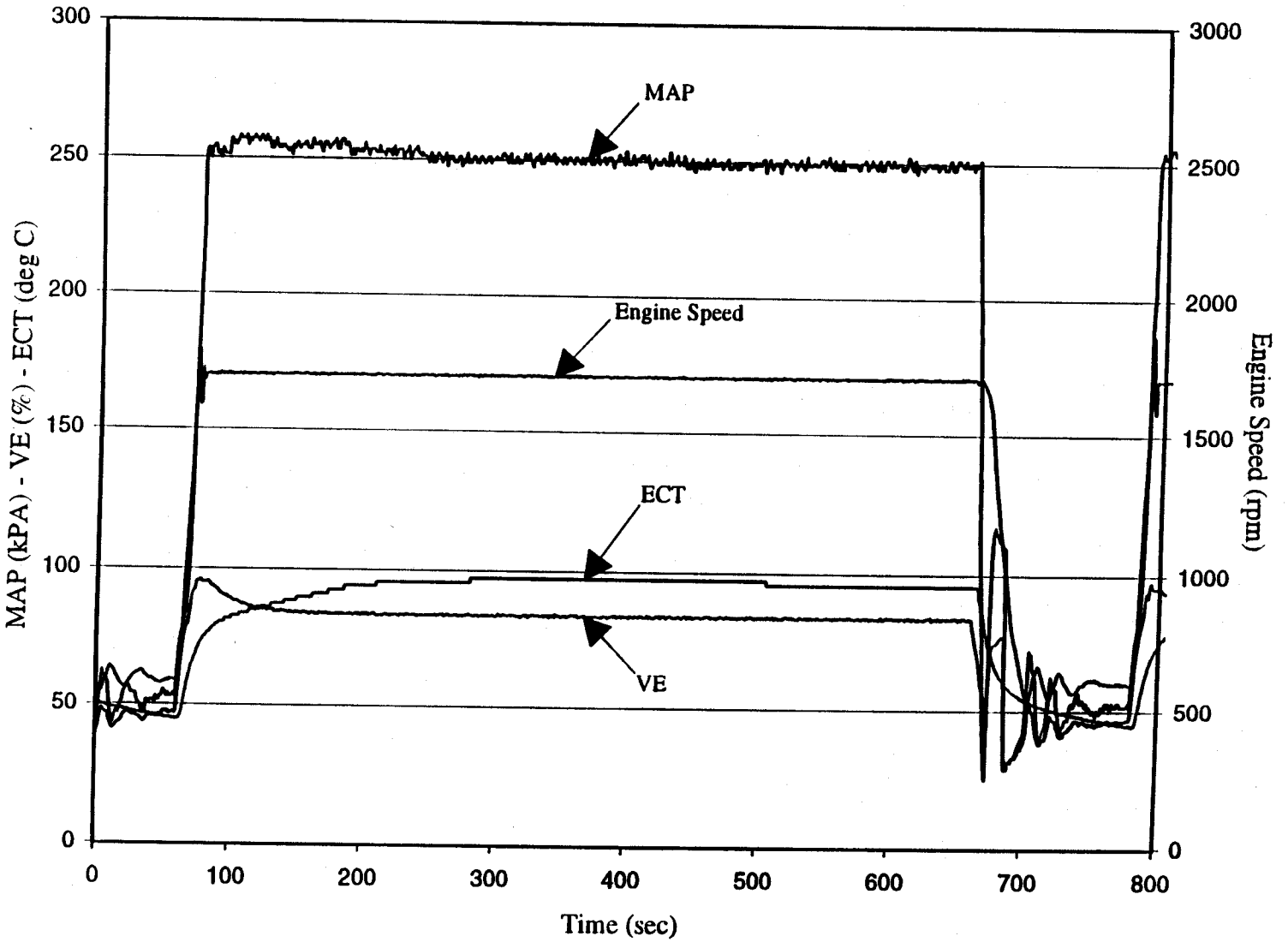
C:\Excel\Mack_data\625.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 650 TEST HOURS



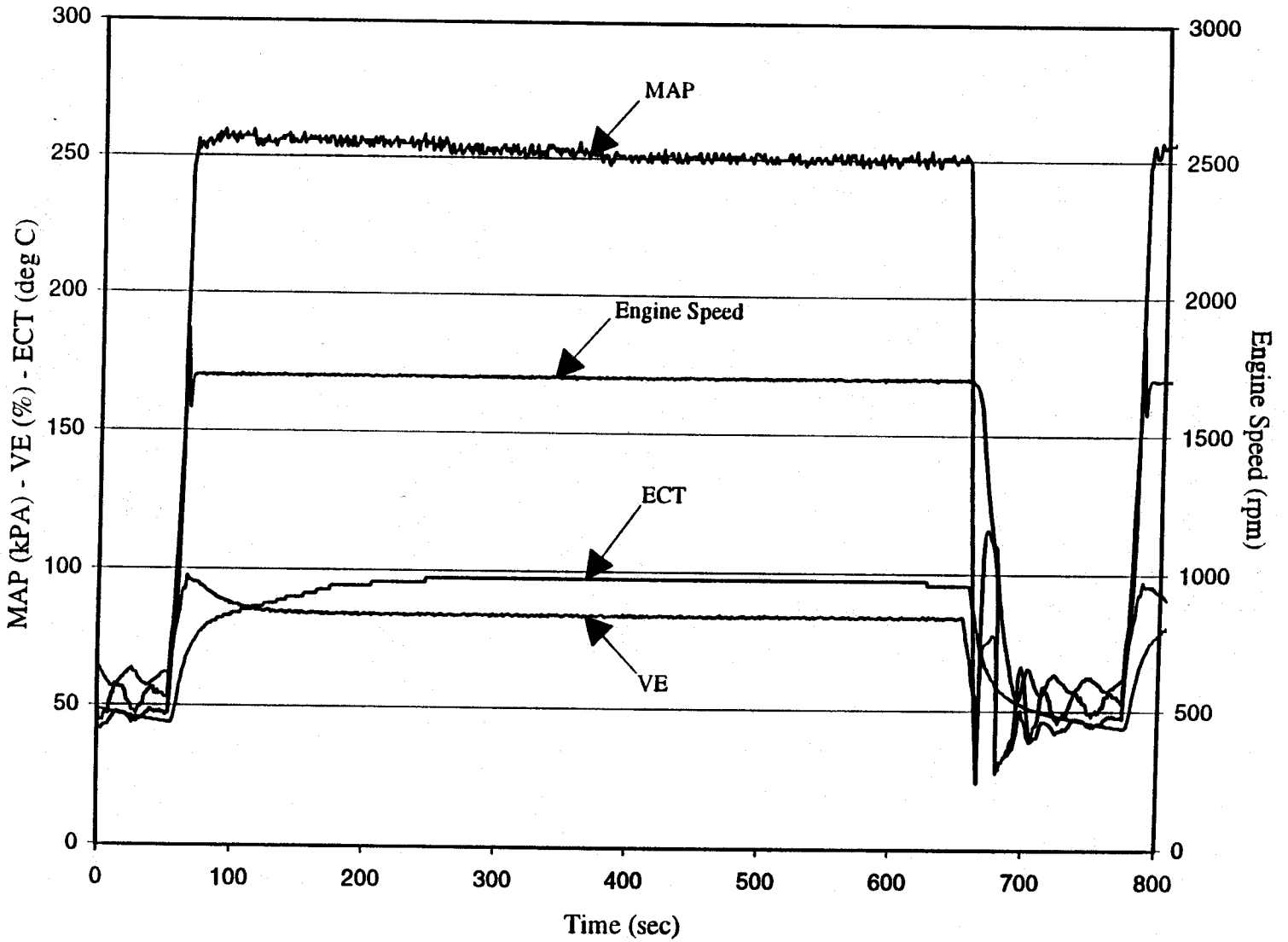
C:\Excel\Mack_data\650.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 675 TEST HOURS



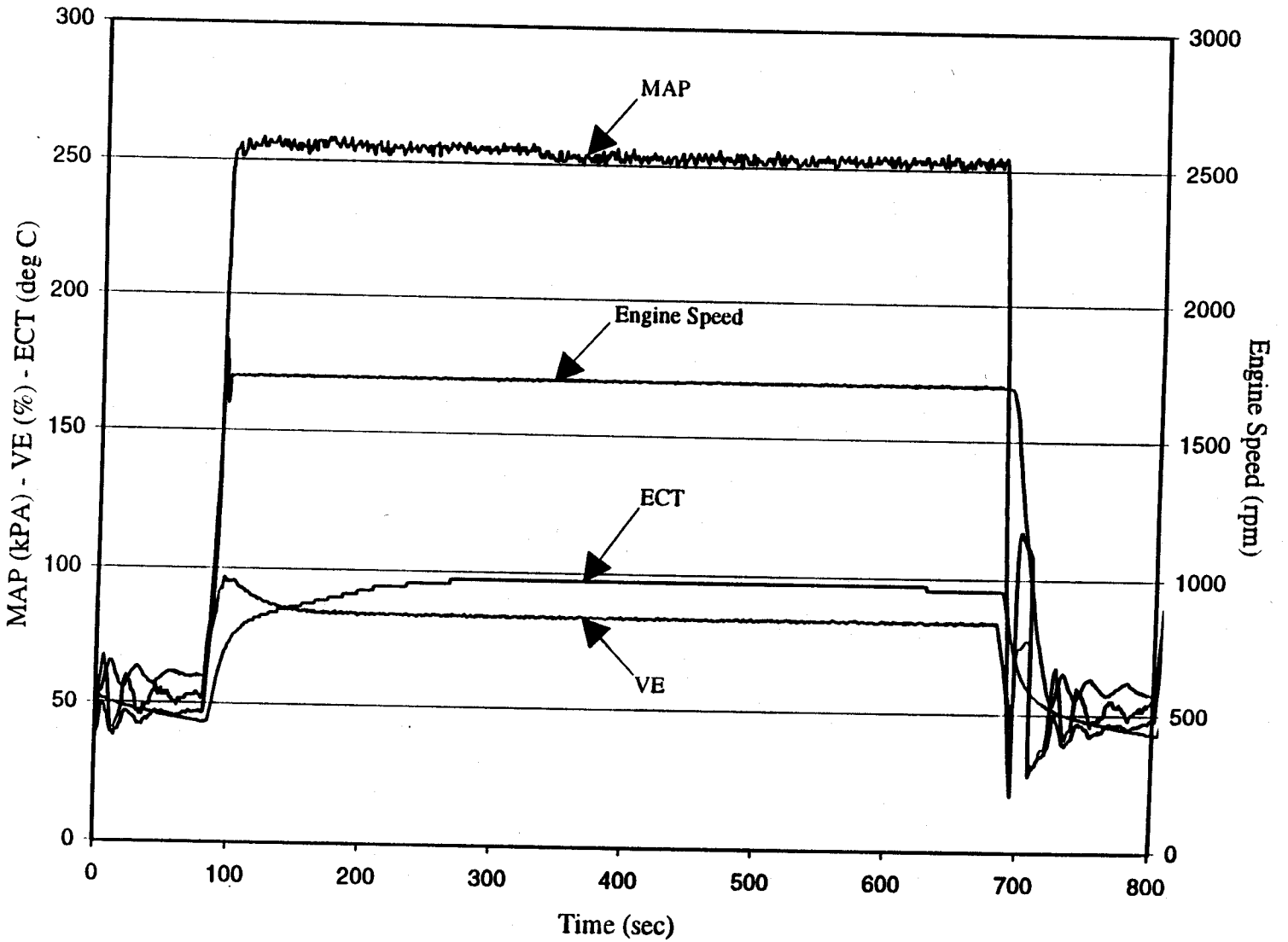
C:\Excel\Mack_data\675.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 700 TEST HOURS



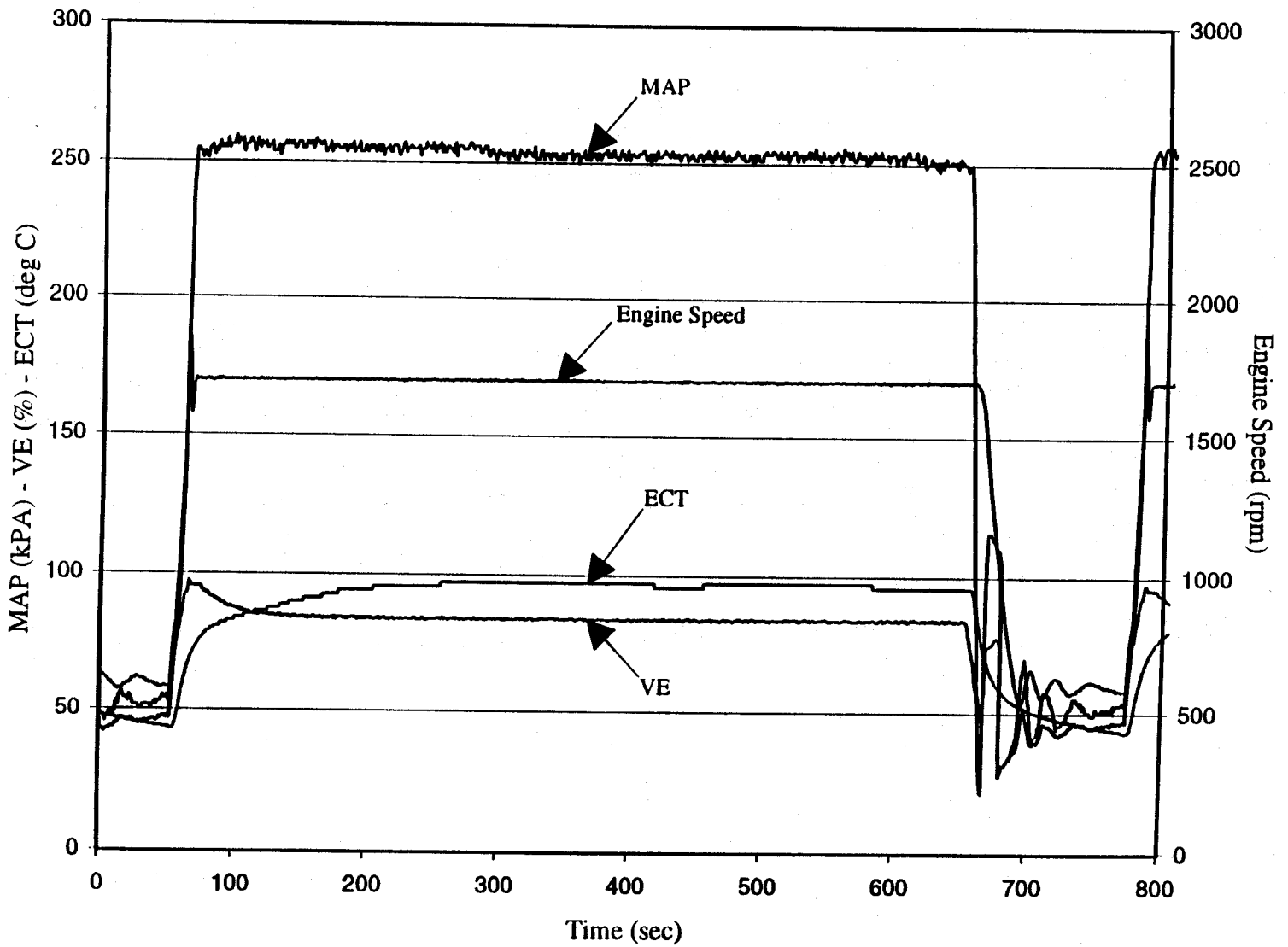
C:\Excel\Mack_data\700.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 725 TEST HOURS



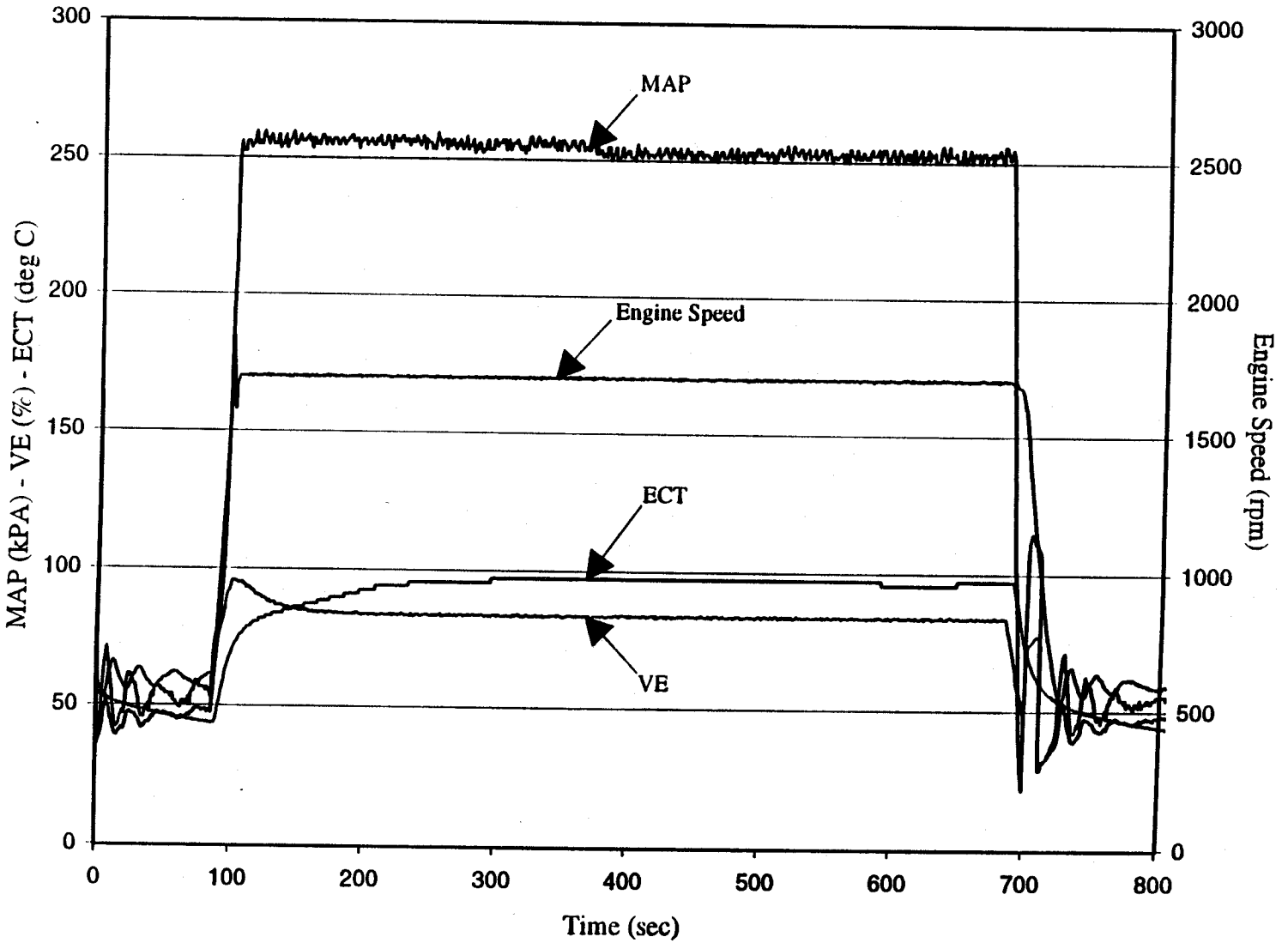
C:\Excel\Mack_data\725.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 750 TEST HOURS



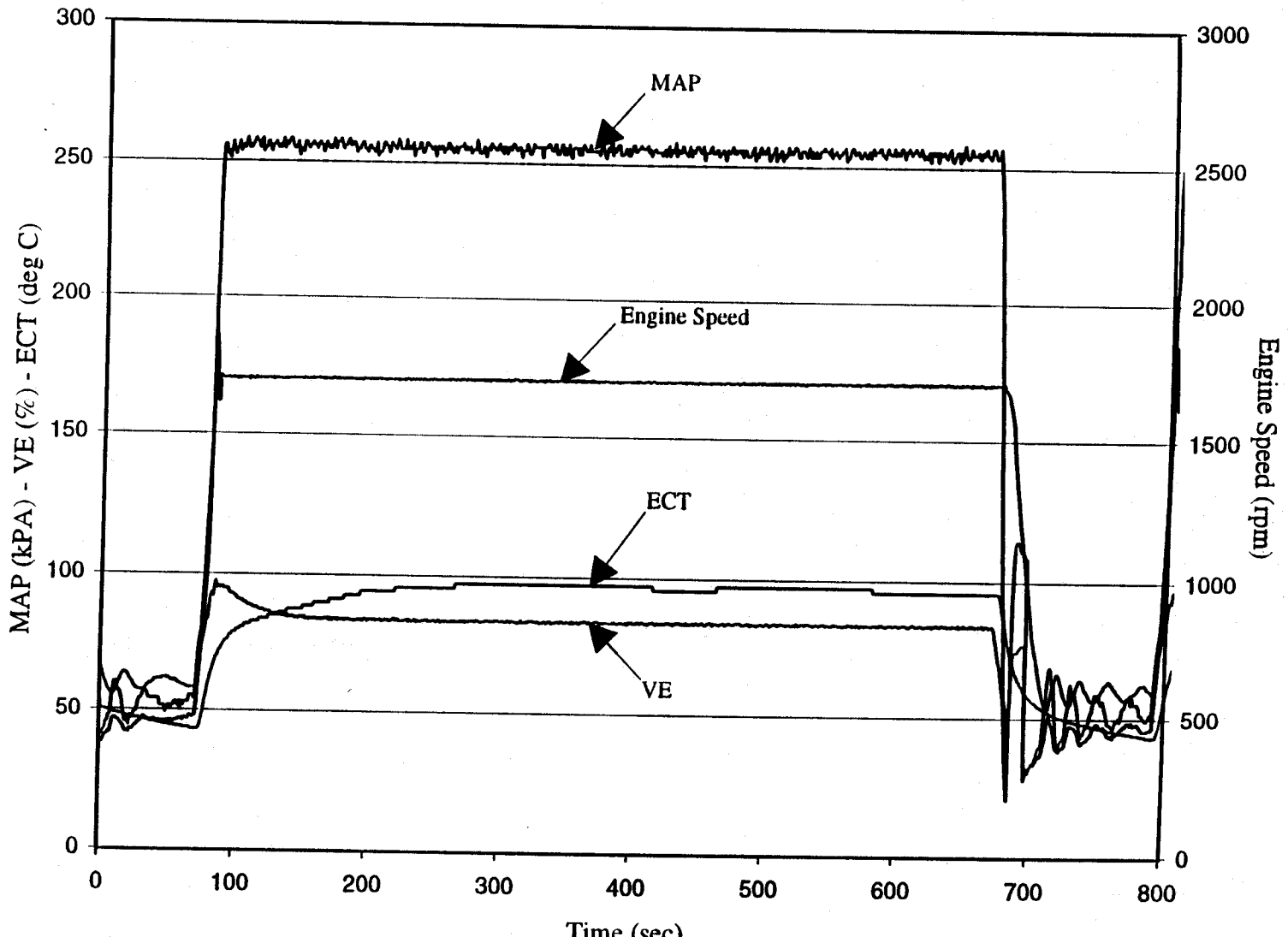
C:\Excel\Mack_data\750.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 775 TEST HOURS



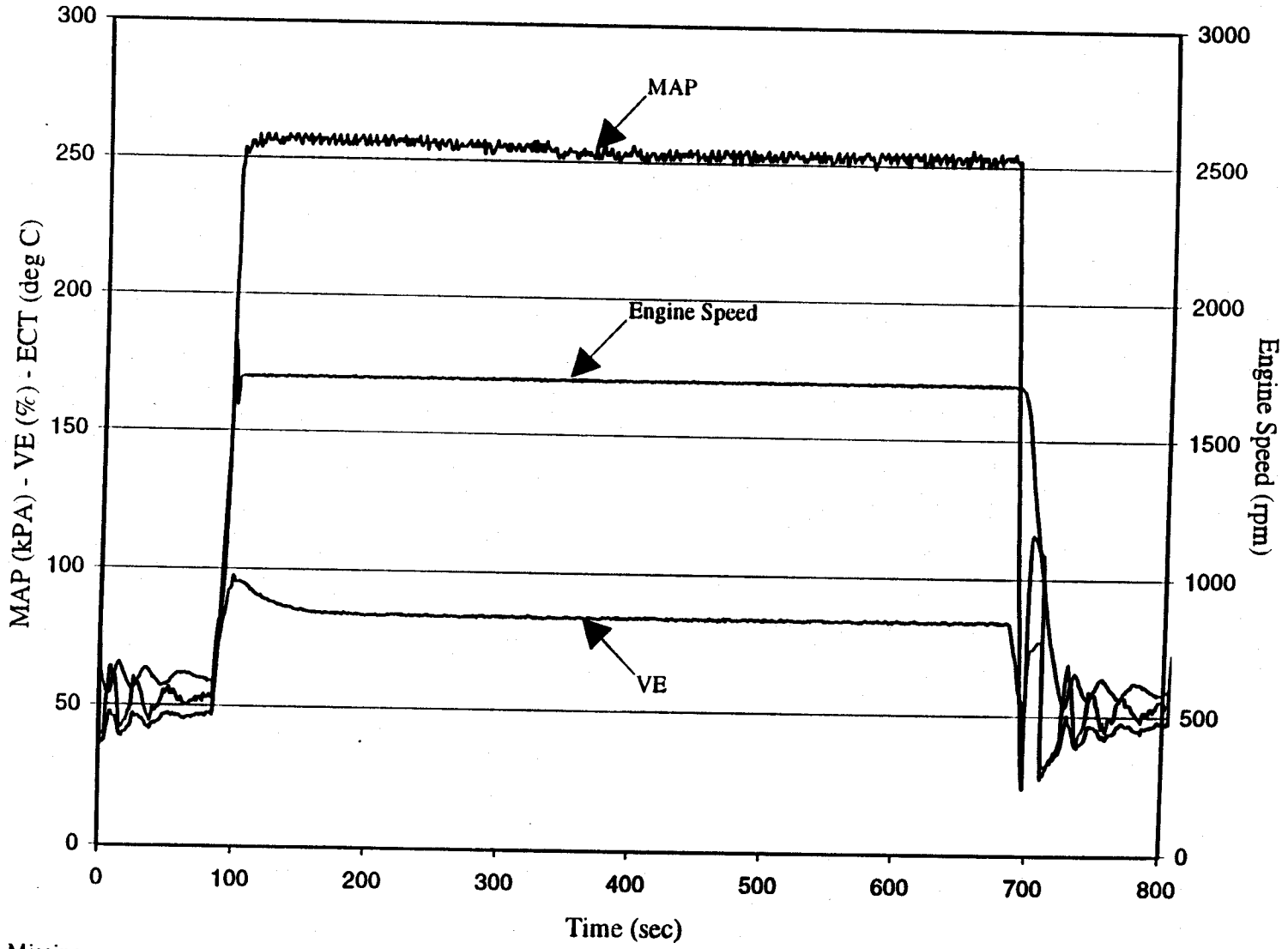
C:\Excel\Mack_data\775.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 800 TEST HOURS



C:\Excel\Mack_data\800.dat

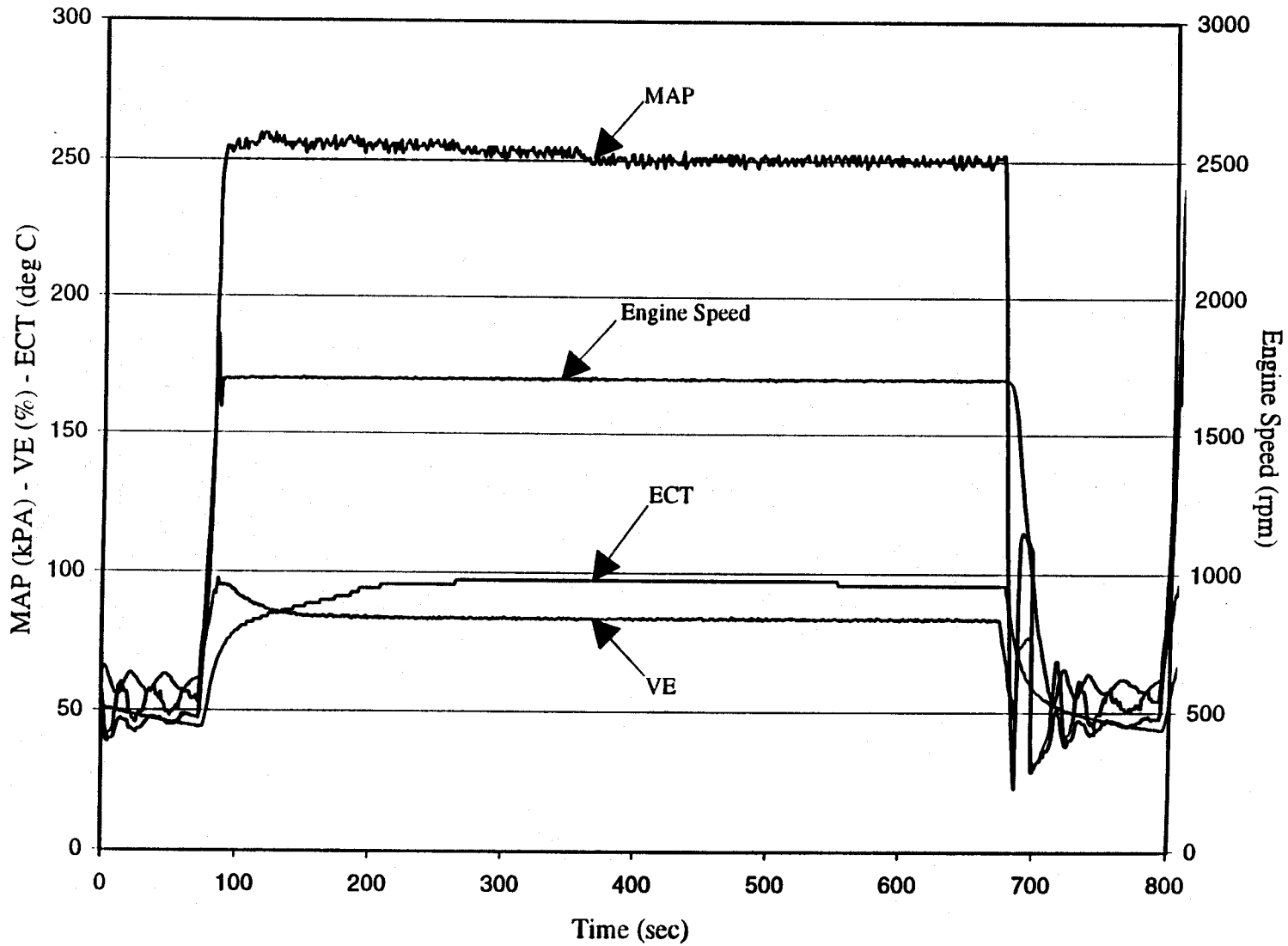
TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 825 TEST HOURS



NOTE: ECT Data Missing

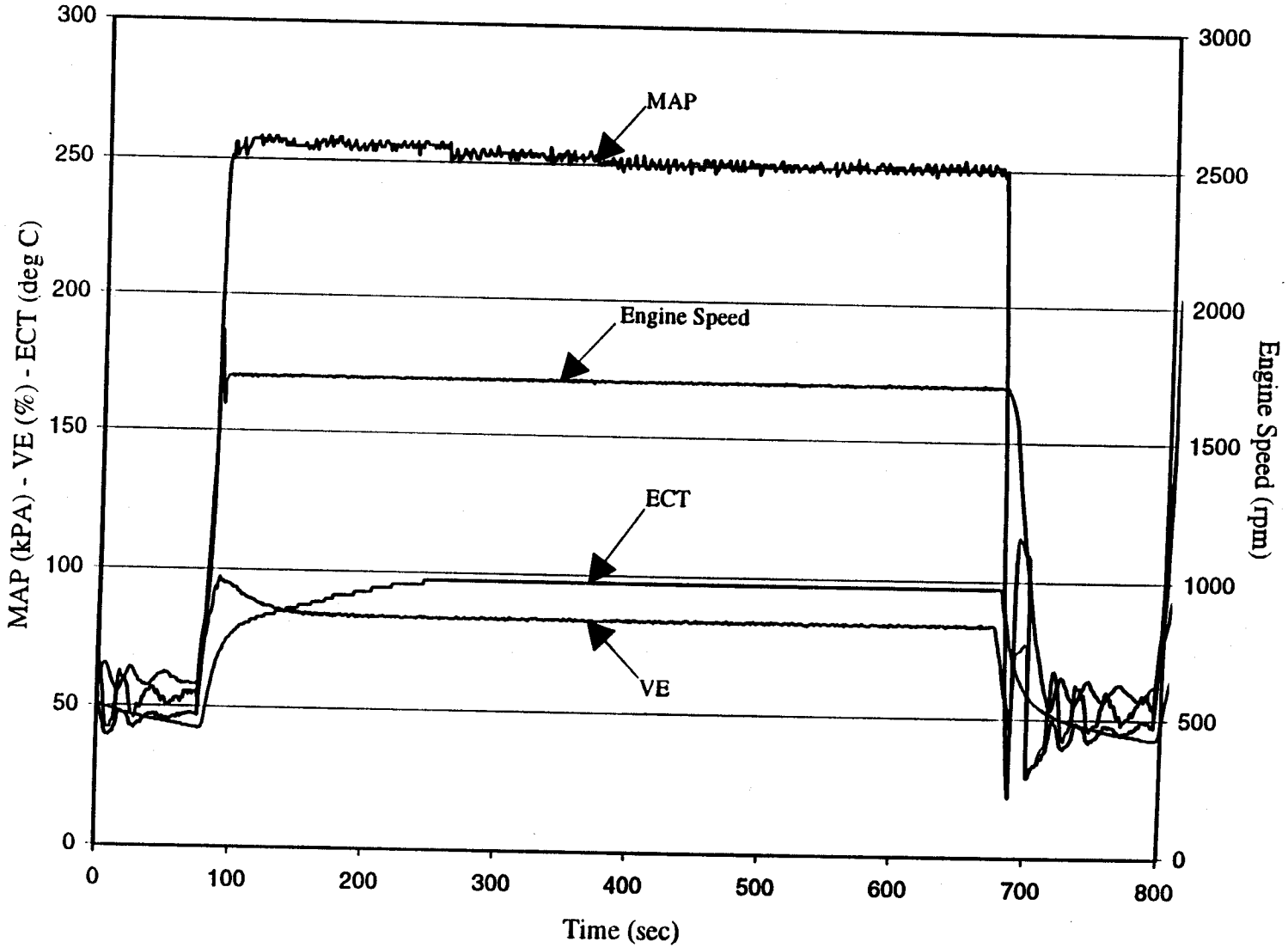
C:\Excel\Mack_data\825.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 850 TEST HOURS



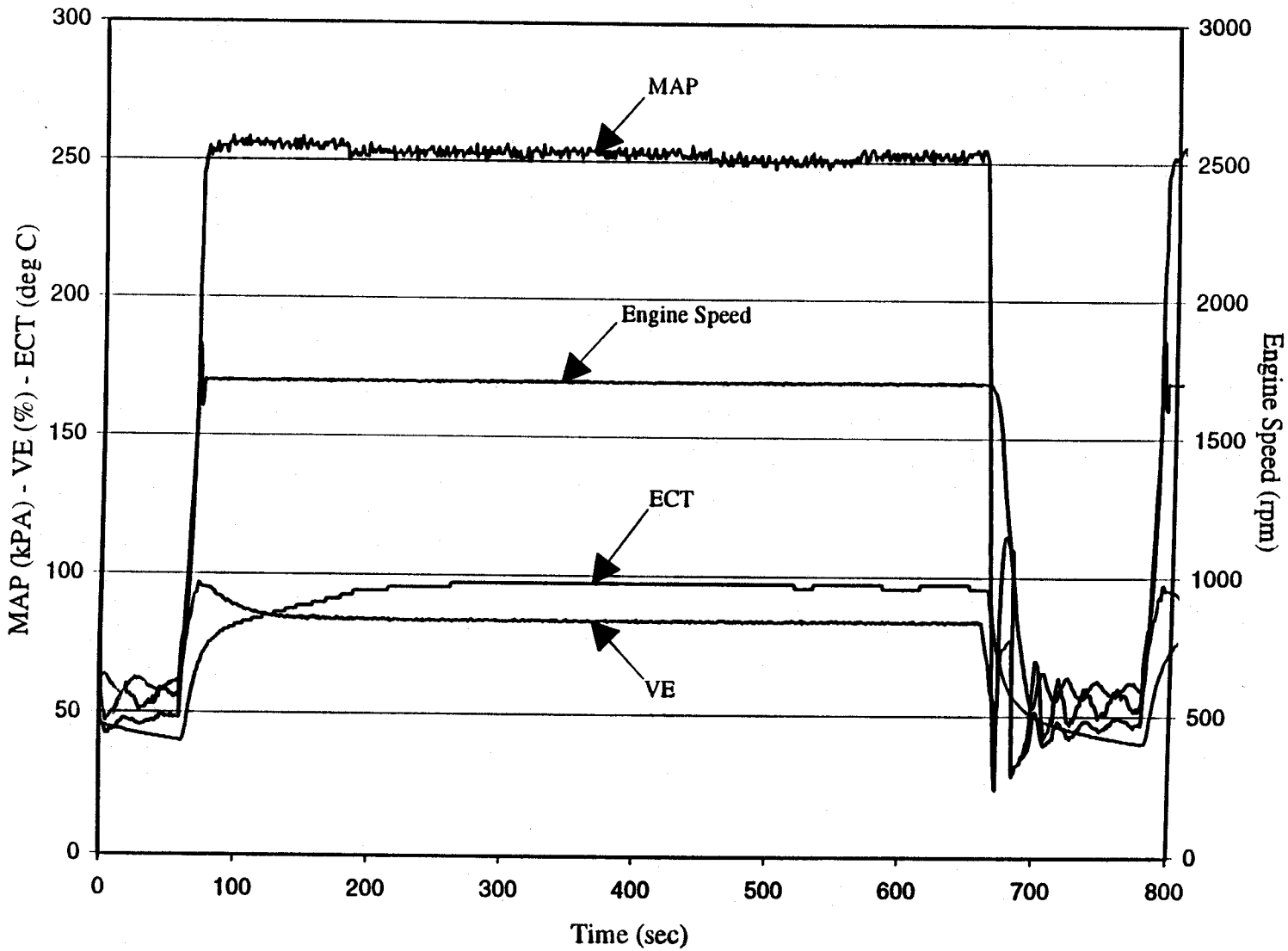
C:\Excel\Mack_data\850.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 875 TEST HOURS



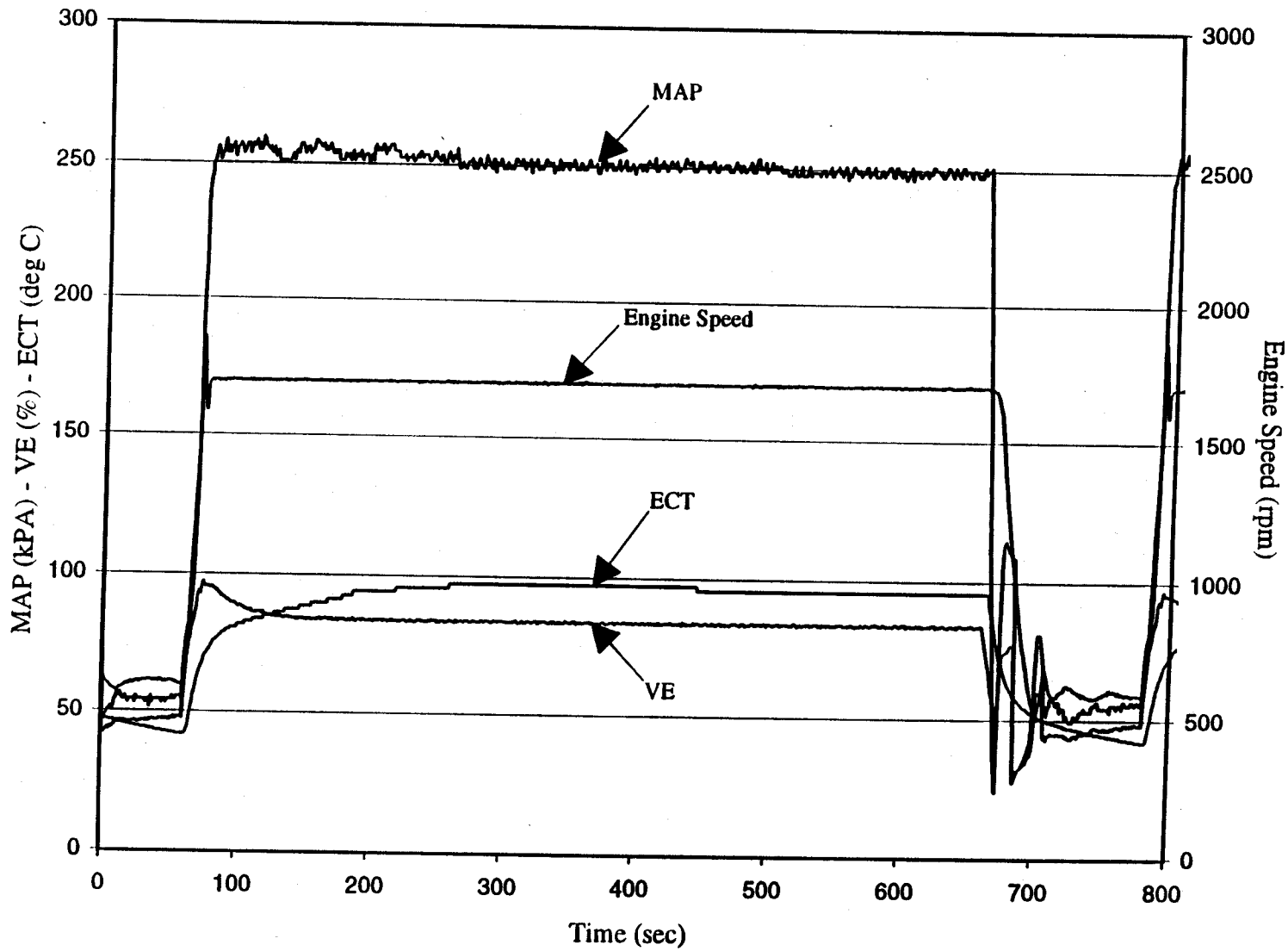
C:\Excel\Mack_data\875.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 900 TEST HOURS



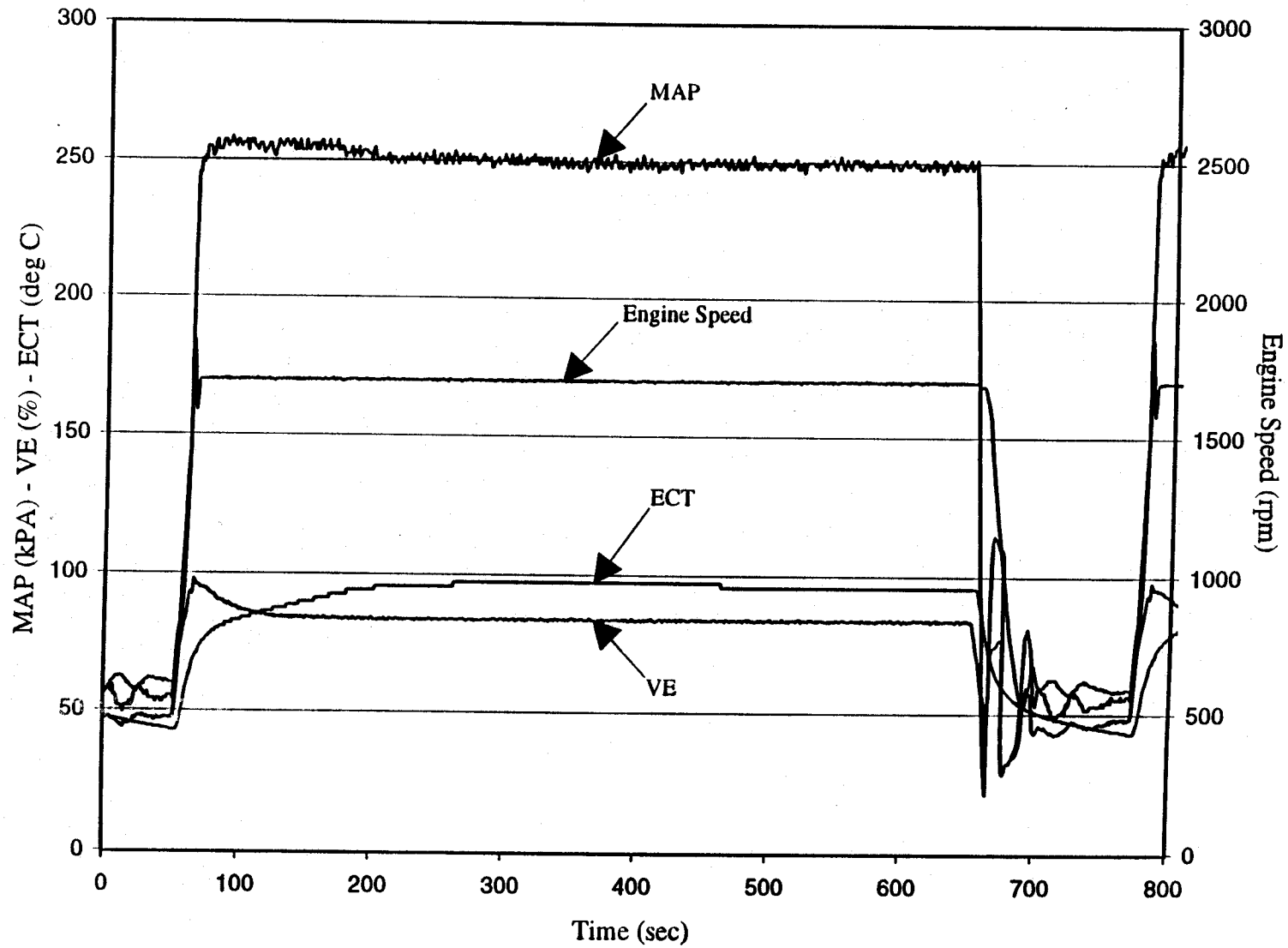
C:\Excel\Mack_data\900.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 928 TEST HOURS



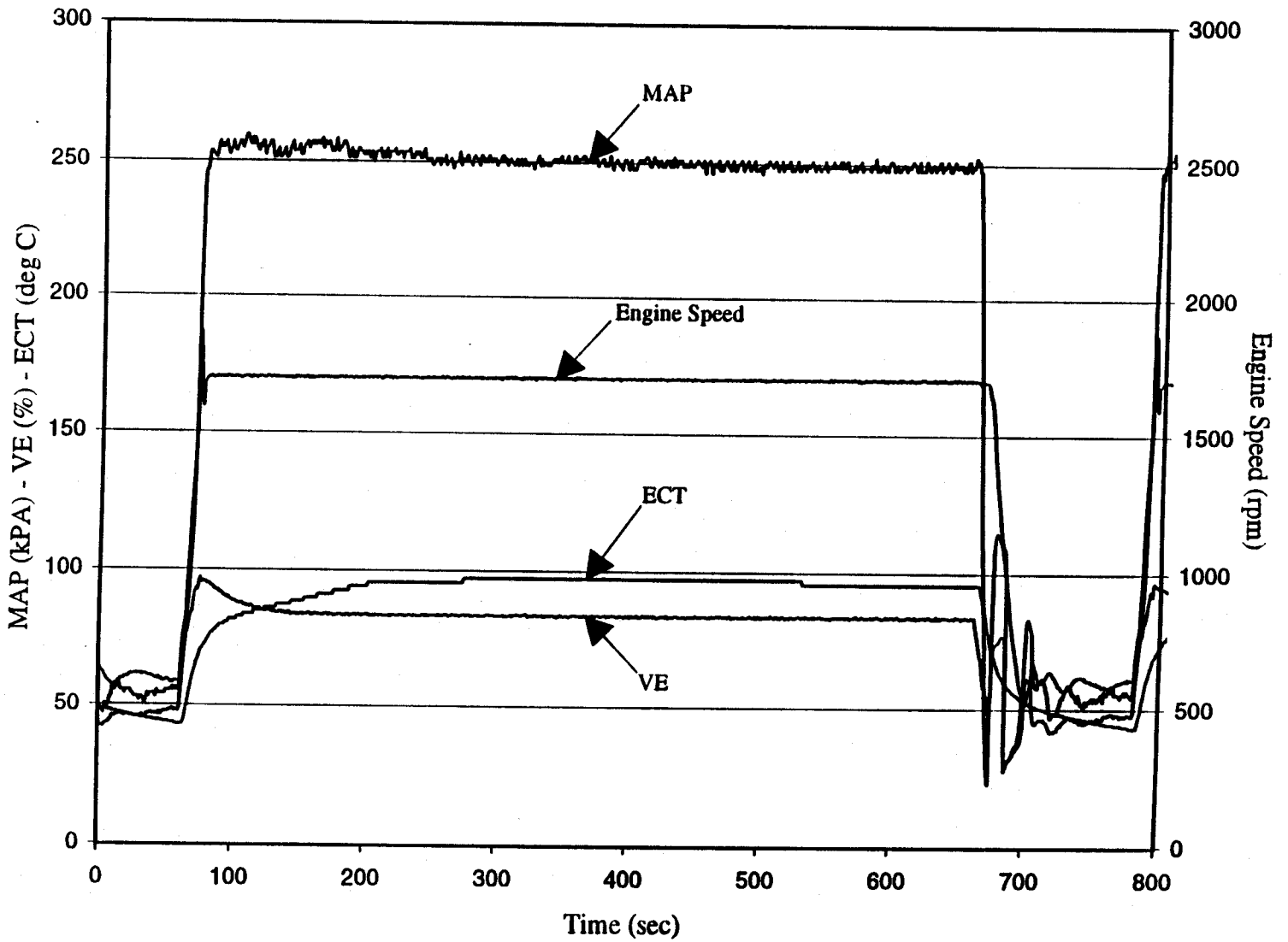
C:\Excel\Mack_data\928.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 950 TEST HOURS



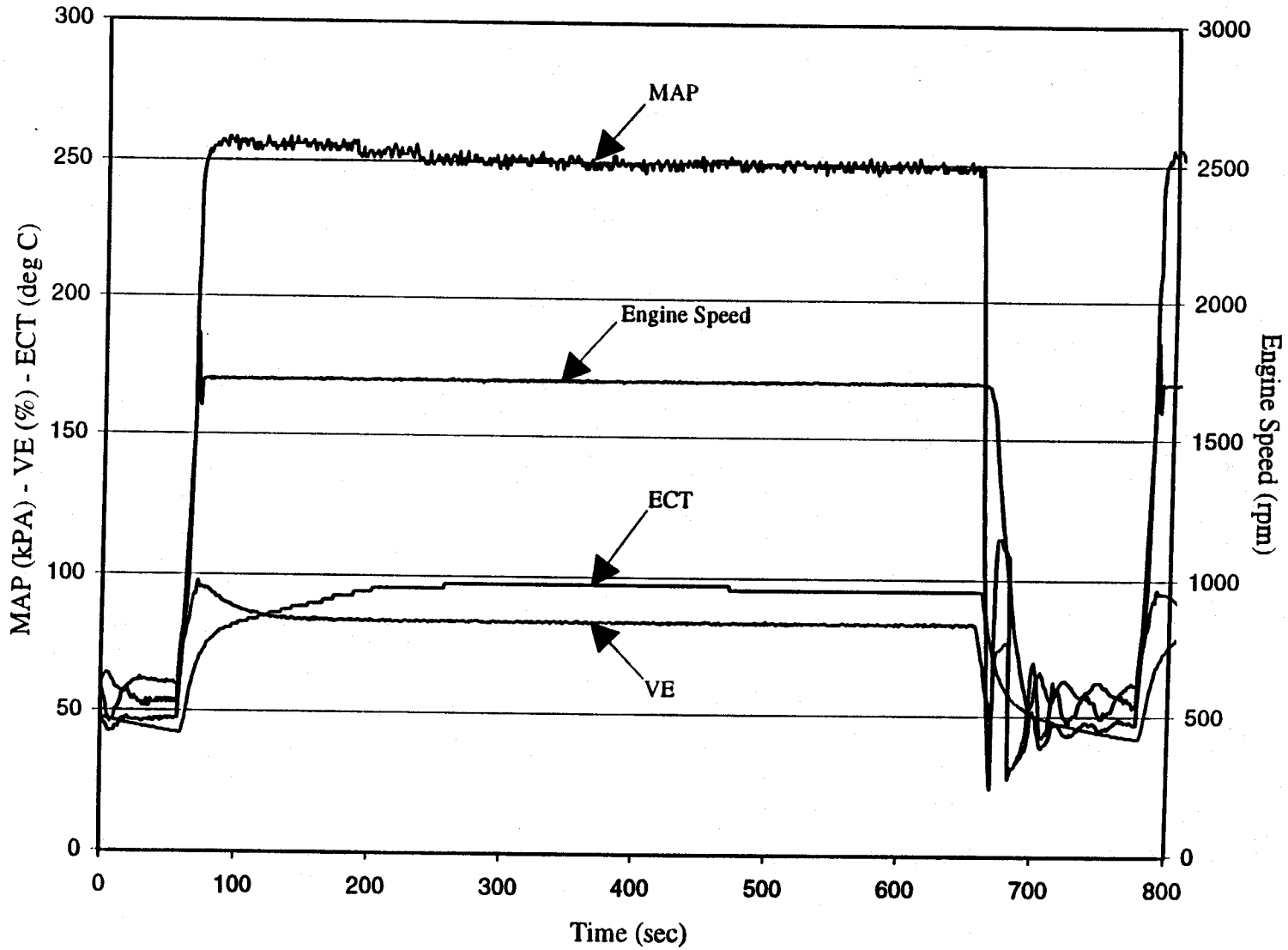
C:\Excel\Mack_data\950.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 975 TEST HOURS



C:\Excel\Mack_data\975.dat

TRANSIENT DATA RECORDED FROM GEM SYSTEM FOR ONE FULL CYCLE AT 1000 TEST HOURS



C:\Excel\Mack_data\1000.dat

APPENDIX C

SAMPLE HOURLY HP DAQ DATA

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	450	451	1507	1508	2567
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	JULY, 22	JULY, 22	AUG., 03	AUG., 03	AUG., 15
Time (Seconds)	10:57:33	11:07:32	20:48:10	20:58:09	18:14:36
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	1.0	1.0	250.0	250.0	500.0
Test Type Code	3	1	3	1	3

***** Engine Performance Data *****

Engine Speed (rpm)	598	1704	621	1702	591
Torque (ft/lbs)	16.6	1152.9	26.1	1180.9	35.0
BHP	1.9	374.0	3.1	382.6	3.9
BSFC (lbs/BHp-hr)	3.312	.315	2.024	.317	1.460
BTE (%)	3.8	40.0	6.3	40.0	8.5
BMEP (psi)	3.4	238.8	5.4	244.6	7.2
Density	.308	.326	.312	.327	.312
Density (New)	.311	.330	.315	.331	.316
NG Flow (lbs/hr)	6.28	117.97	6.25	121.32	5.75
NG Flow [MM] (lbs/hr)	6.28	117.97	6.25	121.32	5.75
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	.126	2.378	.125	2.433	.118
Air Flow (lbs/hr)	141.95	2979.7	3.03	3.98	9.06
Volumetric Eff (%)	51.4	87.0	4.5	5.5	6.2
Equivalence Ratio	.716	.642	33.299	490.97	10.441
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	.16	5.49	.23	5.02	.33

***** Engine Temperature Data *****

Water In (Deg F)	99	201	101	200	101
Water Out (Deg F)	106	209	108	209	108
Oil Sump (Deg F)	223	245	223	249	222
Oil Gallery (DEG F)	184	229	185	231	183
Ambient/LFE (Deg F)	88	88	96	96	89
Boost B4 IC (Deg F)	177	332	178	350	165
Boost AF IC (Deg F)	92	111	91	104	92
Intake (Deg F)	125	108	127	109	123
Gas @ Meter (Deg F)	103	106	107	111	104
Exhaust 1 (Deg F)	679	1046	652	1062	649
Exhaust 2 (Deg F)	707	1087	695	1107	699
Exhaust 3 (Deg F)	734	1077	729	1096	728
Exhaust 4 (Deg F)	721	1073	726	1085	709
Exhaust 5 (Deg F)	715	1072	708	1089	705
Exhaust 6 (Deg F)	668	1062	655	1076	668
Pre-Turbine (Deg F)	803	1162	814	1180	811
Stack (Deg F)	741	940	744	951	736

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	450	451	1507	1508	2567
***** Engine Pressures Data *****					
Main Oil Pres (psig)	22.0	62.8	21.9	60.1	21.8
Fuel Pressure (psig)	94.7	102.0	97.2	103.3	97.5
Compress Out (psig)	.03	23.93	.08	24.38	.04
Boost after IC(psig)	.05	22.74	.11	23.38	.06
Inlet Manifold(psig)	-6.18	22.13	-6.37	22.84	-5.81
Inlet Manifold(psia)	8.16	36.47	7.90	37.11	8.42
Pre-Turbine (psig)	.06	19.32	1.11	18.91	.53
Exhaust Bk Pr ("HG)	.03	2.35	.15	2.38	-.23
Inlet Restrict("H2O)	.17	11.56	-.58	11.30	-.44
LFE Filter Pr ("H2O)	.07	1.74	.01	.02	.03
LFE Delta Pr ("H2O)	.24	6.08	-.02	-.02	-.01
H (lbH2O/lbAir)	.011	.011	.012	.012	.017
RH (out) (%)	33.83	33.34	30.57	31.03	50.60
Barometer ("Hg)	29.19	29.19	29.05	29.05	28.99
***** Natural Gas Composition *****					
NG % Methane	94.89	94.89	95.09	95.09	95.48
NG % Ethane	2.16	2.16	1.77	1.77	2.44
NG % Propane	.29	.29	.28	.28	.18
NG % CO2	1.54	1.54	1.76	1.76	1.25
NG % Nitrogen	1.00	1.00	.97	.97	.59
Butane Actual(%)	.13	.13	.14	.14	.07
MWT	17.03	17.03	17.03	17.03	16.88
Fuel LHV	20157.	20157.	20053.	20053.	20459.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2568	3629	3630	4687	4688
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 29	AUG., 29	SEP., 16	SEP., 16
Time (Seconds)	18:24:36	23:19:46	23:29:48	20:17:44	20:27:41
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	500.0	750.0	750.0	1000.0	1000.0
Test Type Code	1	3	1	3	1

***** Engine Performance Data *****

Engine Speed (rpm)	1702	590	1702	585	1702
Torque (ft/lbs)	1158.4	20.9	1176.3	27.3	1153.2
BHP	375.3	2.4	381.3	3.0	373.7
BSFC (lbs/BHp-hr)	.315	2.200	.312	1.835	.317
BTE (%)	39.5	5.7	40.1	6.9	39.8
BMEP (psi)	240.0	4.3	243.7	5.6	238.9
Density	.326	.317	.327	.319	.346
Density (New)	.330	.321	.331	.323	.351
NG Flow (lbs/hr)	118.07	5.18	119.11	5.57	118.38
NG Flow [MM] (lbs/hr)	118.07	5.18	119.11	5.57	118.38
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.416	.105	2.417	.112	2.388
Air Flow (lbs/hr)	7.79	4.65	7.15	132.65	2960.4
Volumetric Eff (%)	5.6	4.9	5.6	50.9	86.2
Equivalence Ratio	249.23	18.159	271.86	.681	.649
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.58	.19	5.16	.24	5.68

***** Engine Temperature Data *****

Water In (Deg F)	201	102	201	99	201
Water Out (Deg F)	209	109	209	106	209
Oil Sump (Deg F)	247	221	247	222	246
Oil Gallery (DEG F)	229	183	229	183	229
Ambient/LFE (Deg F)	87	84	84	74	74
Boost B4 IC (Deg F)	338	165	333	166	333
Boost AF IC (Deg F)	104	91	104	91	104
Intake (Deg F)	102	128	106	123	103
Gas @ Meter (Deg F)	108	98	100	97	93
Exhaust 1 (Deg F)	1056	622	1058	634	1061
Exhaust 2 (Deg F)	1100	675	1104	684	1107
Exhaust 3 (Deg F)	1095	716	1097	724	1098
Exhaust 4 (Deg F)	1083	707	1080	722	1082
Exhaust 5 (Deg F)	1086	683	1081	702	1085
Exhaust 6 (Deg F)	1069	633	1064	644	1068
Pre-Turbine (Deg F)	1176	797	1172	815	1175
Stack (Deg F)	949	717	951	730	948

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2568	3629	3630	4687	4688
***** Engine Pressures Data *****					
Main Oil Pres (psig)	61.1	21.0	59.4	20.6	59.4
Fuel Pressure (psig)	103.5	97.3	101.2	97.1	105.9
Compress Out (psig)	23.89	.05	23.91	.03	23.77
Boost after IC(psig)	22.76	.08	22.72	.06	22.62
Inlet Manifold(psig)	22.35	-6.78	22.35	-6.37	22.23
Inlet Manifold(psia)	36.58	7.53	36.67	7.90	36.49
Pre-Turbine (psig)	18.65	1.10	18.69	1.45	19.24
Exhaust Bk Pr ("HG)	2.33	.12	2.28	.11	2.29
Inlet Restrict("H2O)	11.37	.13	11.43	.46	11.34
LFE Filter Pr ("H2O)	.01	.04	.02	.06	1.88
LFE Delta Pr ("H2O)	-.02	-.02	-.02	.21	5.82
H (lbH2O/lbAir)	.016	.015	.015	.017	.017
RH (out) (%)	50.63	53.10	54.26	83.84	84.08
Barometer ("Hg)	28.99	29.15	29.15	29.05	29.05
***** Natural Gas Composition *****					
NG % Methane	95.48	95.02	95.02	94.72	94.72
NG % Ethane	2.44	2.14	2.14	2.17	2.17
NG % Propane	.18	.36	.36	.42	.42
NG % CO2	1.25	1.25	1.25	1.50	1.50
NG % Nitrogen	.59	1.05	1.05	1.00	1.00
Butane Actual(%)	.07	.19	.19	.20	.20
MWT	16.88	17.00	17.00	17.09	17.09
Fuel LHV	20459.	20293.	20293.	20175.	20175.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2567	2568	3629	3630
Year	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 29	AUG., 29
Time (Seconds)	18:14:36	18:24:36	23:19:46	23:29:48
Ignition Timing	0.0	0.0	0.0	0.0
Test Hours	500.0	500.0	750.0	750.0
Test Type Code	3	1	3	1

***** Engine Performance Data *****

Engine Speed (rpm)	591	1702	590	1702
Torque (ft/lbs)	35.0	1158.4	20.9	1176.3
BHP	3.9	375.3	2.4	381.3
BSFC (lbs/BHp-hr)	1.460	.315	2.200	.312
BTE (%)	8.5	39.5	5.7	40.1
BMEP (psi)	7.2	240.0	4.3	243.7
Density	.312	.326	.317	.327
Density (New)	.316	.330	.321	.331
NG Flow (lbs/hr)	5.75	118.07	5.18	119.11
NG Flow [MM] (lbs/hr)	5.75	118.07	5.18	119.11
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	.118	2.416	.105	2.417
Air Flow (lbs/hr)	9.06	7.79	4.65	7.15
Volumetric Eff (%)	6.2	5.6	4.9	5.6
Equivalence Ratio	10.441	249.23	18.159	271.86
GEM Timing	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00
BlowBy (cfm)	.33	4.58	.19	5.16

***** Engine Temperature Data *****

Water In (Deg F)	101	201	102	201
Water Out (Deg F)	108	209	109	209
Oil Sump (Deg F)	222	247	221	247
Oil Gallery (DEG F)	183	229	183	229
Ambient/LFE (Deg F)	89	87	84	84
Boost B4 IC (Deg F)	165	338	165	333
Boost AF IC (Deg F)	92	104	91	104
Intake (Deg F)	123	102	128	106
Gas @ Meter (Deg F)	104	108	98	100
Exhaust 1 (Deg F)	649	1056	622	1058
Exhaust 2 (Deg F)	699	1100	675	1104
Exhaust 3 (Deg F)	728	1095	716	1097
Exhaust 4 (Deg F)	709	1083	707	1080
Exhaust 5 (Deg F)	705	1086	683	1081
Exhaust 6 (Deg F)	668	1069	633	1064
Pre-Turbine (Deg F)	811	1176	797	1172
Stack (Deg F)	736	949	717	951

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2567	2568	3629	3630
***** Engine Pressures Data *****				
Main Oil Pres (psig)	21.8	61.1	21.0	59.4
Fuel Pressure (psig)	97.5	103.5	97.3	101.2
Compress Out (psig)	.04	23.89	.05	23.91
Boost after IC(psig)	.06	22.76	.08	22.72
Inlet Manifold(psig)	-5.81	22.35	-6.78	22.35
Inlet Manifold(psia)	8.42	36.58	7.53	36.67
Pre-Turbine (psig)	.53	18.65	1.10	18.69
Exhaust Bk Pr ("HG)	-.23	2.33	.12	2.28
Inlet Restrict("H2O)	-.44	11.37	.13	11.43
LFE Filter Pr ("H2O)	.03	.01	.04	.02
LFE Delta Pr ("H2O)	-.01	-.02	-.02	-.02
H (lbH2O/lbAir)	.017	.016	.015	.015
RH (out) (%)	50.60	50.63	53.10	54.26
Barometer ("Hg)	28.99	28.99	29.15	29.15
***** Natural Gas Composition *****				
NG % Methane	95.48	95.48	95.02	95.02
NG % Ethane	2.44	2.44	2.14	2.14
NG % Propane	.18	.18	.36	.36
NG % CO2	1.25	1.25	1.25	1.25
NG % Nitrogen	.59	.59	1.05	1.05
Butane Actual(%)	.07	.07	.19	.19
MWT	16.88	16.88	17.00	17.00
Fuel LHV	20459.	20459.	20293.	20293.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	450	451	1507	1508
Year	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	JULY, 22	JULY, 22	AUG., 03	AUG., 03
Time (Seconds)	10:57:33	11:07:32	20:48:10	20:58:09
Ignition Timing	0.0	0.0	0.0	0.0
Test Hours	1.0	1.0	250.0	250.0
Test Type Code	3	1	3	1

***** Engine Performance Data *****

Engine Speed (rpm)	598	1704	621	1702
Torque (ft/lbs)	16.6	1152.9	26.1	1180.9
BHP	1.9	374.0	3.1	382.6
BSFC (lbs/BHp-hr)	3.312	.315	2.024	.317
BTE (%)	3.8	40.0	6.3	40.0
BMEP (psi)	3.4	238.8	5.4	244.6
Density	.308	.326	.312	.327
Density (New)	.311	.330	.315	.331
NG Flow (lbs/hr)	6.28	117.97	6.25	121.32
NG Flow [MM] (lbs/hr)	6.28	117.97	6.25	121.32
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	.126	2.378	.125	2.433
Air Flow (lbs/hr)	141.95	2979.7	3.03	3.98
Volumetric Eff (%)	51.4	87.0	4.5	5.5
Equivalence Ratio	.716	.642	33.299	490.97
GEM Timing	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00
BlowBy (cfm)	.16	5.49	.23	5.02

***** Engine Temperature Data *****

Water In (Deg F)	99	201	101	200
Water Out (Deg F)	106	209	108	209
Oil Sump (Deg F)	223	245	223	249
Oil Gallery (DEG F)	184	229	185	231
Ambient/LFE (Deg F)	88	88	96	96
Boost B4 IC (Deg F)	177	332	178	350
Boost AF IC (Deg F)	92	111	91	104
Intake (Deg F)	125	108	127	109
Gas @ Meter (Deg F)	103	106	107	111
Exhaust 1 (Deg F)	679	1046	652	1062
Exhaust 2 (Deg F)	707	1087	695	1107
Exhaust 3 (Deg F)	734	1077	729	1096
Exhaust 4 (Deg F)	721	1073	726	1085
Exhaust 5 (Deg F)	715	1072	708	1089
Exhaust 6 (Deg F)	668	1062	655	1076
Pre-Turbine (Deg F)	803	1162	814	1180
Stack (Deg F)	741	940	744	951

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	450	451	1507	1508
***** Engine Pressures Data *****				
Main Oil Pres (psig)	22.0	62.8	21.9	60.1
Fuel Pressure (psig)	94.7	102.0	97.2	103.3
Compress Out (psig)	.03	23.93	.08	24.38
Boost after IC(psig)	.05	22.74	.11	23.38
Inlet Manifold(psig)	-6.18	22.13	-6.37	22.84
Inlet Manifold(psia)	8.16	36.47	7.90	37.11
Pre-Turbine (psig)	.06	19.32	1.11	18.91
Exhaust Bk Pr ("HG)	.03	2.35	.15	2.38
Inlet Restrict("H2O)	.17	11.56	-.58	11.30
LFE Filter Pr ("H2O)	.07	1.74	.01	.02
LFE Delta Pr ("H2O)	.24	6.08	-.02	-.02
H (lbH2O/lbAir)	.011	.011	.012	.012
RH (out) (%)	33.83	33.34	30.57	31.03
Barometer ("Hg)	29.19	29.19	29.05	29.05
***** Natural Gas Composition *****				
NG % Methane	94.89	94.89	95.09	95.09
NG % Ethane	2.16	2.16	1.77	1.77
NG % Propane	.29	.29	.28	.28
NG % CO2	1.54	1.54	1.76	1.76
NG % Nitrogen	1.00	1.00	.97	.97
Butane Actual(%)	.13	.13	.14	.14
MWT	17.03	17.03	17.03	17.03
Fuel LHV	20157.	20157.	20053.	20053.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	4687	4688
Year	1998	1998
Operator Initials	<..??..>	<..??..>
Julian Day	SEP., 16	SEP., 16
Time (Seconds)	20:17:44	20:27:41
Ignition Timing	0.0	0.0
Test Hours	1000.0	1000.0
Test Type Code	3	1

***** Engine Performance Data *****

Engine Speed (rpm)	585	1702
Torque (ft/lbs)	27.3	1153.2
BHP	3.0	373.7
BSFC (lbs/BHp-hr)	1.835	.317
BTE (%)	6.9	39.8
BMEP (psi)	5.6	238.9
Density	.319	.346
Density (New)	.323	.351
NG Flow (lbs/hr)	5.57	118.38
NG Flow [MM](lbs/hr)	5.57	118.38
NG Flow [RM](lbs/hr)	-.00	-.00
NG Flow(New)(lbs/hr)	-.00	-.00
NG Flow/E+6 (BTU/hr)	.112	2.388
Air Flow (lbs/hr)	132.65	2960.4
Volumetric Eff (%)	50.9	86.2
Equivalence Ratio	.681	.649
GEM Timing	0.0	0.0
GEM Equiv. Ratio	0.00	0.00
GEM Vol. Eff.	0.00	0.00
BlowBy (cfm)	.24	5.68

***** Engine Temperature Data *****

Water In	(Deg F)	99	201
Water Out	(Deg F)	106	209
Oil Sump	(Deg F)	222	246
Oil Gallery	(DEG F)	183	229
Ambient/LFE	(Deg F)	74	74
Boost B4 IC	(Deg F)	166	333
Boost AF IC	(Deg F)	91	104
Intake	(Deg F)	123	103
Gas @ Meter	(Deg F)	97	93
Exhaust 1	(Deg F)	634	1061
Exhaust 2	(Deg F)	684	1107
Exhaust 3	(Deg F)	724	1098
Exhaust 4	(Deg F)	722	1082
Exhaust 5	(Deg F)	702	1085
Exhaust 6	(Deg F)	644	1068
Pre-Turbine	(Deg F)	815	1175
Stack	(Deg F)	730	948

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	4687	4688
***** Engine Pressures Data *****		
Main Oil Pres (psig)	20.6	59.4
Fuel Pressure (psig)	97.1	105.9
Compress Out (psig)	.03	23.77
Boost after IC(psig)	.06	22.62
Inlet Manifold(psig)	-6.37	22.23
Inlet Manifold(psia)	7.90	36.49
Pre-Turbine (psig)	1.45	19.24
Exhaust Bk Pr ("HG)	.11	2.29
Inlet Restrict("H2O)	.46	11.34
LFE Filter Pr ("H2O)	.06	1.88
LFE Delta Pr ("H2O)	.21	5.82
H (lbH2O/lbAir)	.017	.017
RH (out) (%)	83.84	84.08
Barometer ("Hg)	29.05	29.05
***** Natural Gas Composition *****		
NG % Methane	94.72	94.72
NG % Ethane	2.17	2.17
NG % Propane	.42	.42
NG % CO2	1.50	1.50
NG % Nitrogen	1.00	1.00
Butane Actual(%)	.20	.20
MWT	17.09	17.09
Fuel LHV	20175.	20175.

APPENDIX D

SAMPLE SNAPSHOT HP DAQ DATA

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2511	2512	2513	2514	2515
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:35:32	17:35:47	17:36:01	17:36:19	17:36:33
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1701	1700	1702	1701
Torque (ft/lbs)	1149.7	1154.2	1152.0	1151.8	1148.6
BHP	372.4	373.8	372.9	373.1	371.9
BSFC (lbs/BHp-hr)	.316	.315	.316	.315	.317
BTE (%)	39.5	39.6	39.6	39.7	39.5
BMEP (psi)	238.2	239.1	238.6	238.6	237.9
Density	.339	.339	.339	.339	.339
Density (New)	.344	.344	.344	.344	.344
NG Flow (lbs/hr)	117.74	117.85	117.83	117.56	117.81
NG Flow [MM] (lbs/hr)	117.74	117.85	117.83	117.56	117.81
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.398	2.400	2.400	2.394	2.399
Air Flow (lbs/hr)	6.83	8.08	9.10	7.34	7.97
Volumetric Eff (%)	5.5	5.6	5.6	5.6	5.6
Equivalence Ratio	282.28	238.88	211.98	262.38	241.95
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.79	4.81	4.86	4.83	4.81

***** Engine Temperature Data *****

Water In (Deg F)	201	200	200	200	200
Water Out (Deg F)	208	208	208	209	208
Oil Sump (Deg F)	247	247	247	247	247
Oil Gallery (DEG F)	229	228	229	229	229
Ambient/LFE (Deg F)	89	89	88	88	88
Boost B4 IC (Deg F)	341	341	340	339	340
Boost AF IC (Deg F)	105	104	104	104	104
Intake (Deg F)	103	102	103	103	103
Gas @ Meter (Deg F)	103	104	103	104	104
Exhaust 1 (Deg F)	1059	1059	1058	1059	1058
Exhaust 2 (Deg F)	1103	1102	1103	1104	1103
Exhaust 3 (Deg F)	1095	1096	1096	1096	1096
Exhaust 4 (Deg F)	1086	1086	1085	1086	1086
Exhaust 5 (Deg F)	1088	1088	1088	1089	1088
Exhaust 6 (Deg F)	1072	1072	1072	1073	1073
Pre-Turbine (Deg F)	1178	1178	1177	1179	1179
Stack (Deg F)	950	950	949	951	950

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2516	2517	2518	2519	2520
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:36:48	17:37:03	17:37:17	17:37:32	17:37:47
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1699	1048	572	582	610
Torque (ft/lbs)	593.3	82.9	37.7	35.1	35.3
BHP	191.9	16.5	4.1	3.9	4.1
BSFC (lbs/BHp-hr)	.276	.021	.789	1.256	1.472
BTE (%)	45.3	607.3	15.8	9.9	8.5
BMEP (psi)	122.9	17.2	7.8	7.3	7.3
Density	.331	.323	.317	.314	.314
Density (New)	.335	.327	.321	.318	.318
NG Flow (lbs/hr)	52.90	.34	3.23	4.89	6.03
NG Flow [MM](lbs/hr)	52.90	.34	3.23	4.89	6.03
NG Flow [RM](lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New)(lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	1.077	.007	.066	.100	.123
Air Flow (lbs/hr)	7.67	8.64	8.42	9.85	9.40
Volumetric Eff (%)	7.0	.9	6.3	7.0	6.9
Equivalence Ratio	112.97	.645	6.292	8.132	10.506
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	.49	.52	.24	.18	.26

***** Engine Temperature Data *****

Water In (Deg F)	103	111	111	109	107
Water Out (Deg F)	136	127	121	118	115
Oil Sump (Deg F)	247	242	231	231	226
Oil Gallery (DEG F)	215	205	197	191	190
Ambient/LFE (Deg F)	88	88	88	88	89
Boost B4 IC (Deg F)	267	200	200	191	183
Boost AF IC (Deg F)	97	92	91	91	91
Intake (Deg F)	99	102	123	122	121
Gas @ Meter (Deg F)	103	103	103	102	102
Exhaust 1 (Deg F)	1049	906	755	725	707
Exhaust 2 (Deg F)	1090	923	793	769	751
Exhaust 3 (Deg F)	1086	927	809	796	783
Exhaust 4 (Deg F)	1074	911	795	788	775
Exhaust 5 (Deg F)	1081	931	793	773	755
Exhaust 6 (Deg F)	1063	903	760	734	718
Pre-Turbine (Deg F)	1172	964	843	857	857
Stack (Deg F)	1008	802	782	790	783

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2516	2517	2518	2519	2520
***** Engine Pressures Data *****					
Main Oil Pres (psig)	66.9	45.0	25.0	21.1	21.2
Fuel Pressure (psig)	103.9	100.9	98.9	97.7	97.7
Compress Out (psig)	2.69	1.97	.06	.05	.05
Boost after IC(psig)	2.44	1.76	.10	.09	.07
Inlet Manifold(psig)	-.82	1.76	-7.91	-6.94	-6.60
Inlet Manifold(psia)	13.42	15.99	6.33	7.30	7.64
Pre-Turbine (psig)	2.21	2.18	.54	.57	.58
Exhaust Bk Pr ("HG)	.16	.15	.02	.06	.03
Inlet Restrict("H2O)	1.02	.85	-.17	-.17	-.42
LFE Filter Pr ("H2O)	.02	.03	.03	.02	.03
LFE Delta Pr ("H2O)	-.02	-.01	-.01	-.01	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.65	51.58	51.49	51.45	51.43
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2521	2522	2523	2524	2525
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:38:01	17:38:16	17:38:35	17:38:46	17:39:04
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	606	604	617	1192	1702
Torque (ft/lbs)	35.0	35.6	35.7	63.7	1069.4
BHP	4.0	4.1	4.2	14.5	346.4
BSFC (lbs/BHp-hr)	1.453	1.421	1.408	1.393	.348
BTE (%)	8.6	8.8	8.9	9.0	35.9
BMEP (psi)	7.2	7.4	7.4	13.2	221.5
Density	.314	.314	.314	.313	.339
Density (New)	.318	.318	.318	.317	.344
NG Flow (lbs/hr)	5.87	5.81	5.90	20.15	120.56
NG Flow [MM] (lbs/hr)	5.87	5.81	5.90	20.15	120.56
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	.119	.118	.120	.410	2.455
Air Flow (lbs/hr)	8.03	5.87	9.34	6.53	8.23
Volumetric Eff (%)	5.7	5.3	6.2	3.8	5.7
Equivalence Ratio	11.961	16.196	10.344	50.551	239.72
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	.34	.26	.32	2.51	6.76

***** Engine Temperature Data *****

Water In (Deg F)	105	103	101	187	179
Water Out (Deg F)	112	110	107	166	180
Oil Sump (Deg F)	222	219	221	220	216
Oil Gallery (DEG F)	188	185	182	182	202
Ambient/LFE (Deg F)	89	89	89	89	89
Boost B4 IC (Deg F)	177	170	163	156	308
Boost AF IC (Deg F)	91	92	92	92	107
Intake (Deg F)	121	121	121	117	112
Gas @ Meter (Deg F)	102	102	102	102	101
Exhaust 1 (Deg F)	686	674	648	642	875
Exhaust 2 (Deg F)	732	717	694	691	936
Exhaust 3 (Deg F)	764	746	721	715	933
Exhaust 4 (Deg F)	754	737	713	715	934
Exhaust 5 (Deg F)	731	709	681	683	916
Exhaust 6 (Deg F)	698	683	653	655	901
Pre-Turbine (Deg F)	843	823	799	809	1060
Stack (Deg F)	766	749	728	741	861

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2521	2522	2523	2524	2525
***** Engine Pressures Data *****					
Main Oil Pres (psig)	21.0	22.2	22.2	32.2	68.0
Fuel Pressure (psig)	97.7	97.7	97.7	97.4	106.5
Compress Out (psig)	.04	.04	.04	2.16	24.38
Boost after IC(psig)	.07	.07	.07	2.19	23.25
Inlet Manifold(psig)	-5.71	-6.15	-5.97	.49	22.80
Inlet Manifold(psia)	8.53	8.08	8.27	14.73	37.04
Pre-Turbine (psig)	.60	.59	.58	1.98	19.49
Exhaust Bk Pr ("HG)	.49	.04	.29	.11	2.26
Inlet Restrict("H2O)	.49	.44	.63	1.28	11.47
LFE Filter Pr ("H2O)	.03	.03	.03	.04	.06
LFE Delta Pr ("H2O)	-.02	-.02	-.01	-.02	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.38	51.26	51.08	51.08	51.13
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2526	2527	2528	2529	2530
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:39:18	17:39:33	17:39:47	17:40:01	17:40:16
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1701	1701	1703	1699
Torque (ft/lbs)	1119.3	1150.4	1161.9	1154.1	1157.0
BHP	362.4	372.6	376.3	374.2	374.2
BSFC (lbs/BHp-hr)	.329	.322	.319	.318	.318
BTE (%)	38.0	38.9	39.2	39.3	39.3
BMEP (psi)	231.9	238.3	240.7	239.1	239.7
Density	.340	.340	.341	.341	.342
Density (New)	.345	.345	.345	.346	.346
NG Flow (lbs/hr)	119.08	119.84	120.08	118.84	119.01
NG Flow [MM] (lbs/hr)	119.08	119.84	120.08	118.84	119.01
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.425	2.440	2.445	2.420	2.424
Air Flow (lbs/hr)	10.10	8.00	7.18	7.93	7.89
Volumetric Eff (%)	5.7	5.7	5.6	5.6	5.6
Equivalence Ratio	193.07	245.24	273.82	245.25	247.06
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	6.25	5.87	5.53	5.41	5.48

***** Engine Temperature Data *****

Water In (Deg F)	180	183	187	190	194
Water Out (Deg F)	184	188	192	196	199
Oil Sump (Deg F)	217	218	220	221	223
Oil Gallery (DEG F)	204	205	207	209	212
Ambient/LFE (Deg F)	89	89	89	89	89
Boost B4 IC (Deg F)	331	340	343	344	345
Boost AF IC (Deg F)	120	122	110	112	112
Intake (Deg F)	118	121	114	111	114
Gas @ Meter (Deg F)	100	100	99	98	98
Exhaust 1 (Deg F)	979	1010	1024	1031	1037
Exhaust 2 (Deg F)	1033	1060	1072	1079	1083
Exhaust 3 (Deg F)	1022	1049	1062	1070	1073
Exhaust 4 (Deg F)	1013	1039	1052	1058	1062
Exhaust 5 (Deg F)	1012	1039	1052	1060	1065
Exhaust 6 (Deg F)	997	1024	1037	1045	1051
Pre-Turbine (Deg F)	1123	1139	1148	1154	1158
Stack (Deg F)	882	894	906	914	919

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2526	2527	2528	2529	2530
***** Engine Pressures Data *****					
Main Oil Pres (psig)	67.7	67.5	67.2	66.9	66.6
Fuel Pressure (psig)	106.6	106.6	106.6	106.5	106.5
Compress Out (psig)	24.85	24.91	24.64	24.68	24.71
Boost after IC(psig)	23.73	23.68	23.52	23.41	23.54
Inlet Manifold(psig)	23.26	23.34	23.05	23.10	23.13
Inlet Manifold(psia)	37.50	37.58	37.29	37.34	37.36
Pre-Turbine (psig)	19.71	20.02	19.56	19.57	19.56
Exhaust Bk Pr ("HG)	2.25	2.26	2.34	2.35	2.39
Inlet Restrict("H2O)	11.33	12.03	11.52	11.66	11.62
LFE Filter Pr ("H2O)	.04	.03	.02	.01	.03
LFE Delta Pr ("H2O)	-.01	-.02	-.02	-.02	-.02
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.19	51.35	51.58	51.83	51.81
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2531	2532	2533	2534	2535
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:40:34	17:40:48	17:41:03	17:41:17	17:41:31
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1703	1701	1702	1701
Torque (ft/lbs)	1163.1	1159.4	1159.6	1158.4	1151.5
BHP	376.6	375.9	375.6	375.4	372.8
BSFC (lbs/BHp-hr)	.317	.315	.316	.314	.315
BTE (%)	39.5	39.7	39.5	39.8	39.7
BMEP (psi)	240.9	240.2	240.2	240.0	238.5
Density	.340	.340	.340	.340	.340
Density (New)	.345	.344	.344	.344	.345
NG Flow (lbs/hr)	119.27	118.41	118.77	118.00	117.29
NG Flow [MM](lbs/hr)	119.27	118.41	118.77	118.00	117.29
NG Flow [RM](lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New)(lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.429	2.411	2.419	2.403	2.389
Air Flow (lbs/hr)	10.38	7.13	9.17	9.57	9.95
Volumetric Eff (%)	5.7	5.6	5.6	5.7	5.6
Equivalence Ratio	188.15	271.89	212.09	201.91	192.93
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	5.18	5.21	5.13	5.05	4.97

***** Engine Temperature Data *****

Water In (Deg F)	199	202	202	203	203
Water Out (Deg F)	204	207	208	209	210
Oil Sump (Deg F)	225	226	229	231	233
Oil Gallery (DEG F)	214	216	217	219	220
Ambient/LFE (Deg F)	89	89	89	89	89
Boost B4 IC (Deg F)	347	344	345	344	341
Boost AF IC (Deg F)	111	109	109	108	107
Intake (Deg F)	111	109	108	107	106
Gas @ Meter (Deg F)	97	97	97	97	97
Exhaust 1 (Deg F)	1043	1043	1046	1048	1049
Exhaust 2 (Deg F)	1090	1091	1092	1093	1096
Exhaust 3 (Deg F)	1078	1080	1081	1084	1085
Exhaust 4 (Deg F)	1067	1069	1072	1074	1074
Exhaust 5 (Deg F)	1070	1073	1074	1076	1078
Exhaust 6 (Deg F)	1056	1058	1059	1063	1061
Pre-Turbine (Deg F)	1163	1165	1167	1170	1169
Stack (Deg F)	926	930	933	937	939

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2531	2532	2533	2534	2535
***** Engine Pressures Data *****					
Main Oil Pres (psig)	66.1	65.7	65.4	65.0	64.7
Fuel Pressure (psig)	105.9	105.8	105.8	105.7	105.7
Compress Out (psig)	24.59	24.26	24.28	23.89	23.97
Boost after IC(psig)	23.50	23.12	23.12	22.84	22.80
Inlet Manifold(psig)	23.05	22.71	22.72	22.37	22.43
Inlet Manifold(psia)	37.29	36.95	36.96	36.61	36.67
Pre-Turbine (psig)	19.30	19.03	19.14	18.54	18.77
Exhaust Bk Pr ("HG)	2.37	2.26	2.27	2.24	2.37
Inlet Restrict("H2O)	11.85	11.48	11.58	11.50	11.44
LFE Filter Pr ("H2O)	.04	.04	.04	.03	.02
LFE Delta Pr ("H2O)	-.01	-.02	-.01	-.01	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.76	51.72	51.59	51.64	51.68
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2536	2537	2538	2539	2540
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:41:46	17:42:04	17:42:18	17:42:32	17:42:47
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1702	1701	1700	1702	1702
Torque (ft/lbs)	1153.0	1152.8	1150.5	1148.7	1150.7
BHP	373.7	373.4	372.5	372.1	372.9
BSFC (lbs/BHp-hr)	.314	.315	.315	.316	.315
BTE (%)	39.7	39.6	39.6	39.6	39.6
BMEP (psi)	238.8	238.8	238.3	238.0	238.4
Density	.340	.339	.337	.336	.336
Density (New)	.344	.343	.342	.341	.341
NG Flow (lbs/hr)	117.53	117.78	117.44	117.57	117.54
NG Flow [MM](lbs/hr)	117.53	117.78	117.44	117.57	117.54
NG Flow [RM](lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New)(lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.393	2.398	2.392	2.394	2.394
Air Flow (lbs/hr)	9.60	10.07	8.14	7.32	8.21
Volumetric Eff (%)	5.6	5.6	5.6	5.6	5.6
Equivalence Ratio	200.39	191.46	236.31	263.14	234.35
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.82	4.75	4.80	4.72	4.69

***** Engine Temperature Data *****

Water In (Deg F)	203	204	203	203	203
Water Out (Deg F)	210	211	211	211	211
Oil Sump (Deg F)	233	235	237	238	237
Oil Gallery (DEG F)	221	222	223	223	224
Ambient/LFE (Deg F)	89	89	89	89	89
Boost B4 IC (Deg F)	341	341	341	342	342
Boost AF IC (Deg F)	107	107	106	106	106
Intake (Deg F)	105	105	104	104	104
Gas @ Meter (Deg F)	97	97	98	98	98
Exhaust 1 (Deg F)	1049	1052	1053	1055	1056
Exhaust 2 (Deg F)	1095	1098	1098	1099	1100
Exhaust 3 (Deg F)	1085	1087	1088	1089	1090
Exhaust 4 (Deg F)	1075	1077	1078	1080	1080
Exhaust 5 (Deg F)	1080	1079	1081	1082	1082
Exhaust 6 (Deg F)	1062	1060	1061	1063	1066
Pre-Turbine (Deg F)	1170	1170	1171	1174	1174
Stack (Deg F)	940	943	942	945	945

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2536	2537	2538	2539	2540
***** Engine Pressures Data *****					
Main Oil Pres (psig)	64.3	64.1	63.7	63.5	63.3
Fuel Pressure (psig)	105.7	105.4	105.0	104.7	104.7
Compress Out (psig)	23.85	23.97	24.02	23.88	23.86
Boost after IC(psig)	22.86	22.78	22.91	22.77	22.94
Inlet Manifold(psig)	22.30	22.43	22.45	22.34	22.34
Inlet Manifold(psia)	36.54	36.66	36.68	36.58	36.58
Pre-Turbine (psig)	18.64	18.71	18.85	18.69	18.39
Exhaust Bk Pr ("HG)	2.34	2.39	2.26	2.19	2.26
Inlet Restrict("H2O)	10.69	11.28	11.48	11.53	11.60
LFE Filter Pr ("H2O)	.04	.04	.04	.02	.02
LFE Delta Pr ("H2O)	-.01	-.01	-.01	-.02	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.70	51.57	51.48	51.48	51.37
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2541	2542	2543	2544	2545
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:43:01	17:43:19	17:43:33	17:43:48	17:44:02
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1700	1702	1701	1702	1701
Torque (ft/lbs)	1153.5	1146.9	1154.1	1143.0	1146.3
BHP	373.3	371.6	373.8	370.3	371.2
BSFC (lbs/BHp-hr)	.314	.315	.315	.316	.317
BTE (%)	39.8	39.6	39.7	39.5	39.4
BMEP (psi)	238.9	237.6	239.1	236.8	237.5
Density	.336	.335	.334	.333	.333
Density (New)	.340	.340	.338	.338	.338
NG Flow (lbs/hr)	117.24	117.19	117.80	117.09	117.75
NG Flow [MM] (lbs/hr)	117.24	117.19	117.80	117.09	117.75
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.388	2.386	2.399	2.384	2.398
Air Flow (lbs/hr)	8.01	7.74	10.57	9.48	9.37
Volumetric Eff (%)	5.6	5.6	5.7	5.6	5.6
Equivalence Ratio	239.52	247.95	182.43	202.22	205.74
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.68	4.67	4.64	4.64	4.73

***** Engine Temperature Data *****

Water In (Deg F)	203	203	202	202	202
Water Out (Deg F)	211	210	210	210	210
Oil Sump (Deg F)	239	240	240	241	242
Oil Gallery (DEG F)	225	225	225	226	226
Ambient/LFE (Deg F)	89	89	89	88	89
Boost B4 IC (Deg F)	341	341	341	341	341
Boost AF IC (Deg F)	106	105	105	105	105
Intake (Deg F)	104	103	103	103	103
Gas @ Meter (Deg F)	98	99	99	100	100
Exhaust 1 (Deg F)	1056	1057	1058	1058	1059
Exhaust 2 (Deg F)	1099	1101	1103	1101	1102
Exhaust 3 (Deg F)	1090	1091	1093	1093	1092
Exhaust 4 (Deg F)	1081	1082	1083	1082	1083
Exhaust 5 (Deg F)	1084	1084	1085	1085	1085
Exhaust 6 (Deg F)	1069	1068	1069	1070	1070
Pre-Turbine (Deg F)	1176	1176	1176	1176	1176
Stack (Deg F)	946	948	950	948	948

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2541	2542	2543	2544	2545
***** Engine Pressures Data *****					
Main Oil Pres (psig)	63.1	62.9	62.8	62.7	62.6
Fuel Pressure (psig)	104.5	104.5	104.0	104.0	104.0
Compress Out (psig)	23.77	23.75	23.77	23.80	23.87
Boost after IC(psig)	22.53	22.61	22.73	22.74	22.69
Inlet Manifold(psig)	22.26	22.21	22.22	22.24	22.31
Inlet Manifold(psia)	36.50	36.45	36.46	36.48	36.55
Pre-Turbine (psig)	18.78	18.60	18.63	18.55	18.76
Exhaust Bk Pr ("HG)	2.30	2.33	2.24	2.29	2.24
Inlet Restrict("H2O)	11.75	11.54	11.33	11.68	11.41
LFE Filter Pr ("H2O)	.02	.03	.04	.02	.04
LFE Delta Pr ("H2O)	-.02	-.02	-.01	-.01	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.47	51.54	51.57	51.51	51.47
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2546	2547	2548	2549	2550
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:44:17	17:44:31	17:44:49	17:45:03	17:45:18
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1701	1702	1703	1699
Torque (ft/lbs)	1152.0	1152.2	1144.6	1154.7	1146.8
BHP	373.1	373.2	370.8	374.3	370.9
BSFC (lbs/BHp-hr)	.316	.316	.315	.316	.316
BTE (%)	39.6	39.6	39.6	39.6	39.6
BMEP (psi)	238.6	238.7	237.1	239.2	237.6
Density	.333	.333	.333	.333	.333
Density (New)	.337	.337	.337	.337	.337
NG Flow (lbs/hr)	117.74	117.79	116.91	118.25	117.17
NG Flow [MM] (lbs/hr)	117.74	117.79	116.91	118.25	117.17
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.398	2.399	2.381	2.408	2.386
Air Flow (lbs/hr)	8.47	8.43	9.39	7.08	6.58
Volumetric Eff (%)	5.6	5.6	5.6	5.6	5.5
Equivalence Ratio	227.52	228.77	203.93	273.29	291.72
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.70	4.64	4.57	4.63	4.63

***** Engine Temperature Data *****

Water In (Deg F)	202	202	201	201	201
Water Out (Deg F)	210	209	209	209	209
Oil Sump (Deg F)	243	243	243	244	244
Oil Gallery (DEG F)	226	226	227	227	227
Ambient/LFE (Deg F)	89	89	89	88	88
Boost B4 IC (Deg F)	341	341	340	341	340
Boost AF IC (Deg F)	105	105	104	104	104
Intake (Deg F)	103	103	103	102	102
Gas @ Meter (Deg F)	100	100	101	101	101
Exhaust 1 (Deg F)	1061	1060	1059	1058	1059
Exhaust 2 (Deg F)	1104	1103	1102	1103	1103
Exhaust 3 (Deg F)	1093	1093	1093	1093	1093
Exhaust 4 (Deg F)	1083	1084	1082	1083	1083
Exhaust 5 (Deg F)	1087	1086	1086	1086	1086
Exhaust 6 (Deg F)	1069	1070	1069	1069	1068
Pre-Turbine (Deg F)	1176	1177	1176	1177	1177
Stack (Deg F)	950	950	948	949	949

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2546	2547	2548	2549	2550
***** Engine Pressures Data *****					
Main Oil Pres (psig)	62.4	62.3	62.3	62.1	62.0
Fuel Pressure (psig)	104.0	104.0	104.0	104.0	104.0
Compress Out (psig)	23.73	23.79	23.69	23.83	23.90
Boost after IC(psig)	22.75	22.64	22.71	22.72	22.65
Inlet Manifold(psig)	22.20	22.26	22.17	22.28	22.35
Inlet Manifold(psia)	36.44	36.50	36.41	36.51	36.59
Pre-Turbine (psig)	18.60	18.71	18.48	18.78	18.96
Exhaust Bk Pr ("HG)	2.25	2.33	2.30	2.32	2.25
Inlet Restrict("H2O)	11.16	11.54	11.38	11.71	11.25
LFE Filter Pr ("H2O)	.03	.03	.02	.01	.03
LFE Delta Pr ("H2O)	-.01	-.01	-.01	-.02	-.02
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	51.37	51.32	51.28	51.26	51.28
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2551	2552	2553	2554	2555
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:45:32	17:45:47	17:46:01	17:46:19	17:46:33
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1701	1700	1700	1702
Torque (ft/lbs)	1147.4	1138.4	1152.2	1148.1	1149.9
BHP	371.6	368.7	373.0	371.6	372.5
BSFC (lbs/BHp-hr)	.316	.317	.316	.316	.316
BTE (%)	39.6	39.4	39.5	39.6	39.6
BMEP (psi)	237.7	235.8	238.7	237.8	238.2
Density	.332	.332	.332	.332	.332
Density (New)	.337	.337	.336	.336	.336
NG Flow (lbs/hr)	117.26	116.94	117.95	117.31	117.64
NG Flow [MM] (lbs/hr)	117.26	116.94	117.95	117.31	117.64
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.388	2.381	2.402	2.389	2.396
Air Flow (lbs/hr)	7.13	10.76	4.46	10.06	8.06
Volumetric Eff (%)	5.6	5.6	5.5	5.6	5.6
Equivalence Ratio	269.25	177.95	432.96	190.98	238.99
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.67	4.64	4.66	4.63	4.62

***** Engine Temperature Data *****

Water In (Deg F)	201	201	201	201	201
Water Out (Deg F)	209	209	209	209	209
Oil Sump (Deg F)	244	244	245	245	245
Oil Gallery (DEG F)	227	228	228	228	228
Ambient/LFE (Deg F)	89	90	88	88	88
Boost B4 IC (Deg F)	340	340	340	340	340
Boost AF IC (Deg F)	104	105	105	104	104
Intake (Deg F)	102	103	103	103	102
Gas @ Meter (Deg F)	101	101	101	102	102
Exhaust 1 (Deg F)	1059	1059	1058	1059	1060
Exhaust 2 (Deg F)	1103	1103	1103	1103	1103
Exhaust 3 (Deg F)	1094	1095	1095	1094	1094
Exhaust 4 (Deg F)	1084	1085	1086	1085	1085
Exhaust 5 (Deg F)	1087	1088	1087	1088	1087
Exhaust 6 (Deg F)	1071	1072	1071	1073	1073
Pre-Turbine (Deg F)	1177	1178	1178	1178	1179
Stack (Deg F)	949	950	950	950	950

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2556	2557	2558	2559	2560
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:46:48	17:47:02	17:47:17	17:47:34	17:47:49
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1702	1701	1702	1701	1701
Torque (ft/lbs)	1145.9	1148.0	1152.7	1151.7	1153.4
BHP	371.3	371.9	373.5	373.0	373.5
BSFC (lbs/BHp-hr)	.315	.316	.315	.316	.316
BTE (%)	39.7	39.5	39.7	39.6	39.5
BMEP (psi)	237.4	237.8	238.8	238.6	238.9
Density	.332	.332	.332	.332	.332
Density (New)	.336	.336	.336	.336	.336
NG Flow (lbs/hr)	116.91	117.60	117.54	117.80	118.07
NG Flow [MM] (lbs/hr)	116.91	117.60	117.54	117.80	118.07
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.381	2.395	2.394	2.399	2.404
Air Flow (lbs/hr)	6.33	8.55	7.82	7.56	9.25
Volumetric Eff (%)	5.5	5.6	5.6	5.6	5.6
Equivalence Ratio	302.47	225.19	246.05	255.06	208.94
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.63	4.68	4.60	4.59	4.58

***** Engine Temperature Data *****

Water In (Deg F)	201	201	201	201	201
Water Out (Deg F)	209	209	209	209	209
Oil Sump (Deg F)	245	246	246	246	246
Oil Gallery (DEG F)	228	228	228	229	229
Ambient/LFE (Deg F)	88	89	89	88	88
Boost B4 IC (Deg F)	341	341	340	340	340
Boost AF IC (Deg F)	104	104	104	104	104
Intake (Deg F)	103	102	102	102	102
Gas @ Meter (Deg F)	102	102	102	103	103
Exhaust 1 (Deg F)	1061	1061	1061	1060	1059
Exhaust 2 (Deg F)	1103	1103	1103	1104	1104
Exhaust 3 (Deg F)	1095	1095	1095	1095	1096
Exhaust 4 (Deg F)	1085	1085	1086	1085	1084
Exhaust 5 (Deg F)	1086	1086	1087	1087	1087
Exhaust 6 (Deg F)	1071	1070	1068	1067	1068
Pre-Turbine (Deg F)	1178	1178	1178	1177	1177
Stack (Deg F)	950	950	949	950	949

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2556	2557	2558	2559	2560
***** Engine Pressures Data *****					
Main Oil Pres (psig)	61.6	61.5	61.5	61.5	61.3
Fuel Pressure (psig)	104.0	104.0	104.0	104.0	104.0
Compress Out (psig)	23.84	23.80	23.92	23.63	23.91
Boost after IC(psig)	22.64	22.65	22.68	22.62	22.79
Inlet Manifold(psig)	22.33	22.26	22.36	22.13	22.33
Inlet Manifold(psia)	36.56	36.50	36.60	36.37	36.56
Pre-Turbine (psig)	19.01	18.64	19.02	18.51	18.53
Exhaust Bk Pr ("HG)	2.32	2.30	2.30	2.32	2.27
Inlet Restrict("H2O)	11.72	11.62	11.58	11.26	11.73
LFE Filter Pr ("H2O)	.02	.03	.02	.04	.02
LFE Delta Pr ("H2O)	-.02	-.01	-.02	-.02	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	50.88	50.88	50.90	50.90	50.93
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2561	2562	2563	2564	2565
Year	1998	1998	1998	1998	1998
Operator Initials	<..??..>	<..??..>	<..??..>	<..??..>	<..??..>
Julian Day	AUG., 15	AUG., 15	AUG., 15	AUG., 15	AUG., 15
Time (Seconds)	17:48:03	17:48:18	17:48:32	17:48:47	17:49:04
Ignition Timing	0.0	0.0	0.0	0.0	0.0
Test Hours	499.1	499.1	499.1	499.1	499.1
Test Type Code	4	4	4	4	4

***** Engine Performance Data *****

Engine Speed (rpm)	1701	1700	1701	1700	1019
Torque (ft/lbs)	1158.2	1154.5	1148.2	798.0	78.0
BHP	375.0	373.7	372.0	258.4	15.1
BSFC (lbs/BHp-hr)	.315	.315	.316	.282	-.003
BTE (%)	39.7	39.6	39.5	44.3	-4819.
BMEP (psi)	239.9	239.2	237.9	165.3	16.2
Density	.331	.331	.331	.332	.322
Density (New)	.336	.336	.336	.336	.326
NG Flow (lbs/hr)	118.10	117.89	117.59	72.90	-.04
NG Flow [MM] (lbs/hr)	118.10	117.89	117.59	72.90	-.04
NG Flow [RM] (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow(New) (lbs/hr)	-.00	-.00	-.00	-.00	-.00
NG Flow/E+6 (BTU/hr)	2.405	2.401	2.395	1.485	-.001
Air Flow (lbs/hr)	9.64	9.43	9.26	8.88	9.37
Volumetric Eff (%)	5.6	5.6	5.6	7.5	1.0
Equivalence Ratio	200.47	204.68	207.90	134.45	-.069
GEM Timing	0.0	0.0	0.0	0.0	0.0
GEM Equiv. Ratio	0.00	0.00	0.00	0.00	0.00
GEM Vol. Eff.	0.00	0.00	0.00	0.00	0.00
BlowBy (cfm)	4.63	4.67	4.67	.61	.52

***** Engine Temperature Data *****

Water In (Deg F)	201	201	201	102	111
Water Out (Deg F)	209	209	209	151	127
Oil Sump (Deg F)	247	247	247	247	241
Oil Gallery (DEG F)	229	229	229	222	205
Ambient/LFE (Deg F)	88	88	89	89	89
Boost B4 IC (Deg F)	339	340	340	298	199
Boost AF IC (Deg F)	104	105	105	100	93
Intake (Deg F)	102	102	103	100	102
Gas @ Meter (Deg F)	103	103	103	103	103
Exhaust 1 (Deg F)	1057	1057	1057	1054	894
Exhaust 2 (Deg F)	1103	1103	1104	1097	913
Exhaust 3 (Deg F)	1095	1095	1094	1092	915
Exhaust 4 (Deg F)	1086	1087	1087	1080	898
Exhaust 5 (Deg F)	1089	1089	1088	1085	918
Exhaust 6 (Deg F)	1069	1071	1072	1066	891
Pre-Turbine (Deg F)	1178	1179	1179	1175	946
Stack (Deg F)	949	951	950	987	791

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number	2561	2562	2563	2564	2565
***** Engine Pressures Data *****					
Main Oil Pres (psig)	61.3	61.3	61.2	65.3	43.7
Fuel Pressure (psig)	104.0	104.0	104.0	104.3	100.5
Compress Out (psig)	23.84	23.89	23.93	4.85	1.86
Boost after IC(psig)	22.64	22.78	22.83	4.23	1.66
Inlet Manifold(psig)	22.29	22.33	22.35	3.02	1.66
Inlet Manifold(psia)	36.53	36.56	36.59	17.25	15.90
Pre-Turbine (psig)	18.66	18.64	18.68	3.40	2.07
Exhaust Bk Pr ("HG)	2.31	2.29	2.34	.34	.15
Inlet Restrict("H2O)	12.18	11.76	11.66	2.05	.98
LFE Filter Pr ("H2O)	.01	.02	.02	.03	.03
LFE Delta Pr ("H2O)	-.01	-.01	-.01	-.01	-.01
H (lbH2O/lbAir)	.017	.017	.017	.017	.017
RH (out) (%)	50.93	50.85	50.80	50.78	50.74
Barometer ("Hg)	28.99	28.99	28.99	28.99	28.99
***** Natural Gas Composition *****					
NG % Methane	95.31	95.31	95.31	95.31	95.31
NG % Ethane	2.35	2.35	2.35	2.35	2.35
NG % Propane	.19	.19	.19	.19	.19
NG % CO2	1.32	1.32	1.32	1.32	1.32
NG % Nitrogen	.74	.74	.74	.74	.74
Butane Actual(%)	.07	.07	.07	.07	.07
MWT	16.92	16.92	16.92	16.92	16.92
Fuel LHV	20364.	20364.	20364.	20364.	20364.

SOUTHWEST RESEARCH INSTITUTE
Automotive Products and Emissions Research Analytical Laboratory

MACK E7 G
S/N 5N1311
Ethyl Oil for natural gas testing

Test Hours	500	501	550	600	650	700	750	800	850	900	950	1000
	(New oil)											
Base Number, mg KOH/g (D4739)	3.60	3.21	2.98	2.48	2.07	1.78	1.47	1.30	1.12	0.91	1.05	0.76
Elements by ICP, ppm (D5185)												
Barium (Ba)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Boron (B)	44	40	21	11	9	9	10	12	13	13	12	15
Calcium (Ca)	841	851	914	912	922	954	948	942	989	1003	1046	1036
Chromium (Cr)	<1	<1	<1	<1	<1	1	1	1	1	2	2	2
Copper (Cu)	<1	5	12	25	37	44	50	60	72	85	104	120
Iron (Fe)	1	2	3	4	4	5	6	9	9	10	13	14
Lead (Pb)	<1	2	4	4	5	7	7	8	10	10	14	17
Magnesium (Mg)	241	197	223	223	232	236	239	249	253	264	260	258
Molybdenum (Mo)	133	124	130	130	133	135	139	143	144	149	154	155
Phosphorus (P)	588	575	591	570	570	575	577	576	600	604	614	612
Silicon (Si)	6	5	6	8	9	11	11	12	11	11	10	10
Zinc (Zn)	634	643	647	657	673	692	683	699	719	742	782	761
Acid Number, mg KOH/g (D664)												
Buffer	1.14	1.04	1.04	1.27	1.45	1.98	1.95	2.09	2.20	2.31	2.43	2.51
Kinematic Viscosity, cSt (D446)												
40C	110.31	111.47	112.95	111.90	113.50	113.10	113.20	114.70	116.46	117.22	117.38	118.20
100C	13.86	14.07	14.23	14.20	14.19	14.15	14.08	14.11	14.16	14.16	14.12	14.13
Infrared Spectra (E168), ABS/cm												
Oxidation (5.8)		1.92	3.03	3.63	4.97	7.07	9.07	10.98	12.43	14.52	15.52	17.15
Nitration (6.1)		0.36	0.36	0.18	0.27	0.73	2.18	2.27	3.81	5.81	5.17	5.63

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APPENDIX E

ETHYL OIL ANALYSIS RESULTS

VALVE RECESSION DATA

Exhaust Valve Stem Height Measurements (mm)

Test Hrs	Eng Hrs	1 in.	1 ex.	2 in.	2 ex.	3 in.	3 ex.	4 in.	4 ex.	5 in.	5 ex.	6 in.	6 ex.
0	288.1	13.088	13.133	13.088	13.118	13.105	13.277	13.122	13.162	13.058	13.152	13.096	13.215
250	560.3	13.094	13.201	13.169	13.219	13.203	13.467	13.125	13.214	13.113	13.195	13.123	13.248
500	813.7	13.104	13.247	13.186	13.27	13.272	13.622	13.18	13.331	13.203	13.198	13.128	13.264
750	1066.9	13.14	13.265	13.23	13.318	13.377	13.765	13.186	13.346	13.233	13.229	13.135	13.271
1000	1321.6	13.148	13.298	13.25	13.368	13.398	13.904	13.186	13.347	13.235	13.229	13.165	13.305

Calculated Exhaust Valve Recession (mm)

Test Hrs	Eng Hrs	1 in.	1 ex.	2 in.	2 ex.	3 in.	3 ex.	4 in.	4 ex.	5 in.	5 ex.	6 in.	6 ex.
0	288.1	0	0	0	0	0	0	0	0	0	0	0	0
250	560.3	0.006	0.068	0.081	0.101	0.098	0.19	0.003	0.052	0.055	0.043	0.027	0.033
500	813.7	0.016	0.114	0.098	0.152	0.167	0.345	0.058	0.169	0.145	0.046	0.032	0.049
750	1066.9	0.052	0.132	0.142	0.2	0.272	0.488	0.064	0.184	0.175	0.077	0.039	0.056
1000	1321.6	0.06	0.165	0.162	0.25	0.293	0.627	0.064	0.185	0.177	0.077	0.069	0.09

NOTE: in. = intake manifold side of engine, ex. = exhaust manifold side of engine

Intake Valve Stem Height Measurements (mm)

Test Hrs	Eng Hrs	1 in.	1 ex.	2 in.	2 ex.	3 in.	3 ex.	4 in.	4 ex.	5 in.	5 ex.	6 in.	6 ex.
0	288.1	14.139	14.011	14.002	13.908	14.137	13.964	14.075	14.062	13.949	13.95	14.017	13.958
250	560.3	14.149	14.013	14.004	13.897	14.148	13.968	14.076	14.065	13.965	13.955	14.023	13.965
500	813.7	14.152	14.014	14.004	13.906	14.148	14.001	14.117	14.072	13.967	13.956	14.023	13.963
750	1066.9	14.152	14.013	14.004	13.912	14.148	14.002	14.118	14.065	13.969	13.957	14.025	13.963
1000	1321.6	14.152	14.015	14.004	13.912	14.148	14.002	14.118	14.072	13.971	13.957	14.024	13.963

Calculated Intake Valve Recession (mm)

Test Hrs	Eng Hrs	1 in.	1 ex.	2 in.	2 ex.	3 in.	3 ex.	4 in.	4 ex.	5 in.	5 ex.	6 in.	6 ex.
0	288.1	0	0	0	0	0	0	0	0	0	0	0	0
250	560.3	0.01	0.002	0.002	-0.011	0.011	0.004	0.001	0.003	0.016	0.005	0.006	0.007
500	813.7	0.013	0.003	0.002	-0.002	0.011	0.037	0.042	0.01	0.018	0.006	0.006	0.005
750	1066.9	0.013	0.002	0.002	0.004	0.011	0.038	0.043	0.003	0.02	0.007	0.008	0.005
1000	1321.6	0.013	0.004	0.002	0.004	0.011	0.038	0.043	0.01	0.022	0.007	0.007	0.005

NOTE: in. = intake manifold side of engine, ex. = exhaust manifold side of engine

APPENDIX F

VALVE STEM HEIGHT MEASUREMENT AND RECESSION DATA

= Cell 05 MAC4 Project Low-Speed Data =

***** Test Cell Run Information *****

Run Number	2566
Year	1998
Operator Initials	<..??..>
Julian Day	AUG., 15
Time (Seconds)	17:49:19
Ignition Timing	0.0
Test Hours	499.1
Test Type Code	1

***** Engine Performance Data *****

Engine Speed (rpm)	560
Torque (ft/lbs)	37.1
BHP	4.0
BSFC (lbs/BHp-hr)	.827
BTE (%)	15.1
BMEP (psi)	7.7
Density	.318
Density (New)	.322
NG Flow (lbs/hr)	3.27
NG Flow [MM] (lbs/hr)	3.27
NG Flow [RM] (lbs/hr)	-.00
NG Flow(New) (lbs/hr)	-.00
NG Flow/E+6 (BTU/hr)	.067
Air Flow (lbs/hr)	9.80
Volumetric Eff (%)	7.0
Equivalence Ratio	5.463
GEM Timing	0.0
GEM Equiv. Ratio	0.00
GEM Vol. Eff.	0.00
BlowBy (cfm)	.27

***** Engine Temperature Data *****

Water In	(Deg F)	110
Water Out	(Deg F)	121
Oil Sump	(Deg F)	232
Oil Gallery	(DEG F)	197
Ambient/LFE	(Deg F)	90
Boost B4 IC	(Deg F)	201
Boost AF IC	(Deg F)	91
Intake	(Deg F)	124
Gas @ Meter	(Deg F)	102
Exhaust 1	(Deg F)	755
Exhaust 2	(Deg F)	793
Exhaust 3	(Deg F)	810
Exhaust 4	(Deg F)	796
Exhaust 5	(Deg F)	792
Exhaust 6	(Deg F)	758
Pre-Turbine	(Deg F)	845
Stack	(Deg F)	783

= Cell 05 MAC4 Project Low-Speed Data =
(continued)

Run Number 2566

***** Engine Pressures Data *****

Main Oil Pres	(psig)	24.5
Fuel Pressure	(psig)	99.2
Compress Out	(psig)	.06
Boost after IC	(psig)	.09
Inlet Manifold	(psig)	-7.74
Inlet Manifold	(psia)	6.49
Pre-Turbine	(psig)	.46
Exhaust Bk Pr	("HG)	.02
Inlet Restrict	("H2O)	-.18
LFE Filter Pr	("H2O)	.03
LFE Delta Pr	("H2O)	-.01
H	(lbH2O/lbAir)	.017
RH (out)	(%)	50.76
Barometer	("Hg)	28.99

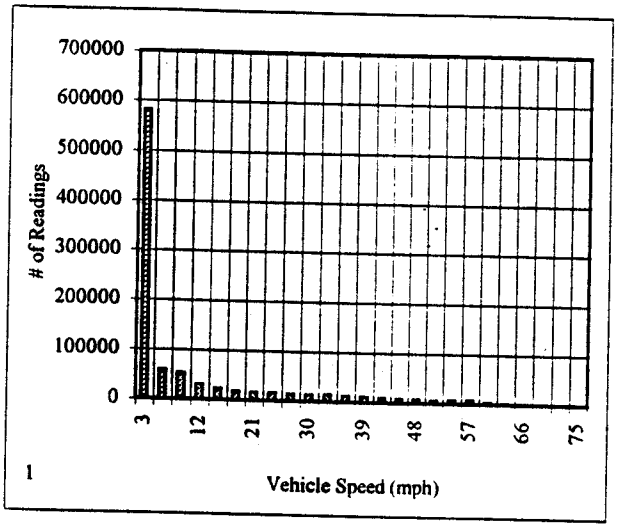
***** Natural Gas Composition *****

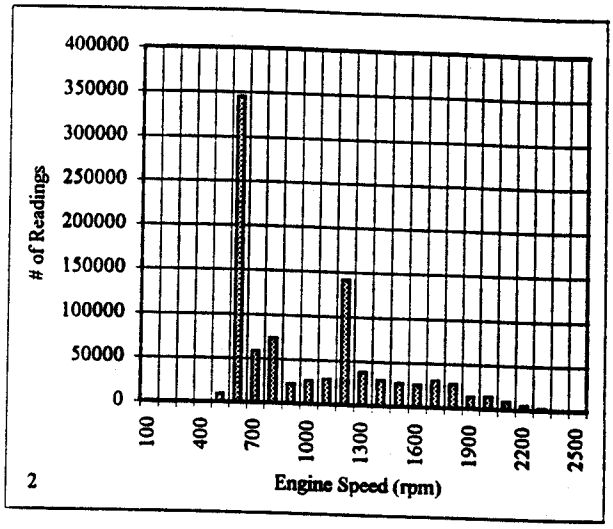
NG % Methane	95.31
NG % Ethane	2.35
NG % Propane	.19
NG % CO2	1.32
NG % Nitrogen	.74
Butane Actual(%)	.07
MWT	16.92
Fuel LHV	20364.

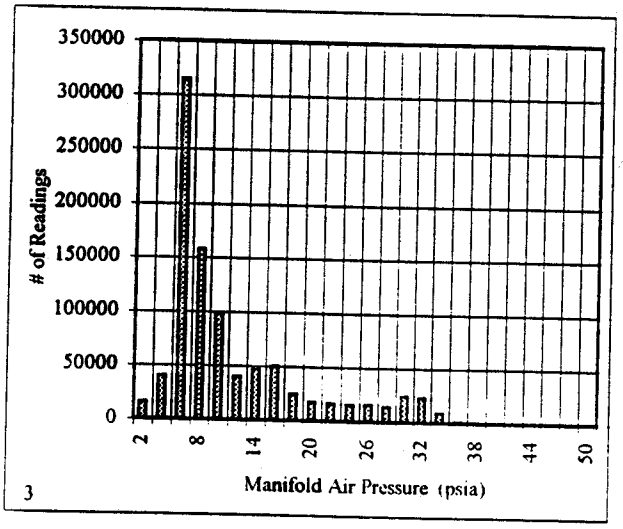
APPENDIX F

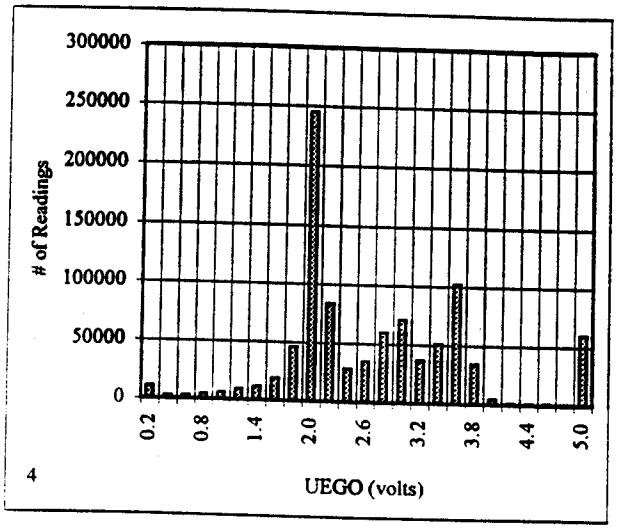
HISTOGRAMS FROM THE DATA LOGGER

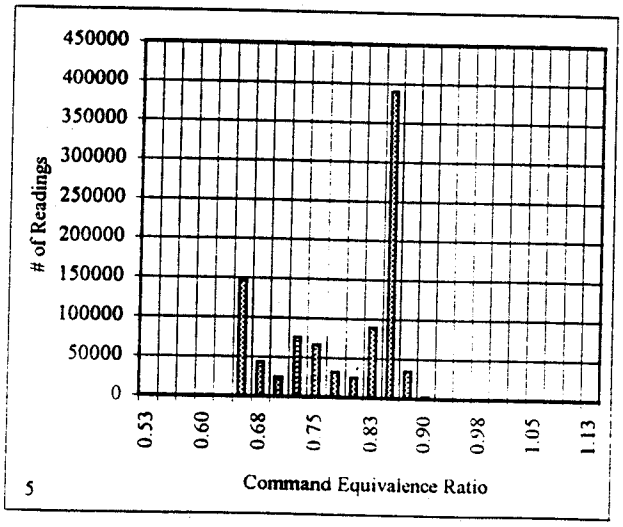
MACK MR LNG Truck
Histogram

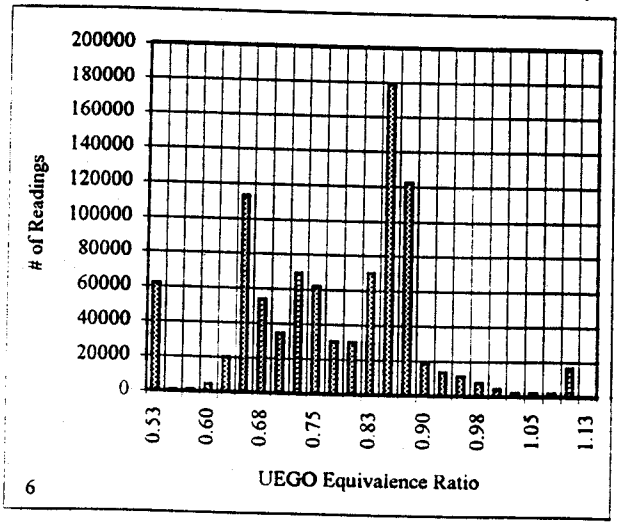




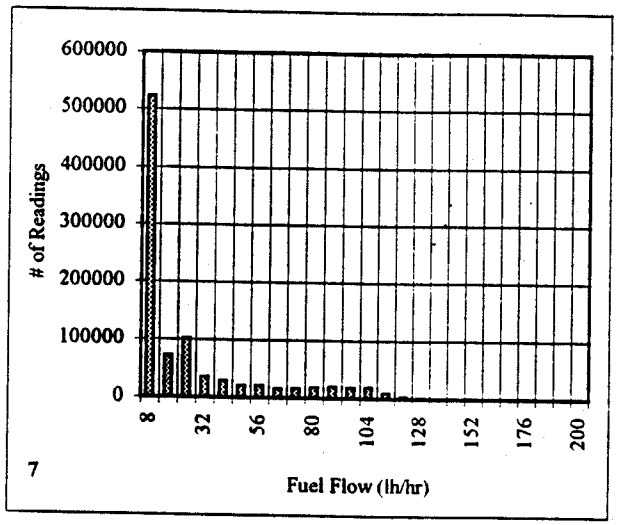


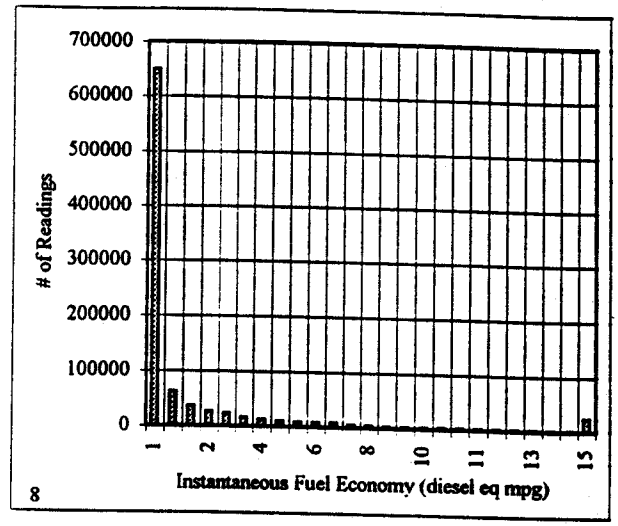


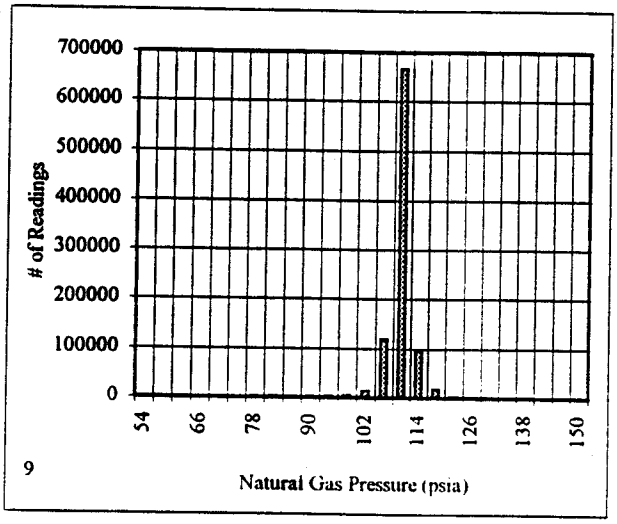


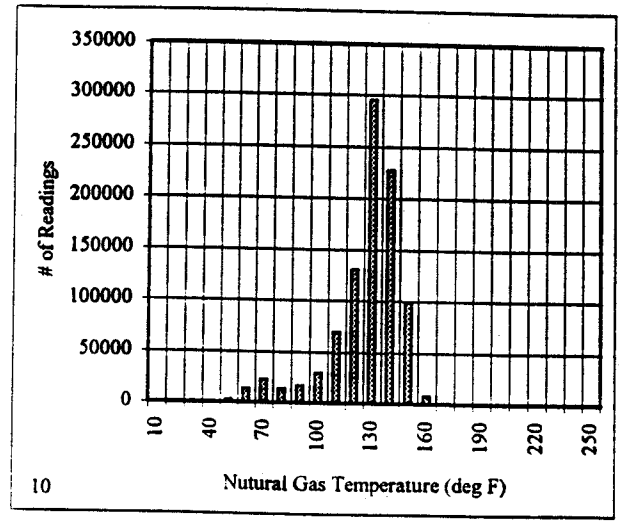


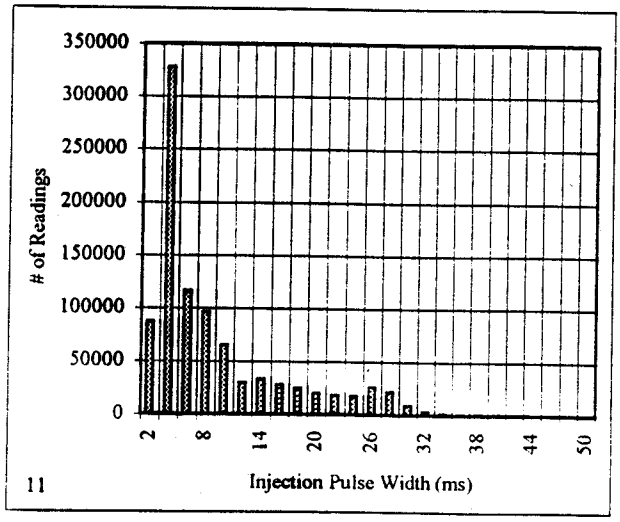
MACK MR LNG Truck
Histogram

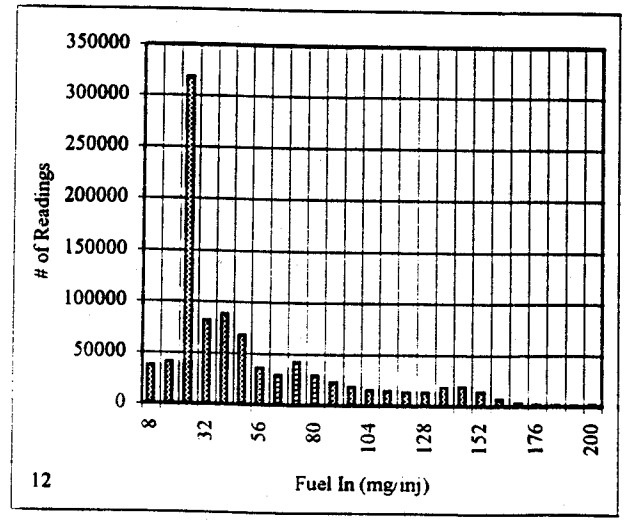




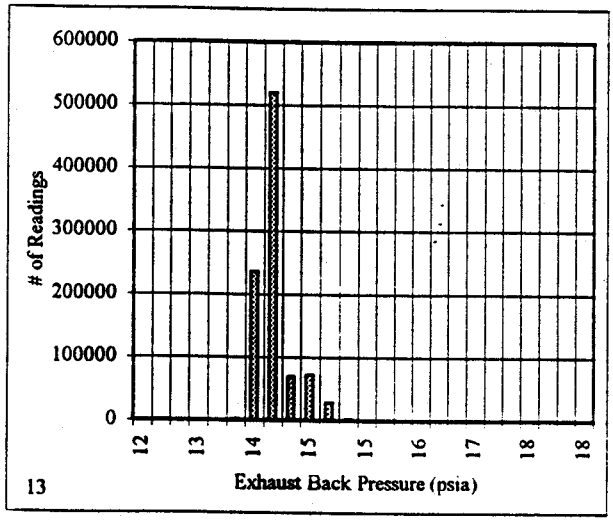








MACK MR LNG Truck
Histogram



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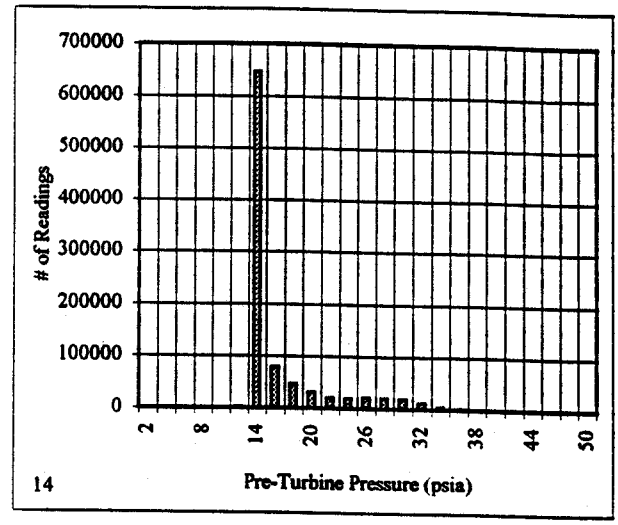

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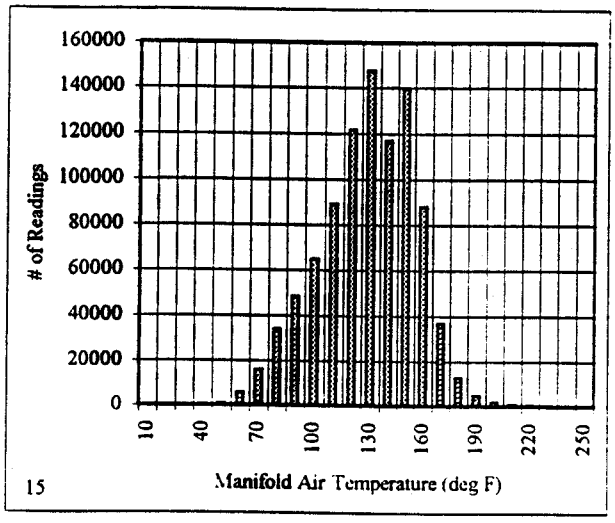

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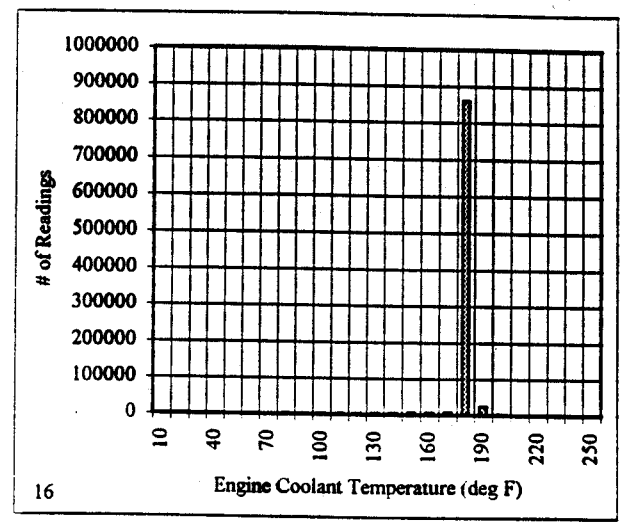

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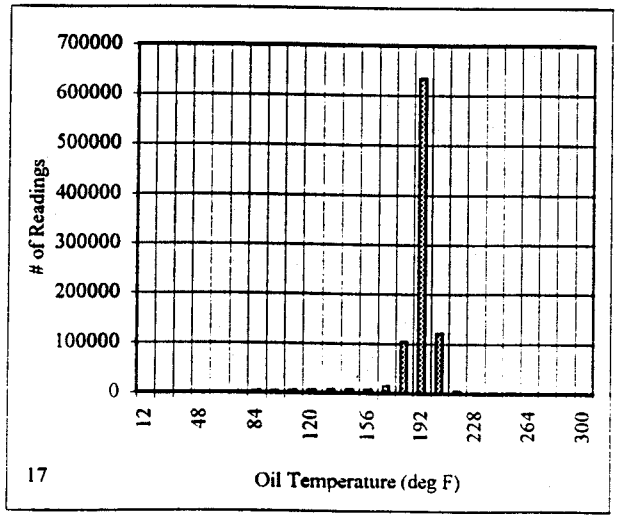

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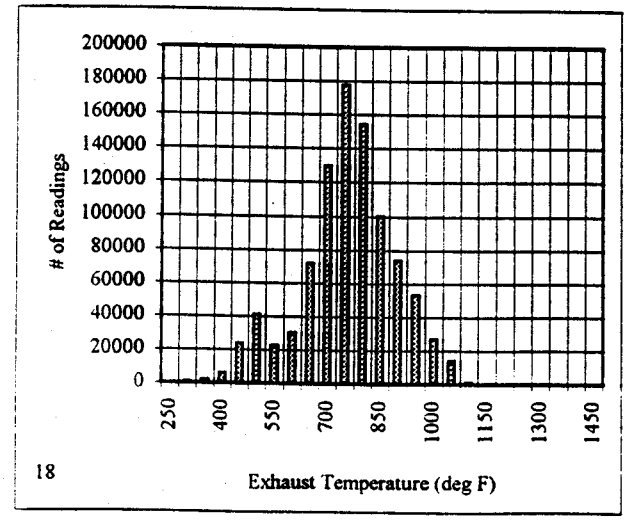

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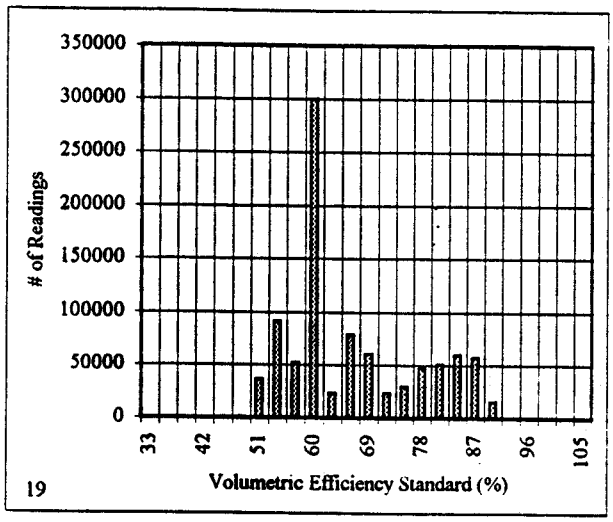
MACK MR LNG Truck
Histogram



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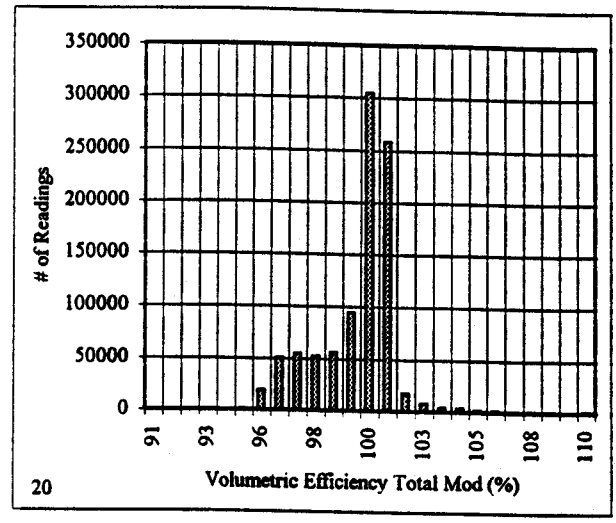

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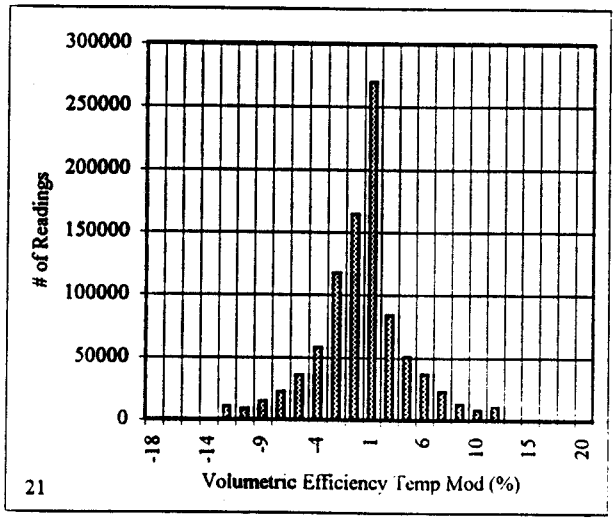

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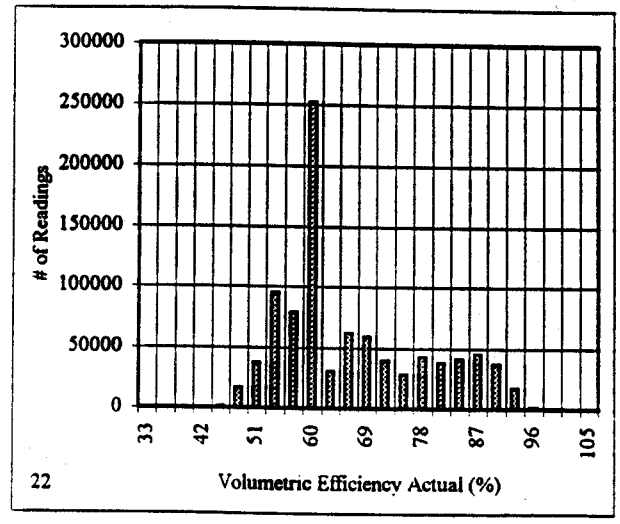

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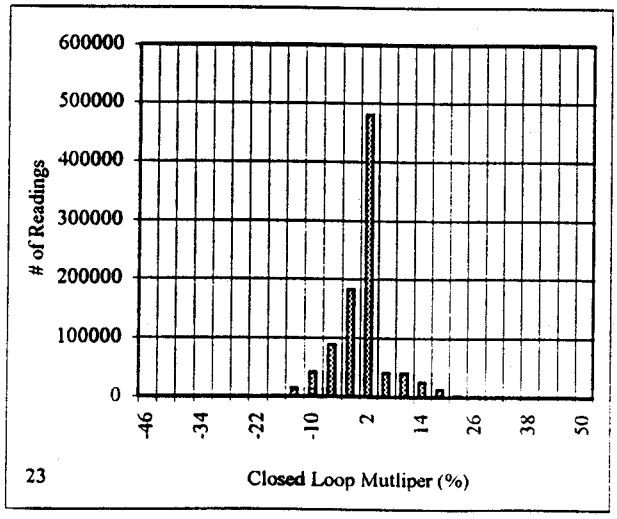

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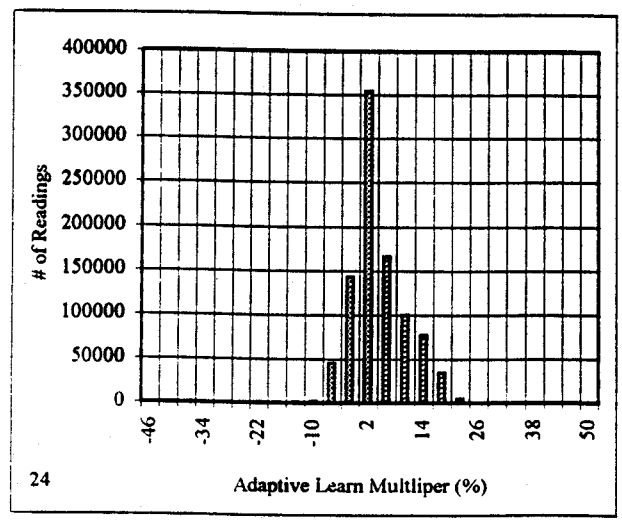

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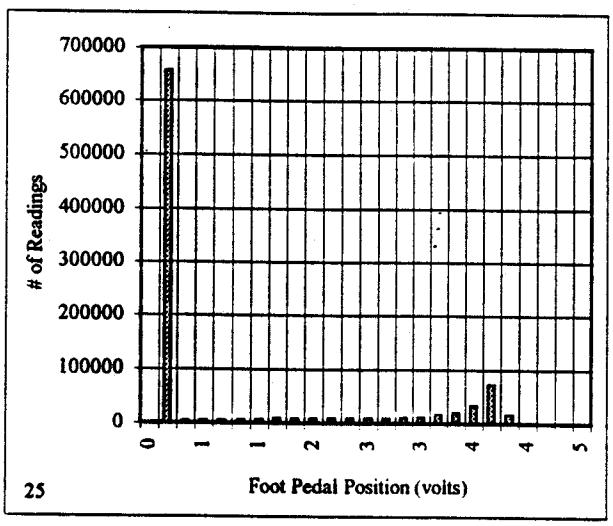
MACK MR LNG Truck
Histogram



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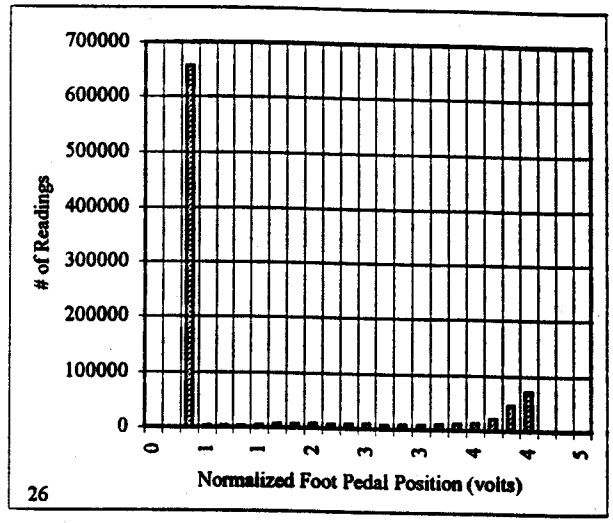

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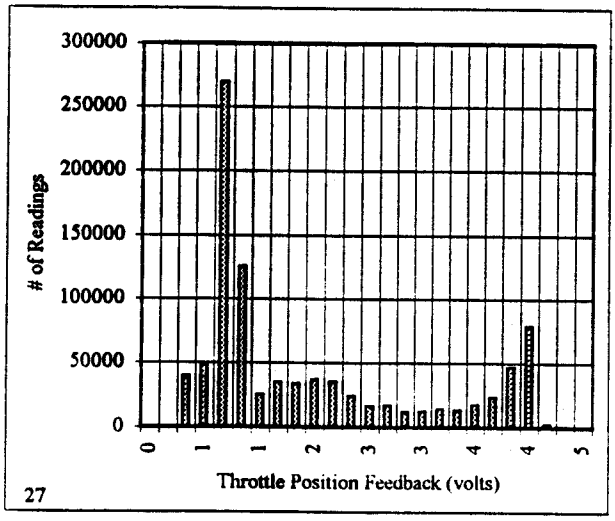

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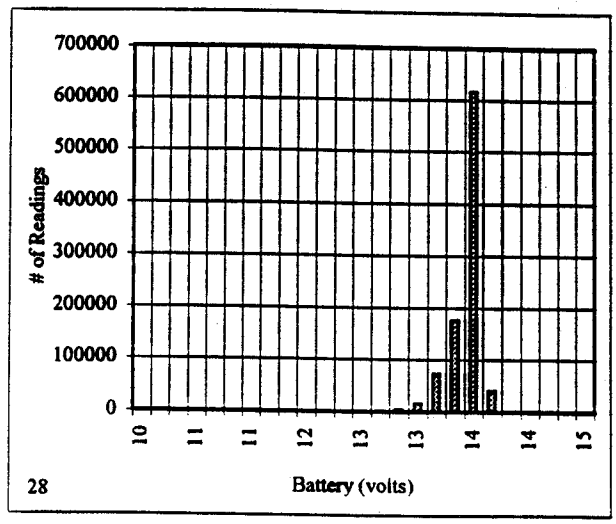

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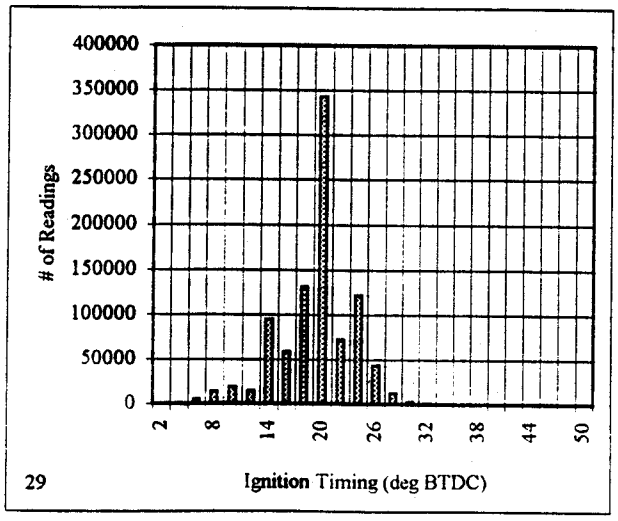

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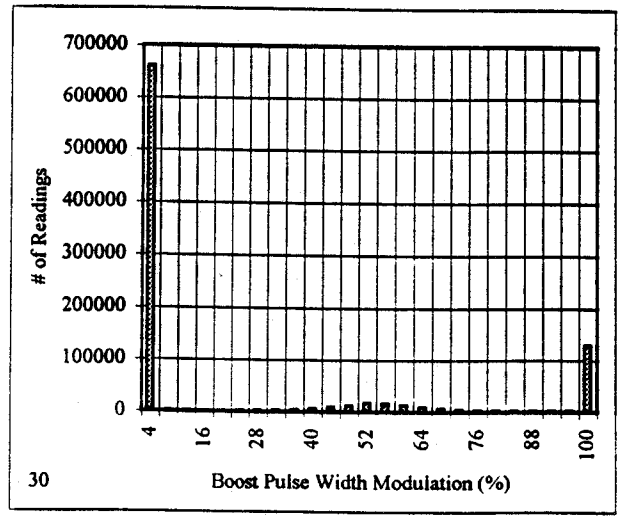

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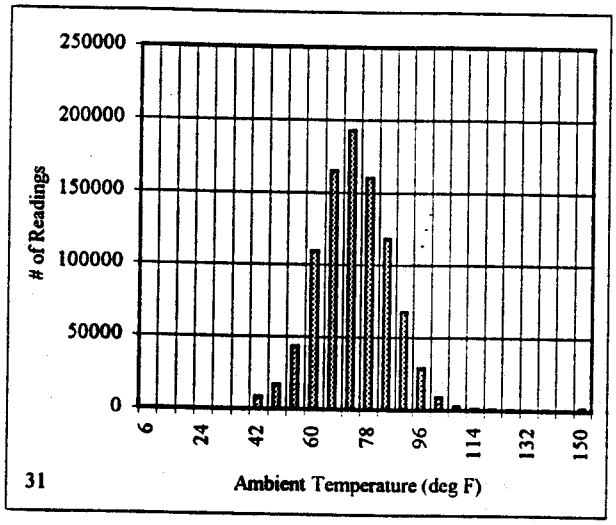
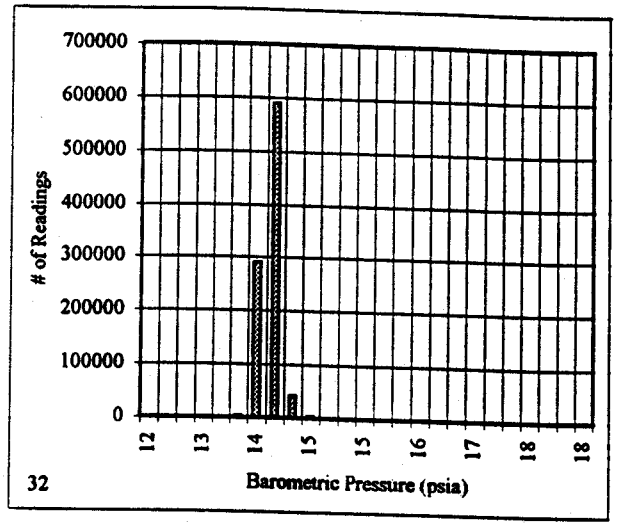
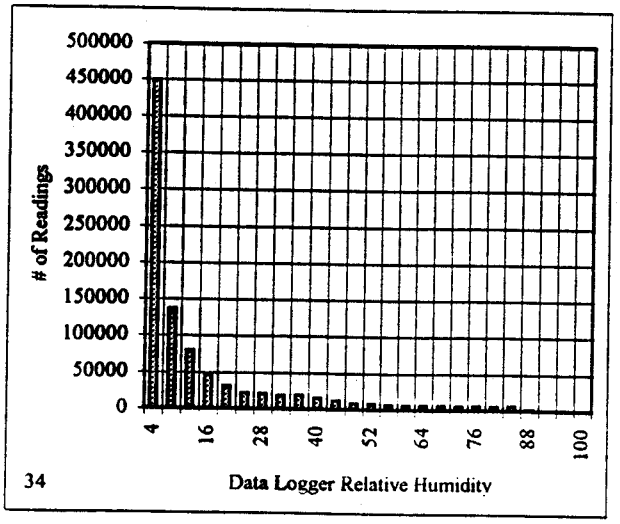
MACK MR LNG Truck
Histogram







APPENDIX G

FINAL REPORT FOR

TRANSIENT EMISSIONS TESTING ON A MACK E7G ENGINE

SwRI PROJECT NO. 03-2377

Chin

SOUTHWEST RESEARCH INSTITUTE

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ENGINE AND VEHICLE RESEARCH DIVISION
FAX: (210) 522-2019

April 15, 1999

Mr. John Bartel
Mack Trucks, Inc.
13302 Pennsylvania Avenue
Hagerstown, MD 21742

Subject: Southwest Research Institute Project No. 03-2377, Final Report, "Transient Emissions Testing on a Mack E7G Engine"

1.0 BACKGROUND

The goal of this project was to perform transient emissions tests after a 1000-hour durability test. This report covers one "0" hour transient emissions test and one "0" hour idle CO test in addition to two "1000" hour transient emissions tests (with the same calibration as the "0" hour test), two 325 bhp transient emissions test (with a revised calibration), and two 350 bhp transient emissions test (with a revised calibration).

Funding for the break-in and 0 hour transient emissions tests was provided by the "Mack LNG Vehicle Development" project (SwRI Project No. 03-7276) conducted by SwRI for Mack Trucks. Funding for the 1000-hour durability tests was provided by the "1000-Hour Super Trhermal Cycle Durability Test on a Mack E-7 Natural Gas Fueled Engine" project (SwRI Project No. 03-1248) conducted by SwRI for Mack Trucks. The transient emissions tests were conducted in SwRI's Automotive Products and Emissions Research Division, Department of Emissions Research.

2.0 TECHNICAL DISCUSSION

A Mack E-7 natural gas fueled engine (S/N 5N1311) was received at SwRI for a 125-hour break-in, a "0" hour transient emissions and idle CO test, a 1000-hour durability test, and "1000" hour transient emissions tests.

The test schedule for the engine is shown in Table 1. The break-in consisted of 125 hours at rated power (1950 rpm, 242 kW). Miscellaneous tests were conducted to ensure proper operation over the entire range of engine conditions. Transient emissions tests were conducted to obtain a "0" hour test for determination of a deterioration factor. A 1000-hour durability test was conducted on the Mack super thermal cycle (STC). Details of the durability test, including maintenance before and during the tests, are included in the final report for the "1000-Hour Super Thermal Cycle Durability Test on a Mack E-7 Natural Gas Fueled Engine", SwRI Project No. 03-1248, December 1998. Transient emissions testing was conducted following the 1000-hour durability test.

Table 1. Runtime History of the Engine

Test	Test Time (hours)	Miscellaneous Time (hours)	Total Engine Time (hours)
Break-In	125.0	35.5	160.5
Miscellaneous Tests	--	15.8	176.3
Transient Emissions	--	111.8	288.1
STC Test	1000	37.9	1326.0
Transient Emissions	--	65.9	1391.9

The transient emissions tests were conducted on the engine as shown in Table 2. An idle CO test was conducted at "0" test hours with the deterioration factor calibration and the Garrett turbocharger. The calibration at idle is identical for the deterioration, 235 BHP, and 350 BHP calibrations. All tests were conducted on natural gas, which meets the CARB specification for emissions testing. All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N. A test facilities description, test results, and natural gas composition are included in Appendices A-G for the transient emissions tests. Idle CO emissions tests results are included in Appendix H.

Table 2. Transient Emissions Testing

Test Numbers	Test	Calibration	Notes
612-C1 612-H1	"0" Hour Test	Deterioration Factor	Transient test performed after the 125 hour break-in.
218-C1 218-H1	"1000" Hour Test	Deterioration Factor	No Maintenance after the 1000-hour durability test
219-C1 219-H1	Test at 325 bhp with Garrett turbocharger	325 BHP Certification	Maximum Turbo Lag Enrichment set to 8%
222-C1 222-H1	"1000" Hour Test	Deterioration Factor	Regapped spark plugs
224-C1 224-H1	Test at 325 bhp with Schwitzer turbocharger	325 BHP Certification	Maximum Turbo Lag Enrichment set to 13%
225-C1 225-H1	Test at 350 bhp with Schwitzer turbocharger	350 BHP Certification	Maximum Turbo Lag Enrichment set to 10%
225-C2 225-H2	Test at 350 bhp with Schwitzer turbocharger	350 BHP Certification	Maximum Turbo Lag Enrichment set to 8%

The tests for the deterioration factors are shown in Table 3. The "1000" hour test is with regapped spark plugs. The projection to 290,000 miles was calculated as shown in Table 4.

Table 3. Deterioration Factor for the Mack E7G Engine

	"0" Hour Test (g/bhp-hr)	"1000" Hour Test (g/bhp-hr)	Deterioration Factor 0-290k miles	Deterioration Factor 76.551-290k miles
THC	5.271	3.927	0.000	0.000
NMHC	0.957	0.506	0.000	0.000
NMHC+NO_x	2.606	2.202	0.178	0.131
NO_x	1.649	1.696	0.178	0.131
CO	1.641	1.607	0.000	0.000
Particulate	0.042	0.030	0.000	0.000
Formaldehyde	0.161	0.145	0.000	0.000

Table 4. Deterioration Factor Calculation

Distance (miles)	290,000
Fuel Economy of the Diesel Truck (mpg)	5.7
Diesel Equivalent Fuel Economy of the Natural Gas Truck (mpg)	4.8
Actual LNG Fuel Economy (mpg)	2.97
Fuel Usage for 290,000 miles (gal)	97667
LNG Fuel Density (lbs/gal)	3.84
Fuel Usage for 290,000 miles (lbs)	375,042
Durability Test Time (hours)	1000
Durability Test Fuel Flow (lb/gal)	99
Durability Test Fuel Usage (lb)	99,000
Equivalent Durability Distance (miles)	76,551
Time to 290,000 Miles (hours)	3,788

Official test results for the Schwitzer turbocharger at 325 bhp and the Schwitzer turbocharger at 350 bhp (maximum turbo lag enrichment set to 10%) are shown in Table 5. The certification levels are shown in Table 6. Certification levels were calculated using the 77.551-290k deterioration factor.

Table 5. Official Test Results

	325 BHP	350 BHP
HC/OMHCE (g/bhp-hr)	3.075	2.905
NMHC/OMNMHCE (g/bhp-hr)	0.324	0.276
HC+NOx (g/bhp-hr)	2.399	2.468
CARBON MONOXIDE (g/bhp-hr)	1.385	1.319
OXIDE OF NITROGEN (g/bhp-hr)	2.075	2.192
PARTICULATE (g/bhp-hr)	0.029	0.026
FORMALDEHYDE (g/bhp-hr)	0.135537	0.116236
IDLE CO (%)	0.11	0.11
CO2 (g/bhp-hr)	462.4	448.9

Table 6. Certification Levels

	325 BHP	350 BHP
HC/OMHCE (g/bhp-hr)	3.1	2.9
NMHC/OMNMHCE)g/bhp-hr)	0.324	0.276
HC+NOx (g/bhp-hr)	2.53	2.60
CARBON MONOXIDE (g/bhp-hr)	1.4	1.3
OXIDE OF NITROGEN (g/bhp-hr)	2.2	2.3
PARTICULATE (g/bhp-hr)	0.03	0.03
FORMALDEHYDE (g/bhp-hr)	0.136	0.116

CLOSURE

If you have any questions or comments, please contact me by telephone at (210) 52-2570, by fax at (210) 522-2019, or by e-mail at jchiu@swri.edu.

Sincerely,

James P. Chiu
Senior Research Engineer
Gas and Industrial Engine Development
Department of Engine Research

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Approved:

Daniel Dickey, Director
Engine Research Department
Division of Engine and Vehicle Research

Appendix A
Test Numbers 612-C1 and 612-H2
"0" Hour Transient Emissions Test
Deterioration Factor Calibration
Garrett Turbocharger

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 3. Cell 3 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 750 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used for engine throttle control and a Compudas computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 06/12/1998 Time: 09:16
Program HDT: 4.03-C
Cell: 3 Bag Cart: 1

NAT GAS CNG, CARB-CNG
HCR: 3.838 FID Resp: 1.00
H= 0.230 C= 0.714 O= 0.000 X= 0.056
Engine Oil:

Test Numbers
Cold: 612-C1 Hot: 612-H1

Brake-Specific Emission Results

BSTHC (Cell)	5.271	g/hp-hr	7.069	g/kW-hr
CO	1.641	g/hp-hr	2.200	g/kW-hr
NOx (Cell)	1.649	g/hp-hr	2.211	g/kW-hr
Particulate	0.042	g/hp-hr	0.056	g/kW-hr
CO2	499.4	g/hp-hr	669.72	g/kW-hr
BSFC	0.436	lb/hp-hr	0.584	kg/kW-hr
NMHC	0.957	g/hp-hr	1.283	g/kW-hr
CH4	4.314	g/hp-hr	5.786	g/kW-hr
Work:	23.84	hp-hr	17.78	kW-hr
Reference Work:	24.94	hp-hr	18.60	kW-hr

Analyzed: 06/17/1998 14:41

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 612-C1
Date: 06/12/1998 Time: 09:16
Program HDT: 4.03-C
Cell: 3 Bag Cart: 1

NAT GAS CNG, CARB-CNG
HCR: 3.838 FID Resp: 1.00
H= 0.230 C= 0.714 O= 0.000 X= 0.056
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.08	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	79.0	°F	26.1 °C
Dew Point:	59.8	°F	15.4 °C
Abs. Humidity:	79.3	gr/lb	11.3 g/kg
Rel. Humidity:	52	%	
Dilution Air:			
Temperature:	78.0	°F	25.6 °C
Abs. Humidity	100.3	gr/lb	14.3 g/kg
Rel. Humidity:	67	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,117.1	59.96
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.49	0.04
Gas Meter 2:	2.40	0.07
Sample Rate:	0.91	0.03
Chemistry Sample Rate:	2.78	0.08
Total Flow Rate:	2,120.77	60.06

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		169.47	ppm	
HC Bckgrd	n/a		6.68	ppm	
CO Sample	30.7	2	29.86	ppm	
CO Bckgrd	0.5	2	0.47	ppm	
NOx Sample	n/a		19.87	ppm	(Dry)
NOx Bckgrd	0.1	2	0.10	ppm	
CO2 Sample	71.2	1	0.6107	%	
CO2 Bckgrd	8.7	1	0.0583	%	
CH4 Sample	n/a	n/a	133.47	ppm	(1.00)
CH4 Bckgrd	n/a	n/a	2.84	ppm	

Particulate Data

Filter Number:	4693.0-78 (pair)
Weight Gain, mg:	0.462
Sample Multiplier:	2.324

Correction Factors

NOx Humidity CF:	1.011
Dry-to-Wet CF, Sample:	0.966
Dry-to-Wet CF, Bckgrd:	0.977
Dilution Factor:	15.42

Test Cycle Data

Sample Time:	1,206.40	sec		
Work:	23.92	hp-hr	17.84	kW-hr
Reference Work:	24.94	hp-hr	18.60	kW-hr
Total Volume (Vmix):	42,585.8	scf	1,206.05	scm

Corrected Concentrations

HC	163.22	ppm
CO	28.25	ppm
NOx	19.10	ppm
CO2	0.5562	%
CH4	130.81	ppm
RHC	32.41	ppm

Brake-Specific Emission Results

BSTHC (Cell)	5.409	g/hp-hr	7.253	g/kW-hr
CO	1.658	g/hp-hr	2.223	g/kW-hr
NOx (Cell)	1.862	g/hp-hr	2.497	g/kW-hr
Particulate	0.045	g/hp-hr	0.060	g/kW-hr
CO2	513.0	g/hp-hr	687.97	g/kW-hr
BSFC	0.447	lb/hp-hr	0.272	kg/kW-hr
NMHC	1.012	g/hp-hr	1.357	g/kW-hr
CH4	4.397	g/hp-hr	5.896	g/kW-hr

Mass Emissions

HC		129.371	grams	
CO		39.660	grams	
NOx		44.539	grams	
Particulate		1.074	grams	
CO2		12.271	kg	
CH4		105.173	grams	
RHC		24.199	grams	
Fuel	10.70 lb		4.85 kg	

alyzed: 06/17/1998 14:41

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 612-C1
Date: 06/12/1998 Time: 09:16
Program HDT: 4.03-C
Cell: 3 Bag Cart: 1

NAT GAS CNG, CARB-CNG
HCR: 3.838 FID Resp: 1.00
H= 0.230 C= 0.714 O= 0.000 X= 0.056
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.844	ppm	0.007	ppm
Mass	4,127.64	mg		
Acetaldehyde				
Concentration	0.099	ppm	0.001	ppm
Mass	208.69	mg		
Acrolein				
Concentration	0.020	ppm	0.000	ppm
Mass	55.13	mg		
Acetone				
Concentration	0.022	ppm	0.004	ppm
Mass	52.59	mg		
Propionaldehyde				
Concentration	0.016	ppm	0.000	ppm
Mass	43.93	mg		
Crotonaldehyde				
Concentration	0.007	ppm	0.000	ppm
Mass	23.93	mg		
Isobutyr + MEK				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.001	ppm	0.000	ppm
Mass	2.81	mg		

Brake-Specific Results

Formaldehyde	172.560	mg/hp-hr	Crotonaldehyde	1.000	mg/hp-hr
Acetaldehyde	8.725	mg/hp-hr	Isobutyr + MEK	0.000	mg/hp-hr
Acrolein	2.305	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	2.199	mg/hp-hr	Hexanaldehyde	0.118	mg/hp-hr
Propionaldehyde	1.837	mg/hp-hr			

Analyzed: 06/17/1998 14:41

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 612-H1
Date: 06/12/1998 Time: 09:56
Program HDT: 4.03-C
Cell: 3 Bag Cart: 1

NAT GAS CNG, CARB-CNG
HCR: 3.838 FID Resp: 1.00
H= 0.230 C= 0.714 O= 0.000 X= 0.056
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.09	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	80.0	°F	26.7 °C
Dew Point:	60.0	°F	15.6 °C
Abs. Humidity:	79.8	gr/lb	11.4 g/kg
Rel. Humidity:	51	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	104.3	gr/lb	14.9 g/kg
Rel. Humidity:	68	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,117.4	59.97
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.49	0.04
Gas Meter 2:	2.39	0.07
Sample Rate:	0.90	0.03
Chemistry Sample Rate:	2.75	0.08
Total Flow Rate:	2,121.04	60.07

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		163.66	ppm	
HC Bckgrd	n/a		6.39	ppm	
CO Sample	30.2	2	29.37	ppm	
CO Bckgrd	0.5	2	0.47	ppm	
NOx Sample	n/a		17.14	ppm	(Dry)
NOx Bckgrd	0.1	2	0.10	ppm	
CO2 Sample	69.6	1	0.5908	%	
CO2 Bckgrd	8.6	1	0.0576	%	
CH4 Sample	n/a	n/a	130.29	ppm	(1.00)
CH4 Bckgrd	n/a	n/a	3.05	ppm	

Particulate Data

Filter Number:	4695.0-80 (pair)
Weight Gain, mg:	0.421
Sample Multiplier:	2.345

Correction Factors

NOx Humidity CF:	1.013
Dry-to-Wet CF, Sample:	0.965
Dry-to-Wet CF, Bckgrd:	0.977
Dilution Factor:	15.94

Test Cycle Data

Sample Time:	1,206.50	sec		
Work:	23.83	hp-hr	17.77	kW-hr
Reference Work:	24.94	hp-hr	18.60	kW-hr
Total Volume (Vmix):	42,595.2	scf	1,206.32	scm

Corrected Concentrations

HC	157.67	ppm
CO	27.79	ppm
NOx	16.45	%
CO2	0.5368	%
CH4	127.43	ppm
RHC	30.24	ppm

Brake-Specific Emission Results

BSTHC (Cell)	5.248	g/hp-hr	7.038	g/kW-hr
CO	1.638	g/hp-hr	2.196	g/kW-hr
NOx (Cell)	1.613	g/hp-hr	2.163	g/kW-hr
Particulate	0.041	g/hp-hr	0.056	g/kW-hr
CO2	497.1	g/hp-hr	666.67	g/kW-hr
BSFC	0.434	lb/hp-hr	0.264	kg/kW-hr
NMHC	0.947	g/hp-hr	1.271	g/kW-hr
CH4	4.301	g/hp-hr	5.767	g/kW-hr

Mass Emissions

HC	125.060	grams		
CO	39.026	grams		
NOx	38.433	grams		
Particulate	0.987	grams		
CO2	11.847	kg		
CH4	102.482	grams		
RHC	22.578	grams		
Fuel	10.33	lb	4.69	kg

Analyzed: 01/20/1999 14:52

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 612-H1
Date: 06/12/1998 Time: 09:56
Program HDT: 4.03-C
Cell: 3 Bag Cart: 1

NAT GAS CNG, CARB-CNG
HCR: 3.838 FID Resp: 1.00
H= 0.230 C= 0.714 O= 0.000 X= 0.056
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.610	ppm	0.007	ppm
Mass	3,785.62	mg		
Acetaldehyde				
Concentration	0.095	ppm	0.001	ppm
Mass	200.62	mg		
Acrolein				
Concentration	0.018	ppm	0.000	ppm
Mass	49.97	mg		
Acetone				
Concentration	0.018	ppm	0.004	ppm
Mass	39.73	mg		
Propionaldehyde				
Concentration	0.006	ppm	0.000	ppm
Mass	16.67	mg		
Crotonaldehyde				
Concentration	0.006	ppm	0.000	ppm
Mass	19.10	mg		
Isobutyr + MEK				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	158.859	mg/hp-hr	Crotonaldehyde	0.802	mg/hp-hr
Acetaldehyde	8.419	mg/hp-hr	Isobutyr + MEK	0.000	mg/hp-hr
Acrolein	2.097	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	1.667	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	0.700	mg/hp-hr			

Analyzed: 01/20/1999 14:52

Source:
Station #:
Station Name:
Field:

Report Date: 06/05/1998
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\037276eg.3

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.661	0.000	0.035	
METHANE	90.603	915.090	0.502	
CO2	0.000	0.000	0.000	
ETHANE	3.672	64.980	0.038	
H2S	0.000	0.000	0.000	
PROPANE	2.064	51.932	0.031	0.567
ISO-BUTANE	0.000	0.000	0.000	
BUTANE	0.000	0.000	0.000	
ISO-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1032.002	0.607	0.567

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1034.286
Sat. = 1017.456
Actual = 1034.286
(0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.567
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.567

Real Specific Gravity Calculated = 0.6079
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Remarks: _____

Appendix B
Test Numbers 218-C1 and 218-H1
"1000" Hour Transient Emissions Test
Deterioration Factor Calibration
Garrett Turbocharger
No Engine Maintenance

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 4. Cell 4 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 400 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 02/18/1999 Time: 11:20
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Test Numbers
Cold: 0218-C1 Hot: 0218-H1

Brake-Specific Emission Results

BSTHC (Cell)	3.863	g/hp-hr	5.180	g/kW-hr
CO	1.490	g/hp-hr	1.998	g/kW-hr
NOx (Cell)	1.763	g/hp-hr	2.365	g/kW-hr
Particulate	0.029	g/hp-hr	0.039	g/kW-hr
CO2	482.6	g/hp-hr	647.17	g/kW-hr
BSFC	0.421	lb/hp-hr	0.564	kg/kW-hr
NMHC	0.451	g/hp-hr	0.604	g/kW-hr
CH4	3.412	g/hp-hr	4.576	g/kW-hr
Work:	24.92	hp-hr	18.58	kW-hr
Reference Work:	24.41	hp-hr	18.20	kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0218-C1
Date: 02/18/1999 Time: 11:20
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.00	in Hg	98.2 kPa
Engine Inlet Air			
Temperature:	73.0	°F	22.8 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.7	gr/lb	11.5 g/kg
Rel. Humidity:	64	%	
Dilution Air:			
Temperature:	74.0	°F	23.3 °C
Abs. Humidity	52.1	gr/lb	7.4 g/kg
Rel. Humidity:	40	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,159.7	61.17
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.49	0.04
Gas Meter 2:	2.38	0.07
Sample Rate:	0.89	0.03
Chemistry Sample Rate:	2.50	0.07
Total Flow Rate:	2,163.13	61.26

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		146.31	ppm	
HC Bckgrd	n/a		3.80	ppm	
CO Sample	29.2	2	28.34	ppm	
CO Bckgrd	0.4	2	0.39	ppm	
NOx Sample	n/a		22.41	ppm	(Dry)
NOx Bckgrd	0.1	2	0.10	ppm	
CO2 Sample	62.1	1	0.5959	%	
CO2 Bckgrd	5.6	1	0.0509	%	
CH4 Sample	n/a	n/a	112.75	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	1.86	ppm	

Particulate Data

Filter Number:	1103.0-1 (pair)
Weight Gain, mg:	0.340
Sample Multiplier:	2.416

Correction Factors

NOx Humidity CF:	1.015
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.988
Dilution Factor:	15.83

Test Cycle Data

Sample Time:	1,207.90	sec		
Work:	24.86	hp-hr	18.54	kW-hr
Reference Work:	24.41	hp-hr	18.20	kW-hr
Total Volume (Vmix):	43,497.1	scf	1,231.86	scm

Corrected Concentrations

HC	142.75	ppm
CO	27.11	ppm
NOx	21.79	ppm
CO2	0.5482	%
CH4	111.01	ppm
RHC	17.31	ppm

Brake-Specific Emission Results

BSTHC (Cell)	4.198	g/hp-hr	5.630	g/kW-hr
CO	1.564	g/hp-hr	2.098	g/kW-hr
NOx (Cell)	2.096	g/hp-hr	2.811	g/kW-hr
Particulate	0.033	g/hp-hr	0.044	g/kW-hr
CO2	497.0	g/hp-hr	666.44	g/kW-hr
BSFC	0.434	lb/hp-hr	0.264	kg/kW-hr
NMHC	0.531	g/hp-hr	0.712	g/kW-hr
CH4	3.667	g/hp-hr	4.918	g/kW-hr

Mass Emissions

HC		104.362	grams	
CO		38.885	grams	
NOx		52.106	grams	
Particulate		0.821	grams	
CO2		12.355	kg	
CH4		91.163	grams	
RHC		13.199	grams	
Fuel	10.78 lb		4.89 kg	

Analyzed: 03/01/1999 16:14

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0218-C1
Date: 02/18/1999 Time: 11:20
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.402	ppm	0.003	ppm
Mass	3,604.01	mg		
Acetaldehyde				
Concentration	0.073	ppm	0.001	ppm
Mass	158.98	mg		
Acrolein				
Concentration	0.014	ppm	0.000	ppm
Mass	40.54	mg		
Acetone				
Concentration	0.004	ppm	0.002	ppm
Mass	6.35	mg		
Propionaldehyde				
Concentration	0.015	ppm	0.000	ppm
Mass	43.25	mg		
Crotonaldehyde				
Concentration	0.003	ppm	0.000	ppm
Mass	10.62	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.000	ppm
Mass	5.34	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	1.79	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	144.972	mg/hp-hr	Crotonaldehyde	0.427	mg/hp-hr
Acetaldehyde	6.395	mg/hp-hr	Isobutyr + MEK	0.215	mg/hp-hr
Acrolein	1.631	mg/hp-hr	Benzaldehyde	0.072	mg/hp-hr
Acetone	0.255	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.740	mg/hp-hr			

Analyzed: 03/01/1999 16:14

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0218-H1
Date: 02/18/1999 Time: 12:00
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	28.99	in Hg	98.2 kPa
Engine Inlet Air			
Temperature:	75.0	°F	23.9 °C
Dew Point:	58.8	°F	14.9 °C
Abs. Humidity:	76.7	gr/lb	11.0 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	74.0	°F	23.3 °C
Abs. Humidity	56.6	gr/lb	8.1 g/kg
Rel. Humidity:	44	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,160.1	61.18
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.48	0.04
Gas Meter 2:	2.38	0.07
Sample Rate:	0.90	0.03
Chemistry Sample Rate:	2.47	0.07
Total Flow Rate:	2,163.51	61.27

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		134.10	ppm	
HC Bckgrd	n/a		4.50	ppm	
CO Sample	27.5	2	26.68	ppm	
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		18.53	ppm	(Dry)
NOx Bckgrd	0.1	2	0.10	ppm	
CO2 Sample	60.0	1	0.5747	%	
CO2 Bckgrd	5.1	1	0.0464	%	
CH4 Sample	n/a	n/a	103.95	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	1.78	ppm	

Particulate Data

Filter Number:	1119.0-2 (pair)
Weight Gain, mg:	0.295
Sample Multiplier:	2.397

Correction Factors

NOx Humidity CF:	1.004
Dry-to-Wet CF, Sample:	0.976
Dry-to-Wet CF, Bckgrd:	0.987
Dilution Factor:	16.43

Test Cycle Data

Sample Time:	1,207.90	sec		
Work:	24.93	hp-hr	18.59	kW-hr
Reference Work:	24.41	hp-hr	18.20	kW-hr
Total Volume (Vmix):	43,505.2	scf	1,232.09	scm

Corrected Concentrations

HC	129.87	ppm
CO	25.68	ppm
NOx	17.99	ppm
CO2	0.5311	%
CH4	102.28	ppm
RHC	14.29	ppm

Brake-Specific Emission Results

BSTHC (Cell)	3.807	g/hp-hr	5.106	g/kW-hr
CO	1.477	g/hp-hr	1.981	g/kW-hr
NOx (Cell)	1.708	g/hp-hr	2.290	g/kW-hr
Particulate	0.028	g/hp-hr	0.038	g/kW-hr
CO2	480.2	g/hp-hr	643.97	g/kW-hr
BSFC	0.419	lb/hp-hr	0.255	kg/kW-hr
NMHC	0.437	g/hp-hr	0.586	g/kW-hr
CH4	3.370	g/hp-hr	4.519	g/kW-hr

Mass Emissions

HC		94.914	grams	
CO		36.830	grams	
NOx		42.580	grams	
Particulate		0.707	grams	
CO2		11.972	kg	
CH4		84.013	grams	
RHC		10.902	grams	
Fuel	10.43 lb		4.73 kg	

nalyzed: 03/01/1999 16:12

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0218-H1
Date: 02/18/1999 Time: 12:00
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.171	ppm	0.003	ppm
Mass	3,256.01	mg		
Acetaldehyde				
Concentration	0.065	ppm	0.001	ppm
Mass	140.76	mg		
Acrolein				
Concentration	0.013	ppm	0.000	ppm
Mass	35.29	mg		
Acetone				
Concentration	0.001	ppm	0.002	ppm
Mass	0.00	mg		
Propionaldehyde				
Concentration	0.014	ppm	0.000	ppm
Mass	40.67	mg		
Crotonaldehyde				
Concentration	0.003	ppm	0.000	ppm
Mass	9.11	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.000	ppm
Mass	2.20	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	2.15	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	130.606	mg/hp-hr	Crotonaldehyde	0.365	mg/hp-hr
Acetaldehyde	5.646	mg/hp-hr	Isobutyr + MEK	0.088	mg/hp-hr
Acrolein	1.416	mg/hp-hr	Benzaldehyde	0.086	mg/hp-hr
Acetone	0.000	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.631	mg/hp-hr			

Analyzed: 03/01/1999 16:12

Source:
Station #:
Station Name:
Field:

Report Date: 02/06/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott
File: c:\ezchrom\chrom\032377jbo.3

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.929	0.000	0.038	
METHANE	90.470	913.747	0.501	
CO2	0.000	0.000	0.000	
ETHANE	3.650	64.590	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.951	49.089	0.030	0.536
ISO-BUTANE	0.000	0.000	0.000	
'TANE	0.000	0.000	0.000	
;O-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1027.427	0.607	0.536

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1029.683
Sat. = 1012.930
Actual = 1029.683
0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.536
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.536

Real Specific Gravity Calculated = 0.6078
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

marks:

Appendix C
Test Numbers 219-C1 and 219-H1
"1000" Hour Transient Emissions Test
325 BHP Calibration
Maximum Turbo Lag Enrichment = 8%
Garrett Turbocharger
No Engine Maintenance

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 4. Cell 4 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 400 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 02/19/1999 Time: 09:15
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Test Numbers
Cold: 0219-C1 Hot: 0219-H1

Brake-Specific Emission Results

BSTHC (Cell)	3.235	g/hp-hr	4.339	g/kW-hr
CO	1.385	g/hp-hr	1.858	g/kW-hr
NOx (Cell)	2.150	g/hp-hr	2.883	g/kW-hr
Particulate	0.027	g/hp-hr	0.036	g/kW-hr
CO2	456.9	g/hp-hr	612.69	g/kW-hr
BSFC	0.397	lb/hp-hr	0.533	kg/kW-hr
NMHC	0.389	g/hp-hr	0.521	g/kW-hr
CH4	2.847	g/hp-hr	3.817	g/kW-hr
Work:	25.17	hp-hr	18.77	kW-hr
Reference Work:	24.59	hp-hr	18.34	kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0219-C1
Date: 02/19/1999 Time: 09:15
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.17	in Hg	98.8 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	58.2	°F	14.6 °C
Abs. Humidity:	74.5	gr/lb	10.6 g/kg
Rel. Humidity:	54	%	
Dilution Air:			
Temperature:	73.0	°F	22.8 °C
Abs. Humidity	24.7	gr/lb	3.5 g/kg
Rel. Humidity:	20	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,177.3	61.66
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.46	0.04
Gas Meter 2:	2.35	0.07
Sample Rate:	0.89	0.03
Chemistry Sample Rate:	2.46	0.07
Total Flow Rate:	2,180.66	61.76

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		121.08	ppm	
HC Bckgrd	n/a		3.80	ppm	
CO Sample	27.8	2	26.97	ppm	
CO Bckgrd	0.3	2	0.29	ppm	
NOx Sample	n/a		26.96	ppm	(Dry)
NOx Bckgrd	0.3	2	0.30	ppm	
CO2 Sample	59.8	1	0.5727	%	
CO2 Bckgrd	4.9	1	0.0445	%	
CH4 Sample	n/a	n/a	94.82	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	1.89	ppm	

Particulate Data

Filter Number:	1120.0-3 (pair)
Weight Gain, mg:	0.259
Sample Multiplier:	2.444

Correction Factors

NOx Humidity CF:	0.999
Dry-to-Wet CF, Sample:	0.983
Dry-to-Wet CF, Bckgrd:	0.994
Dilution Factor:	16.52

Test Cycle Data

Sample Time:	1,207.40	sec		
Work:	25.17	hp-hr	18.77	kW-hr
Reference Work:	24.59	hp-hr	18.34	kW-hr
Total Volume (Vmix):	43,832.5	scf	1,241.36	scm

Corrected Concentrations

HC	117.51	ppm
CO	26.07	ppm
NOx	26.23	ppm
CO2	0.5309	%
CH4	93.04	ppm
RHC	12.37	ppm

Brake-Specific Emission Results

BSTHC (Cell)	3.437	g/hp-hr	4.609	g/kW-hr
CO	1.497	g/hp-hr	2.007	g/kW-hr
NOx (Cell)	2.471	g/hp-hr	3.313	g/kW-hr
Particulate	0.025	g/hp-hr	0.034	g/kW-hr
CO2	479.0	g/hp-hr	642.35	g/kW-hr
BSFC	0.417	lb/hp-hr	0.253	kg/kW-hr
NMHC	0.378	g/hp-hr	0.506	g/kW-hr
CH4	3.059	g/hp-hr	4.102	g/kW-hr

Mass Emissions

HC		86.504	grams	
CO		37.678	grams	
NOx		62.191	grams	
Particulate		0.633	grams	
CO2		12.056	kg	
CH4		76.999	grams	
RHC		9.505	grams	
Fuel	10.49 lb		4.76 kg	

Analyzed: 03/01/1999 16:16

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0219-C1
Date: 02/19/1999 Time: 09:15
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.004	ppm	0.002	ppm
Mass	3,051.93	mg		
Acetaldehyde				
Concentration	0.062	ppm	0.002	ppm
Mass	135.07	mg		
Acrolein				
Concentration	0.010	ppm	0.000	ppm
Mass	27.11	mg		
Acetone				
Concentration	0.004	ppm	0.002	ppm
Mass	6.04	mg		
Propionaldehyde				
Concentration	0.013	ppm	0.001	ppm
Mass	35.29	mg		
Crotonaldehyde				
Concentration	0.005	ppm	0.001	ppm
Mass	12.68	mg		
Isobutyr + MEK				
Concentration	0.002	ppm	0.000	ppm
Mass	5.64	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	121.253	mg/hp-hr	Crotonaldehyde	0.504	mg/hp-hr
Acetaldehyde	5.366	mg/hp-hr	Isobutyr + MEK	0.224	mg/hp-hr
Acrolein	1.077	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	0.240	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.402	mg/hp-hr			

Analyzed: 03/01/1999 16:16

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0219-H1
Date: 02/19/1999 Time: 09:55
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.17	in Hg	98.8 kPa
Engine Inlet Air			
Temperature:	78.0	°F	25.6 °C
Dew Point:	58.2	°F	14.6 °C
Abs. Humidity:	74.5	gr/lb	10.6 g/kg
Rel. Humidity:	51	%	
Dilution Air:			
Temperature:	73.0	°F	22.8 °C
Abs. Humidity	24.7	gr/lb	3.5 g/kg
Rel. Humidity:	20	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,177.2	61.66
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.47	0.04
Gas Meter 2:	2.38	0.07
Sample Rate:	0.90	0.03
Chemistry Sample Rate:	2.54	0.07
Total Flow Rate:	2,180.63	61.76

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		112.69	ppm	
HC Bckgrd	n/a		3.50	ppm	
CO Sample	25.2	2	24.44	ppm	
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		22.71	ppm	(Dry)
NOx Bckgrd	0.1	2	0.10	ppm	
CO2 Sample	56.7	1	0.5416	%	
CO2 Bckgrd	4.6	1	0.0418	%	
CH4 Sample	n/a	n/a	87.20	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	1.83	ppm	

Particulate Data

Filter Number:	1121.0-4 (pair)
Weight Gain, mg:	0.287
Sample Multiplier:	2.408

Correction Factors

NOx Humidity CF:	0.999
Dry-to-Wet CF, Sample:	0.984
Dry-to-Wet CF, Bckgrd:	0.994
Dilution Factor:	17.48

Test Cycle Data

Sample Time:	1,207.70	sec		
Work:	25.17	hp-hr	18.77	kW-hr
Reference Work:	24.59	hp-hr	18.34	kW-hr
Total Volume (Vmix):	43,841.3	scf	1,241.61	scm

Corrected Concentrations

HC	109.39	ppm
CO	23.80	ppm
NOx	22.25	ppm
CO2	0.5022	%
CH4	85.48	ppm
RHC	12.79	ppm

Brake-Specific Emission Results

BSTHC (Cell)	3.202	g/hp-hr	4.294	g/kW-hr
CO	1.367	g/hp-hr	1.833	g/kW-hr
NOx (Cell)	2.097	g/hp-hr	2.811	g/kW-hr
Particulate	0.027	g/hp-hr	0.037	g/kW-hr
CO2	453.2	g/hp-hr	607.74	g/kW-hr
BSFC	0.394	lb/hp-hr	0.240	kg/kW-hr
NMHC	0.391	g/hp-hr	0.524	g/kW-hr
CH4	2.811	g/hp-hr	3.770	g/kW-hr

Mass Emissions

HC		80.589		grams
CO		34.402		grams
NOx		52.770		grams
Particulate		0.691		grams
CO2		11.407		kg
CH4		70.757		grams
RHC		9.832		grams
Fuel	9.92 lb		4.50 kg	

Analyzed: 03/01/1999 15:09

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0219-H1
Date: 02/19/1999 Time: 09:55
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.023	ppm	0.002	ppm
Mass	3,084.26	mg		
Acetaldehyde				
Concentration	0.061	ppm	0.002	ppm
Mass	131.84	mg		
Acrolein				
Concentration	0.008	ppm	0.000	ppm
Mass	22.89	mg		
Acetone				
Concentration	0.004	ppm	0.002	ppm
Mass	7.02	mg		
Propionaldehyde				
Concentration	0.015	ppm	0.001	ppm
Mass	41.84	mg		
Crotonaldehyde				
Concentration	0.007	ppm	0.001	ppm
Mass	21.89	mg		
Isobutyr + MEK				
Concentration	0.002	ppm	0.000	ppm
Mass	6.47	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	1.39	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	122.537	mg/hp-hr	Crotonaldehyde	0.870	mg/hp-hr
Acetaldehyde	5.238	mg/hp-hr	Isobutyr + MEK	0.257	mg/hp-hr
Acrolein	0.909	mg/hp-hr	Benzaldehyde	0.055	mg/hp-hr
Acetone	0.279	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.662	mg/hp-hr			

Analyzed: 03/01/1999 15:09

Source:
Station #:
Station Name:
Field:

Report Date: 02/06/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\032377jbo.3

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.929	0.000	0.038	
METHANE	90.470	913.747	0.501	
CO2	0.000	0.000	0.000	
ETHANE	3.650	64.590	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.951	49.089	0.030	0.536
ISO-BUTANE	0.000	0.000	0.000	
TANE	0.000	0.000	0.000	
O-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1027.427	0.607	0.536

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1029.683
Sat. = 1012.930
Actual = 1029.683
0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.536
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.536

Real Specific Gravity Calculated = 0.6078
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Remarks:

Appendix D
Test Numbers 222-C1 and 222-H1
"1000" Hour Transient Emissions Test
Deterioration Factor Calibration
Garrett Turbocharger
Spark Plugs Regapped

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 4. Cell 4 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 400 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 02/22/1999 Time: 09:50
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Test Numbers
Cold: 0222-C1 Hot: 0222-H1

Brake-Specific Emission Results

BSTHC (Cell)	3.927	g/hp-hr	5.267	g/kW-hr
CO	1.607	g/hp-hr	2.155	g/kW-hr
NOx (Cell)	1.696	g/hp-hr	2.274	g/kW-hr
Particulate	0.030	g/hp-hr	0.040	g/kW-hr
CO2	481.1	g/hp-hr	645.13	g/kW-hr
BSFC	0.420	lb/hp-hr	0.563	kg/kW-hr
NMHC	0.506	g/hp-hr	0.679	g/kW-hr
CH4	3.421	g/hp-hr	4.588	g/kW-hr
Work:	25.17	hp-hr	18.77	kW-hr
Reference Work:	24.69	hp-hr	18.41	kW-hr

Analyzed: 03/16/1999 11:29

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model:	98 Mack E7 CNG	Test No.:	0222-C1	NAT GAS	CNG, CARB-CNG
Engine Desc.:	0.0 L (0 CID) 6	Date: 02/22/1999	Time: 09:50	HCR:	3.865 FID Resp: 1.13
Engine Cycle:	Diesel	Program HDT:	4.04-C	H= 0.230 C= 0.709 O= 0.000 X= 0.061	
Engine S/N:		Cell: 4	Bag Cart: 2	Engine Oil:	

Ambient/Test Cell Conditions

Barometer:	29.35	in Hg	99.4 kPa
Engine Inlet Air			
Temperature:	74.0	°F	23.3 °C
Dew Point:	57.4	°F	14.1 °C
Abs. Humidity:	71.9	gr/lb	10.3 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	74.0	°F	23.3 °C
Abs. Humidity	38.4	gr/lb	5.5 g/kg
Rel. Humidity:	30	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,188.1	61.97
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.46	0.04
Gas Meter 2:	2.34	0.07
Sample Rate:	0.88	0.02
Chemistry Sample Rate:	2.54	0.07
Total Flow Rate:	2,191.52	62.07

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		143.89	ppm	
HC Bckgrd	n/a		4.70	ppm	
CO Sample	31.5	2	30.58	ppm	
CO Bckgrd	0.5	2	0.49	ppm	
NOx Sample	n/a		23.55	ppm	(Dry)
NOx Bckgrd	0.5	2	0.50	ppm	
CO2 Sample	62.3	1	0.5980	%	
CO2 Bckgrd	5.4	1	0.0491	%	
CH4 Sample	n/a	n/a	112.34	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.69	ppm	

Particulate Data

Filter Number:	1133.0-5 (pair)
Weight Gain, mg:	0.291
Sample Multiplier:	2.480

Correction Factors

NOx Humidity CF:	0.992
Dry-to-Wet CF, Sample:	0.980
Dry-to-Wet CF, Bckgrd:	0.991
Dilution Factor:	15.77

Test Cycle Data

Sample Time:	1,207.50	sec		
Work:	25.03	hp-hr	18.66	kW-hr
Reference Work:	24.69	hp-hr	18.41	kW-hr
Total Volume (Vmix):	44,053.1	scf	1,247.61	scm

Corrected Concentrations

HC	139.49	ppm
CO	29.29	ppm
NOx	22.60	ppm
CO2	0.5520	%
CH4	109.83	ppm
RHC	15.38	ppm

Brake-Specific Emission Results

BSTHC (Cell)	4.124	g/hp-hr	5.530	g/kW-hr
CO	1.700	g/hp-hr	2.279	g/kW-hr
NOx (Cell)	2.138	g/hp-hr	2.867	g/kW-hr
Particulate	0.029	g/hp-hr	0.039	g/kW-hr
CO2	503.4	g/hp-hr	675.02	g/kW-hr
BSFC	0.439	lb/hp-hr	0.267	kg/kW-hr
NMHC	0.474	g/hp-hr	0.636	g/kW-hr
CH4	3.649	g/hp-hr	4.894	g/kW-hr

Mass Emissions

HC		103.217		grams
CO		42.543		grams
NOx		53.505		grams
Particulate		0.722		grams
CO2		12.599		kg
CH4		91.347		grams
RHC		11.871		grams
Fuel	10.99	lb	4.99	kg

Analyzed: 03/16/1999 11:29

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0222-C1
Date: 02/22/1999 Time: 09:50
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.597	ppm	0.004	ppm
Mass	3,958.28	mg		
Acetaldehyde				
Concentration	0.079	ppm	0.003	ppm
Mass	172.00	mg		
Acrolein				
Concentration	0.006	ppm	0.000	ppm
Mass	15.12	mg		
Acetone				
Concentration	0.019	ppm	0.005	ppm
Mass	43.27	mg		
Propionaldehyde				
Concentration	0.008	ppm	0.000	ppm
Mass	24.16	mg		
Crotonaldehyde				
Concentration	0.000	ppm	0.001	ppm
Mass	0.00	mg		
Isobutyr + MEK				
Concentration	0.003	ppm	0.001	ppm
Mass	5.45	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	158.141	mg/hp-hr	Crotonaldehyde	0.000	mg/hp-hr
Acetaldehyde	6.872	mg/hp-hr	Isobutyr + MEK	0.218	mg/hp-hr
Acrolein	0.604	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	1.729	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	0.965	mg/hp-hr			

Analyzed: 03/16/1999 11:29

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0222-H1
Date: 02/22/1999 Time: 12:24
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.29	in Hg	99.2 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	60.3	°F	15.7 °C
Abs. Humidity:	80.1	gr/lb	11.4 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	76.0	°F	24.4 °C
Abs. Humidity	43.7	gr/lb	6.2 g/kg
Rel. Humidity:	32	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		137.07	ppm	
HC Bckgrd	n/a		4.60	ppm	
CO Sample	29.4	2	28.53	ppm	
CO Bckgrd	0.1	2	0.10	ppm	
NOx Sample	n/a		17.49	ppm	(Dry)
NOx Bckgrd	0.2	2	0.20	ppm	
CO2 Sample	60.1	1	0.5757	%	
CO2 Bckgrd	5.6	1	0.0509	%	
CH4 Sample	n/a	n/a	104.60	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.04	ppm	

Corrected Concentrations

HC	132.75	ppm
CO	27.66	ppm
NOx	16.93	ppm
CO2	0.5279	%
CH4	102.68	ppm
RHC	16.72	ppm

Mass Emissions

HC	98.113	grams		
CO	40.096	grams		
NOx	40.869	grams		
Particulate	0.755	grams		
CO2	12.025	kg		
CH4	85.236	grams		
RHC	12.877	grams		
Fuel	10.49	lb	4.76	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,183.4	61.84
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.48	0.04
Gas Meter 2:	2.39	0.07
Sample Rate:	0.91	0.03
Chemistry Sample Rate:	2.54	0.07
Total Flow Rate:	2,186.85	61.93

Particulate Data

Filter Number:	1136.0-8 (pair)
Weight Gain, mg:	0.313
Sample Multiplier:	2.412

Correction Factors

NOx Humidity CF:	1.014
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.990
Dilution Factor:	16.39

Test Cycle Data

Sample Time:	1,207.70	sec		
Work:	25.19	hp-hr	18.78	kW-hr
Reference Work:	24.69	hp-hr	18.41	kW-hr
Total Volume (Vmix):	43,966.5	scf	1,245.16	scm

Brake-Specific Emission Results

BSTHC (Cell)	3.895	g/hp-hr	5.223	g/kW-hr
CO	1.592	g/hp-hr	2.135	g/kW-hr
NOx (Cell)	1.622	g/hp-hr	2.176	g/kW-hr
Particulate	0.030	g/hp-hr	0.040	g/kW-hr
CO2	477.4	g/hp-hr	640.18	g/kW-hr
BSFC	0.417	lb/hp-hr	0.253	kg/kW-hr
NMHC	0.511	g/hp-hr	0.686	g/kW-hr
CH4	3.384	g/hp-hr	4.538	g/kW-hr

Analyzed: 03/16/1999 12:57

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0222-H1
Date: 02/22/1999 Time: 12:24
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.865 FID Resp: 1.13
H= 0.230 C= 0.709 O= 0.000 X= 0.061
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.363	ppm	0.004	ppm
Mass	3,591.99	mg		
Acetaldehyde				
Concentration	0.072	ppm	0.003	ppm
Mass	153.91	mg		
Acrolein				
Concentration	0.006	ppm	0.000	ppm
Mass	16.11	mg		
Acetone				
Concentration	0.000	ppm	0.005	ppm
Mass	0.00	mg		
Propionaldehyde				
Concentration	0.005	ppm	0.000	ppm
Mass	14.36	mg		
Crotonaldehyde				
Concentration	0.002	ppm	0.001	ppm
Mass	5.29	mg		
Isobutyr + MEK				
Concentration	0.003	ppm	0.001	ppm
Mass	5.98	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	142.596	mg/hp-hr	Crotonaldehyde	0.210	mg/hp-hr
Acetaldehyde	6.110	mg/hp-hr	Isobutyr + MEK	0.237	mg/hp-hr
Acrolein	0.639	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	0.000	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	0.570	mg/hp-hr			

Analyzed: 03/16/1999 12:57

Source:
Station #:
Station Name:
Field:

Report Date: 02/15/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\031732jc.1

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.824	0.000	0.037	
METHANE	90.768	916.757	0.503	
CO2	0.000	0.000	0.000	
ETHANE	3.623	64.113	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.785	44.912	0.027	0.491
ISO-BUTANE	0.000	0.000	0.000	
TANE	0.000	0.000	0.000	
ISO-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1025.782	0.605	0.491

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1028.022
Sat. = 1011.297
Actual = 1028.022
(0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.491
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.491

Real Specific Gravity Calculated = 0.6056
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

arks:

Appendix E
Test Numbers 224-C1 and 224-H1
"1000" Hour Transient Emissions Test
325 BHP Calibration
Maximum Turbo Lag Enrichment = 13%
Schwitzer Turbocharger
Spark Plugs Regapped

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0224-H1
Date: 02/24/1999 Time: 09:38
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.37	in Hg	99.4 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.6	°F	15.3 °C
Abs. Humidity:	77.9	gr/lb	11.1 g/kg
Rel. Humidity:	55	%	
Dilution Air:			
Temperature:	75.0	°F	23.9 °C
Abs. Humidity	67.8	gr/lb	9.7 g/kg
Rel. Humidity:	51	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,189.7	62.01
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.46	0.04
Gas Meter 2:	2.38	0.07
Sample Rate:	0.92	0.03
Chemistry Sample Rate:	2.52	0.07
Total Flow Rate:	2,193.15	62.11

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		108.21	ppm	
HC Bckgrd	n/a		4.80	ppm	
CO Sample	25.4	2	24.63	ppm	
CO Bckgrd	n/a	2	0.00	ppm	
NOx Sample	n/a		22.56	ppm	(Dry)
NOx Bckgrd	3.3	1	0.85	ppm	
CO2 Sample	59.3	1	0.5677	%	
CO2 Bckgrd	7.0	1	0.0638	%	
CH4 Sample	n/a	n/a	84.46	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.10	ppm	

Particulate Data

Filter Number:	1202.0- (pair)
Weight Gain, mg:	0.306
Sample Multiplier:	2.379

Correction Factors

NOx Humidity CF:	1.008
Dry-to-Wet CF, Sample:	0.974
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	16.74

Test Cycle Data

Sample Time:	1,207.90	sec		
Work:	25.31	hp-hr	18.87	kW-hr
Reference Work:	24.90	hp-hr	18.57	kW-hr
Total Volume (Vmix):	44,100.9	scf	1,248.96	scm

Corrected Concentrations

HC	103.70	ppm
CO	23.81	ppm
NOx	21.17	ppm
CO2	0.5077	%
CH4	82.49	ppm
RHC	10.49	ppm

Brake-Specific Emission Results

BSTHC (Cell)	3.034	g/hp-hr	4.068	g/kW-hr
CO	1.368	g/hp-hr	1.835	g/kW-hr
NOx (Cell)	2.013	g/hp-hr	2.699	g/kW-hr
Particulate	0.029	g/hp-hr	0.039	g/kW-hr
CO2	458.3	g/hp-hr	614.64	g/kW-hr
BSFC	0.396	lb/hp-hr	0.241	kg/kW-hr
NMHC	0.320	g/hp-hr	0.429	g/kW-hr
CH4	2.714	g/hp-hr	3.639	g/kW-hr

Mass Emissions

HC		76.782	grams	
CO		34.624	grams	
NOx		50.945	grams	
Particulate		0.728	grams	
CO2		11.601	kg	
CH4		68.681	grams	
RHC		8.101	grams	
Fuel	10.03 lb		4.55 kg	

Analyzed: 03/16/1999 13:21

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0224-H1
Date: 02/24/1999 Time: 09:38
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.247	ppm	0.005	ppm
Mass	3,405.64	mg		
Acetaldehyde				
Concentration	0.067	ppm	0.002	ppm
Mass	144.26	mg		
Acrolein				
Concentration	0.004	ppm	0.000	ppm
Mass	11.86	mg		
Acetone				
Concentration	0.003	ppm	0.003	ppm
Mass	0.45	mg		
Propionaldehyde				
Concentration	0.003	ppm	0.000	ppm
Mass	9.74	mg		
Crotonaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.000	ppm
Mass	3.78	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.001	ppm	0.000	ppm
Mass	4.77	mg		

Brake-Specific Results

Formaldehyde	134.557	mg/hp-hr	Crotonaldehyde	0.000	mg/hp-hr
Acetaldehyde	5.700	mg/hp-hr	Isobutyr + MEK	0.149	mg/hp-hr
Acrolein	0.469	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	0.018	mg/hp-hr	Hexanaldehyde	0.188	mg/hp-hr
Propionaldehyde	0.385	mg/hp-hr			

Analyzed: 03/16/1999 13:21

Source:
Station #:
Station Name:
Field: U

Report Date: 02/22/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\031732Chiu.2

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.592	0.000	0.035	
METHANE	90.867	917.757	0.503	
CO2	0.000	0.000	0.000	
ETHANE	3.660	64.767	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.881	47.328	0.029	0.517
ISO-BUTANE	0.000	0.000	0.000	
TANE	0.000	0.000	0.000	
ISO-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
NONANES	0.000	0.000	0.000	
Ideal Total	100.000	1029.852	0.605	0.517

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1032.117
Sat. = 1015.323
Actual = 1032.117
0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.517
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.517

Real Specific Gravity Calculated = 0.6058
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Marks:

Appendix F

Test Numbers 225-C1 and 225-H1
"1000" Hour Transient Emissions Test
350 BHP Calibration
Maximum Turbo Lag Enrichment = 10%
Schwitzer Turbocharger
Spark Plugs Regapped

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 4. Cell 4 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 400 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 02/25/1999 Time: 08:55
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Test Numbers
Cold: 0225-C1 Hot: 0225-H1

Brake-Specific Emission Results

BSTHC (Cell)	2.905	g/hp-hr	3.895	g/kW-hr
CO	1.319	g/hp-hr	1.769	g/kW-hr
NOx (Cell)	2.192	g/hp-hr	2.940	g/kW-hr
Particulate	0.026	g/hp-hr	0.035	g/kW-hr
CO2	448.9	g/hp-hr	602.01	g/kW-hr
BSFC	0.388	lb/hp-hr	0.520	kg/kW-hr
NMHC	0.276	g/hp-hr	0.370	g/kW-hr
CH4	2.629	g/hp-hr	3.525	g/kW-hr
Work:	25.23	hp-hr	18.82	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr

Analyzed: 03/04/1999 16:52

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-C1
Date: 02/25/1999 Time: 08:55
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.23	in Hg	99.0 kPa
Engine Inlet Air			
Temperature:	75.0	°F	23.9 °C
Dew Point:	58.2	°F	14.6 °C
Abs. Humidity:	74.4	gr/lb	10.6 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	74.0	°F	23.3 °C
Abs. Humidity	74.8	gr/lb	10.7 g/kg
Rel. Humidity:	58	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,178.7	61.70
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.47	0.04
Gas Meter 2:	2.39	0.07
Sample Rate:	0.92	0.03
Chemistry Sample Rate:	2.55	0.07
Total Flow Rate:	2,182.21	61.80

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		105.78	ppm	
HC Bckgrd	n/a		4.90	ppm	
CO Sample	25.7	2	24.92	ppm	
CO Bckgrd	n/a	2	0.00	ppm	
NOx Sample	n/a		28.43	ppm	(Dry)
NOx Bckgrd	1.2	1	0.31	ppm	
CO2 Sample	59.6	1	0.5707	%	
CO2 Bckgrd	5.6	1	0.0509	%	
CH4 Sample	n/a	n/a	84.10	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.07	ppm	

Particulate Data

Filter Number:	1203.0-11 (pair)
Weight Gain, mg:	0.299
Sample Multiplier:	2.372

Correction Factors

NOx Humidity CF:	0.998
Dry-to-Wet CF, Sample:	0.972
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	16.66

Test Cycle Data

Sample Time:	1,207.70	sec		
Work:	25.24	hp-hr	18.82	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr
Total Volume (Vmix):	43,872.8	scf	1,242.50	scm

Corrected Concentrations

HC	101.17	ppm
CO	24.04	ppm
NOx	27.35	ppm
CO2	0.5229	%
CH4	82.16	ppm
RHC	8.34	ppm

Brake-Specific Emission Results

BSTHC (Cell)	2.950	g/hp-hr	3.956	g/kW-hr
CO	1.378	g/hp-hr	1.847	g/kW-hr
NOx (Cell)	2.570	g/hp-hr	3.447	g/kW-hr
Particulate	0.028	g/hp-hr	0.038	g/kW-hr
CO2	470.9	g/hp-hr	631.45	g/kW-hr
BSFC	0.407	lb/hp-hr	0.247	kg/kW-hr
NMHC	0.254	g/hp-hr	0.341	g/kW-hr
CH4	2.696	g/hp-hr	3.616	g/kW-hr

Mass Emissions

HC		74.460	grams	
CO		34.768	grams	
NOx		64.876	grams	
Particulate		0.709	grams	
CO2		11.885	kg	
CH4		68.051	grams	
RHC		6.409	grams	
Fuel	10.27 lb		4.66 kg	

Analyzed: 03/04/1999 16:52

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-C1
Date: 02/25/1999 Time: 08:55
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	2.046	ppm	0.005	ppm
Mass	3,080.11	mg		
Acetaldehyde				
Concentration	0.066	ppm	0.002	ppm
Mass	141.11	mg		
Acrolein				
Concentration	0.011	ppm	0.000	ppm
Mass	31.34	mg		
Acetone				
Concentration	0.009	ppm	0.004	ppm
Mass	13.58	mg		
Propionaldehyde				
Concentration	0.014	ppm	0.000	ppm
Mass	40.09	mg		
Crotonaldehyde				
Concentration	0.006	ppm	0.001	ppm
Mass	20.36	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.001	ppm
Mass	0.77	mg		
Benzaldehyde				
Concentration	0.001	ppm	0.000	ppm
Mass	3.91	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	122.033	mg/hp-hr	Crotonaldehyde	0.807	mg/hp-hr
Acetaldehyde	5.591	mg/hp-hr	Isobutyr + MEK	0.030	mg/hp-hr
Acrolein	1.241	mg/hp-hr	Benzaldehyde	0.155	mg/hp-hr
Acetone	0.538	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.588	mg/hp-hr			

Analyzed: 03/04/1999 16:52

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-H1
Date: 02/25/1999 Time: 09:35
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.23	in Hg	99.0 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.1	gr/lb	11.3 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	74.0	°F	23.3 °C
Abs. Humidity	79.8	gr/lb	11.4 g/kg
Rel. Humidity:	62	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		103.28	ppm	
HC Bckgrd	n/a		4.40	ppm	
CO Sample	24.4	2	23.66	ppm	
CO Bckgrd	n/a	2	0.00	ppm	
NOx Sample	n/a		23.26	ppm	(Dry)
NOx Bckgrd	1.1	1	0.28	ppm	
CO2 Sample	57.3	1	0.5476	%	
CO2 Bckgrd	6.3	1	0.0574	%	
CH4 Sample	n/a	n/a	81.50	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.00	ppm	

Corrected Concentrations

HC	99.13	ppm
CO	22.81	ppm
NOx	22.33	ppm
CO2	0.4935	%
CH4	79.61	ppm
RHC	9.17	ppm

Mass Emissions

HC	73.099	grams		
CO	33.039	grams		
NOx	53.720	grams		
Particulate	0.640	grams		
CO2	11.234	kg		
CH4	66.039	grams		
RHC	7.060	grams		
Fuel	9.71 lb		4.40 kg	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,181.9	61.79
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.47	0.04
Gas Meter 2:	2.41	0.07
Sample Rate:	0.94	0.03
Chemistry Sample Rate:	2.54	0.07
Total Flow Rate:	2,185.34	61.89

Particulate Data

Filter Number:	1204.0-12 (pair)
Weight Gain, mg:	0.275
Sample Multiplier:	2.327

Correction Factors

NOx Humidity CF:	1.011
Dry-to-Wet CF, Sample:	0.971
Dry-to-Wet CF, Bckgrd:	0.982
Dilution Factor:	17.36

Test Cycle Data

Sample Time:	1,207.70	sec		
Work:	25.23	hp-hr	18.81	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr
Total Volume (Vmix):	43,936.0	scf	1,244.29	scm

Brake-Specific Emission Results

BSTHC (Cell)	2.897	g/hp-hr	3.885	g/kW-hr
CO	1.310	g/hp-hr	1.756	g/kW-hr
NOx (Cell)	2.129	g/hp-hr	2.855	g/kW-hr
Particulate	0.025	g/hp-hr	0.034	g/kW-hr
CO2	445.3	g/hp-hr	597.10	g/kW-hr
BSFC	0.385	lb/hp-hr	0.234	kg/kW-hr
NMHC	0.280	g/hp-hr	0.375	g/kW-hr
CH4	2.617	g/hp-hr	3.510	g/kW-hr

Analyzed: 03/04/1999 15:48

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-H1
Date: 02/25/1999 Time: 09:35
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	1.931	ppm	0.005	ppm
Mass	2,908.25	mg		
Acetaldehyde				
Concentration	0.063	ppm	0.002	ppm
Mass	133.71	mg		
Acrolein				
Concentration	0.010	ppm	0.000	ppm
Mass	28.43	mg		
Acetone				
Concentration	0.007	ppm	0.004	ppm
Mass	6.67	mg		
Propionaldehyde				
Concentration	0.013	ppm	0.000	ppm
Mass	37.96	mg		
Crotonaldehyde				
Concentration	0.006	ppm	0.001	ppm
Mass	19.31	mg		
Isobutyr + MEK				
Concentration	0.002	ppm	0.001	ppm
Mass	3.11	mg		
Benzaldehyde				
Concentration	0.001	ppm	0.000	ppm
Mass	4.98	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	115.270	mg/hp-hr	Crotonaldehyde	0.765	mg/hp-hr
Acetaldehyde	5.300	mg/hp-hr	Isobutyr + MEK	0.123	mg/hp-hr
Acrolein	1.127	mg/hp-hr	Benzaldehyde	0.197	mg/hp-hr
Acetone	0.264	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.505	mg/hp-hr			

Analyzed: 03/04/1999 15:48

Source:
Station #:
Station Name:
Field:

Report Date: 02/22/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\031732Chiu.2

Gas Analysis by Chrometograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.592	0.000	0.035	
METHANE	90.867	917.757	0.503	
CO2	0.000	0.000	0.000	
ETHANE	3.660	64.767	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.881	47.328	0.029	0.517
ISO-BUTANE	0.000	0.000	0.000	
TANE	0.000	0.000	0.000	
ISO-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
NONANES	0.000	0.000	0.000	
Ideal Total	100.000	1029.852	0.605	0.517

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1032.117
Sat. = 1015.323
Actual = 1032.117
0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.517
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.517

Real Specific Gravity Calculated = 0.6058
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Remarks:

Appendix G
Test Numbers 225-C2 and 225-H2
"1000" Hour Transient Emissions Test
350 BHP Calibration
Maximum Turbo Lag Enrichment = 8%
Schwitzer Turbocharger
Spark Plugs Regapped

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 4. Cell 4 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 400 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

Southwest Research Institute - Department of Emissions Research
Composite Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Date: 02/25/1999 Time: 02:40
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Test Numbers
Cold: 0225-C2 Hot: 0225-H2

Brake-Specific Emission Results

BSTHC (Cell)	2.858	g/hp-hr	3.833	g/kW-hr
CO	1.341	g/hp-hr	1.798	g/kW-hr
NOx (Cell)	2.197	g/hp-hr	2.947	g/kW-hr
Particulate	0.028	g/hp-hr	0.038	g/kW-hr
CO2	452.4	g/hp-hr	606.64	g/kW-hr
BSFC	0.391	lb/hp-hr	0.524	kg/kW-hr
NMHC	0.210	g/hp-hr	0.281	g/kW-hr
CH4	2.649	g/hp-hr	3.552	g/kW-hr
Work:	25.14	hp-hr	18.75	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-C2
Date: 02/25/1999 Time: 02:40
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.11	in Hg	98.6 kPa
Engine Inlet Air			
Temperature:	74.0	°F	23.3 °C
Dew Point:	58.8	°F	14.9 °C
Abs. Humidity:	76.4	gr/lb	10.9 g/kg
Rel. Humidity:	59	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	76.9	gr/lb	11.0 g/kg
Rel. Humidity:	50	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,166.2	61.35
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.47	0.04
Gas Meter 2:	2.38	0.07
Sample Rate:	0.91	0.03
Chemistry Sample Rate:	2.49	0.07
Total Flow Rate:	2,169.55	61.44

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		110.86	ppm	
HC Bckgrd	n/a		5.50	ppm	
CO Sample	26.4	2	25.61	ppm	
CO Bckgrd	n/a	2	0.00	ppm	
NOx Sample	n/a		26.99	ppm	(Dry)
NOx Bckgrd	0.5	2	0.50	ppm	
CO2 Sample	60.9	1	0.5838	%	
CO2 Bckgrd	7.4	1	0.0675	%	
CH4 Sample	n/a	n/a	88.12	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	2.05	ppm	

Particulate Data

Filter Number:	1229.0-13 (pair)
Weight Gain, mg:	0.294
Sample Multiplier:	2.383

Correction Factors

NOx Humidity CF:	1.004
Dry-to-Wet CF, Sample:	0.971
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	16.28

Test Cycle Data

Sample Time:	1,207.60	sec		
Work:	25.25	hp-hr	18.83	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr
Total Volume (Vmix):	43,615.7	scf	1,235.22	scm

Corrected Concentrations

HC	105.70	ppm
CO	24.76	ppm
NOx	25.75	ppm
CO2	0.5204	%
CH4	86.20	ppm
RHC	8.29	ppm

Brake-Specific Emission Results

BSTHC (Cell)	3.062	g/hp-hr	4.106	g/kW-hr
CO	1.410	g/hp-hr	1.891	g/kW-hr
NOx (Cell)	2.417	g/hp-hr	3.242	g/kW-hr
Particulate	0.028	g/hp-hr	0.037	g/kW-hr
CO2	465.8	g/hp-hr	624.61	g/kW-hr
BSFC	0.403	lb/hp-hr	0.245	kg/kW-hr
NMHC	0.251	g/hp-hr	0.337	g/kW-hr
CH4	2.811	g/hp-hr	3.770	g/kW-hr

Mass Emissions

HC		77.318	grams	
CO		35.600	grams	
NOx		61.041	grams	
Particulate		0.701	grams	
CO2		11.761	kg	
CH4		70.981	grams	
RHC		6.338	grams	
Fuel	10.17 lb		4.61 kg	

Analyzed: 03/05/1999 08:36

Southwest Research Institute - Department of Emissions Research
EPA Cold Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-C2
Date: 02/25/1999 Time: 02:40
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	1.942	ppm	0.007	ppm
Mass	2,900.67	mg		
Acetaldehyde				
Concentration	0.063	ppm	0.003	ppm
Mass	133.11	mg		
Acrolein				
Concentration	0.010	ppm	0.000	ppm
Mass	28.12	mg		
Acetone				
Concentration	0.013	ppm	0.005	ppm
Mass	21.60	mg		
Propionaldehyde				
Concentration	0.011	ppm	0.000	ppm
Mass	30.80	mg		
Crotonaldehyde				
Concentration	0.008	ppm	0.001	ppm
Mass	22.79	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.000	ppm
Mass	1.82	mg		
Benzaldehyde				
Concentration	0.001	ppm	0.000	ppm
Mass	3.12	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	114.878	mg/hp-hr	Crotonaldehyde	0.902	mg/hp-hr
Acetaldehyde	5.272	mg/hp-hr	Isobutyr + MEK	0.072	mg/hp-hr
Acrolein	1.114	mg/hp-hr	Benzaldehyde	0.124	mg/hp-hr
Acetone	0.855	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.220	mg/hp-hr			

Analyzed: 03/05/1999 08:36

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-H2
Date: 02/25/1999 Time: 03:20
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

Ambient/Test Cell Conditions

Barometer:	29.10	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.2	°F	15.1 °C
Abs. Humidity:	77.5	gr/lb	11.1 g/kg
Rel. Humidity:	54	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	75.2	gr/lb	10.7 g/kg
Rel. Humidity:	48	%	

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,168.5	61.41
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	1.47	0.04
Gas Meter 2:	2.37	0.07
Sample Rate:	0.90	0.03
Chemistry Sample Rate:	2.47	0.07
Total Flow Rate:	2,171.89	61.51

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		101.32	ppm	
HC Bckgrd	n/a		4.70	ppm	
CO Sample	24.7	2	23.95	ppm	
CO Bckgrd	n/a	2	0.00	ppm	
NOx Sample	n/a		24.22	ppm	(Dry)
NOx Bckgrd	0.8	2	0.80	ppm	
CO2 Sample	58.6	1	0.5606	%	
CO2 Bckgrd	7.1	1	0.0647	%	
CH4 Sample	n/a	n/a	81.70	ppm	(1.13)
CH4 Bckgrd	n/a	n/a	1.96	ppm	

Particulate Data

Filter Number:	1230.0-14 (pair)
Weight Gain, mg:	0.295
Sample Multiplier:	2.402

Correction Factors

NOx Humidity CF:	1.007
Dry-to-Wet CF, Sample:	0.972
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	16.97

Test Cycle Data

Sample Time:	1,207.90	sec		
Work:	25.12	hp-hr	18.73	kW-hr
Reference Work:	25.64	hp-hr	19.12	kW-hr
Total Volume (Vmix):	43,673.9	scf	1,236.87	scm

Corrected Concentrations

HC	96.90	ppm
CO	23.19	ppm
NOx	22.79	ppm
CO2	0.4997	%
CH4	79.86	ppm
RHC	6.65	ppm

Brake-Specific Emission Results

BSTHC (Cell)	2.824	g/hp-hr	3.787	g/kW-hr
CO	1.329	g/hp-hr	1.783	g/kW-hr
NOx (Cell)	2.160	g/hp-hr	2.897	g/kW-hr
Particulate	0.028	g/hp-hr	0.038	g/kW-hr
CO2	450.1	g/hp-hr	603.63	g/kW-hr
BSFC	0.389	lb/hp-hr	0.236	kg/kW-hr
NMHC	0.203	g/hp-hr	0.272	g/kW-hr
CH4	2.622	g/hp-hr	3.516	g/kW-hr

Mass Emissions

HC		70.941	grams	
CO		33.390	grams	
NOx		54.271	grams	
Particulate		0.709	grams	
CO2		11.307	kg	
CH4		65.853	grams	
RHC		5.088	grams	
Fuel	9.77 lb		4.43 kg	

Analyzed: 03/04/1999 15:48

Southwest Research Institute - Department of Emissions Research
EPA Hot Transient Emission Test Results
Project No. 03-7276-004

Engine Model: 98 Mack E7 CNG
Engine Desc.: 0.0 L (0 CID) 6
Engine Cycle: Diesel
Engine S/N:

Test No.: 0225-H2
Date: 02/25/1999 Time: 03:20
Program HDT: 4.04-C
Cell: 4 Bag Cart: 2

NAT GAS CNG, CARB-CNG
HCR: 3.849 FID Resp: 1.13
H= 0.230 C= 0.712 O= 0.000 X= 0.057
Engine Oil:

	Sample		Background	
Formaldehyde				
Concentration	1.904	ppm	0.007	ppm
Mass	2,850.43	mg		
Acetaldehyde				
Concentration	0.063	ppm	0.003	ppm
Mass	133.52	mg		
Acrolein				
Concentration	0.010	ppm	0.000	ppm
Mass	29.23	mg		
Acetone				
Concentration	0.010	ppm	0.005	ppm
Mass	14.97	mg		
Propionaldehyde				
Concentration	0.011	ppm	0.000	ppm
Mass	32.45	mg		
Crotonaldehyde				
Concentration	0.006	ppm	0.001	ppm
Mass	18.70	mg		
Isobutyr + MEK				
Concentration	0.001	ppm	0.000	ppm
Mass	3.64	mg		
Benzaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		
Hexanaldehyde				
Concentration	0.000	ppm	0.000	ppm
Mass	0.00	mg		

Brake-Specific Results

Formaldehyde	113.473	mg/hp-hr	Crotonaldehyde	0.744	mg/hp-hr
Acetaldehyde	5.315	mg/hp-hr	Isobutyr + MEK	0.145	mg/hp-hr
Acrolein	1.164	mg/hp-hr	Benzaldehyde	0.000	mg/hp-hr
Acetone	0.596	mg/hp-hr	Hexanaldehyde	0.000	mg/hp-hr
Propionaldehyde	1.292	mg/hp-hr			

Analyzed: 03/04/1999 15:48

Source:
Station #:
Station Name:
Field:

Report Date: 02/22/1999
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\031732Chiu.2

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.592	0.000	0.035	
METHANE	90.867	917.757	0.503	
CO2	0.000	0.000	0.000	
ETHANE	3.660	64.767	0.038	
H2S	0.000	0.000	0.000	
PROPANE	1.881	47.328	0.029	0.517
ISO-BUTANE	0.000	0.000	0.000	
TANE	0.000	0.000	0.000	
O-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1029.852	0.605	0.517

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1032.117
Sat. = 1015.323
Actual = 1032.117
(0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.517
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.517

Real Specific Gravity Calculated = 0.6058
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Remarks:

Appendix H
Test Number CO61698-MACK03
"0" Hour Idle CO Test
Deterioration Factor Calibration
Garrett Turbocharger

TEST FACILITIES DESCRIPTION

Emission certification testing was conducted at:

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78228-0510

Certification activities at Southwest Research Institute were in test cell 3. Cell 3 uses a General Electric direct current dyno in combination with a Mid-West inductor dyno for a combined power absorption ability of 750 hp. A Lebow (rotary transformer) in line torque meter is used for torque measurement. Air to air intercooling is simulated as required per SAE 1937. Engine inlet air is conditioned for temperature and humidity. A LabVIEW -based computer system is used for engine throttle control and a Compudas computer system is used to control the engine and dynamometer and acquire data. The data is then processed via SwRI Fortran code.

Gaseous emissions are measured dilute utilizing the full-flow dilution method and particulate sampling makes use of the double dilution method. Both primary and secondary dilution air is filtered and temperature controlled.

The main dilution tunnel uses a positive displacement pump driven at a constant speed in combination with a heat exchanger. The particulate measurement system uses gas meters to measure the secondary dilution air supply and total sample volumes, and particulate is collected on Pallflex 90mm filters.

All equipment and procedures used for testing and calculations are in accordance with 40 CFR Part 86 Subpart N.

03 - 7276 - 004
Project Number

CO61698-MACK03
Test Number

IDLE CO
HEAVY-DUTY OTTO-CYCLE ENGINE
USING RAW EMISSION SAMPLING

Date: 6-16-98 Time: PM	Engine Model: MACK E7G	
Cell No.: 3	Serial No. or ID: 5N1311	
Engine Operator: J. ELIZONDO	Curb Idle Speed: 600 ± 5 rpm	Project Leader: M. STARR
CO ANALYZER	Analyzer ID: 2000210	Range Used: 3,000 PPM
Cart Operator: W. SHACKELFORD	Calibration Date: 5-25-98	Curve Date: 5-25-98
☑ Replace Flip-Top Filter	☑ Calibrate Temperature	☑ Leak Check Sampling System
Pre-Test Zero: Ø md	Pre-Test Span: 89.4 md / 2,682.96 PPM	
Post-Test Zero: -0.4 md	Post-Test Span: 89.6 md	
Difference: -0.4 md (Limit = 2 MD)	Difference: +0.2 md (Limit = 2 MD)	

IDLE TEST: *(No delay time between steps, except as noted)*

1. WARM- UP ENGINE: ☑ – Transient Test ☐ – Power Map *(<1 minute prior to Step 2)*
2. OPERATE ENGINE AT ~~2500~~ 1200 ±50 RPM FOR 60 SECONDS:
   - 2.a. Barometric Pressure: 28.88 "Hg
   - 2.b. Engine Intake Air Dewpoint: 58.0 °F
   - 2.c. Engine Intake Air Temperature: 90 °F
   - 2.d. Time at ~~2500~~ 1200 ±50 rpm: 60 Seconds (±30)
3. CURB IDLE SPEED FOR 30 SECONDS (zero torque & CO to Sample) : 30 Seconds (±5) 600 rpm
4. CO TEST SAMPLING AT IDLE FOR 60→64 SECONDS:
   - 4.a. CO Analyzer Inlet Pressure: 3 "H_2O (Start of Sample)
   - 4.b. CO Analyzer Sample Gas Temperature: 71.8 °F (45°F maximum)
   - 4.c. CO Analyzer Inlet Pressure: 3 "H_2O (End of Sample)
   - 4.d. CO Test Sampling Period: 60 Seconds (60→64)
5. IMMEDIATE POST-SAMPLING DATA AT IDLE:
   - 5.a. Barometric Pressure: 28.86 "Hg
   - 5.b. Engine Intake Air Dewpoint: 58.6 °F
   - 5.c. Engine Intake Air Temperature: 90 °F

☑ No Comment ☐ Comments Provided on Test Comment Form ☐ NCAR Submitted

CO VALUE: Average CO over 60 second sampling period in Step 4. *(Use 10 meter division readings at 6-second intervals)*

0.1 * (50.0 + 49.0 + 48.3 + 48.3 + 49.0 + 47.7 + 48.4 + 47.4 + 48.2 + 47.5) = 48.4

IDLE CO: 0.11 % *(On a Dry Basis — convert as necessary.)*

SwRI - Department of Emissions Research
FORM 07-025A
Revision 1

QUALITY\FORMS\07-002A.R-1

Source:
Station #:
Station Name: 0
Field:

Report Date: 06/05/1998
Sample Date:
Flowing Pressure: 0 psig
Flowing Temp.: 0 F

Method: c:\ezchrom\methods\scott.
File: c:\ezchrom\chrom\037276eg.3

Gas Analysis by Chromatograph

Name	Mole %	BTU	SG	GPM
NITROGEN	3.661	0.000	0.035	
METHANE	90.603	915.090	0.502	
CO2	0.000	0.000	0.000	
ETHANE	3.672	64.980	0.038	
H2S	0.000	0.000	0.000	
PROPANE	2.064	51.932	0.031	0.567
ISO-BUTANE	0.000	0.000	0.000	
BUTANE	0.000	0.000	0.000	
ISO-PENTANE	0.000	0.000	0.000	
PENTANE	0.000	0.000	0.000	
HEXANES	0.000	0.000	0.000	
HEPTANES	0.000	0.000	0.000	
OCTANES	0.000	0.000	0.000	
ISONONANES	0.000	0.000	0.000	
Ideal Total	100.000	1032.002	0.607	0.567

Gross BTU/Real Cu. Ft.
(@ 60 deg F, 0.000)
Dry = 1034.286
Sat. = 1017.456
Actual = 1034.286
(0.000 lbs. water/MMCF)

Gasoline Content
Propane GPM = 0.567
Butane GPM = 0.000
Gasoline GPM = 0.000
26# Gasoline GPM = 0.000
Total GPM = 0.567

Real Specific Gravity Calculated = 0.6079
On-Site Specific Gravity = 0.0000

Gas Compressability = 0.9978

Remarks:

0

APPENDIX H

FINAL CALIBRATION

350 bhp

GEM Lean Burn Control System Monitor PROM ID: 2570-008- 09/11/98

Speed	0	rpm	Raw Voltages:				Diagnostics:
MAP	14.4	psia	MAP raw	1.57	volts		NORMAL
ECT	128	°F	ECT raw	1.43	volts		
MAT	122	°F	MAT raw	1.37	volts		Spark:
PTP	14.2	psia	PTP raw	1.63	volts		(firing order)
EBP	14.41	psia	EBP raw	2.41	volts		1 - ENABLED
NGP	57.8	psia	NGP raw	1.67	volts		2 - ENABLED
NGT	106	°F	NGT raw	1.96	volts		3 - ENABLED
NGTP	0	psig	NGTP raw	0.02	volts		4 - ENABLED
NGTT	-50	°F	NGTT raw	5.00	volts		5 - ENABLED
UEGO	1.006	phi	UEGO raw	0.94	volts		6 - ENABLED
FPP	0.51	%	FPP raw	0.41	volts		7 - ENABLED
TPS_Command	1.99	volts					8 - ENABLED
TPS_Feedbck	0.02	volts	RunTime	00:00:00			
Baro	14.71	psia	ControlMode	OPEN LOOP			Injector:
Battery	14.2	volts	RunMode	STOPPED			1 - ENABLED
SparkAdv	5.0	°BTDC					2 - ENABLED
PW	30.7	ms					3 - ENABLED
CL_Mult	+0.00	%	FPP Minimum	0.41	volts		4 - ENABLED
AL_Mult	+0.00	%	FuelGauge	0	%		

GEM Lean Burn Control System Faults PROM ID: 2570-008- 09/11/98

Voltage	HIGH	LOW
EBP	17:OK	18:OK
FPP	21:OK	22:OK
TPS	54:OK	56:OK
MAT	23:OK	25:OK
MAP	33:OK	34:OK
PTP	37:OK	48:OK
ECT	26:OK	27:OK
NGT	14:OK	15:OK
NGP	38:OK	39:OK
NGTT	64:OK	65:OK
NGTP	66:OK	67:OK
UEGOP	63:OK	62:OK
UEGOH	58:OK	59:OK
UEGOR	68:OK	69:OK
Batt	53:OK	52:OK

Function	HIGH	LOW
EBP Exp	19:OK	29:OK
TPS Exp	57:OK	81:OK
NGP Exp	41:OK	43:OK
BP Exp	35:OK	36:OK
BoostExp	71:OK	72:OK
CL Limit	44:OK	45:OK
AL Limit	46:OK	47:OK

Miscellaneous	
Trigger	42:OK
TPS Cal	82:OK
J1708 Rx	83:OK
J1708 Tx	84:OK

Function	
ECT High Exp	28:OK
MAT High Exp	24:OK
NGTP High Exp	83:OK
PTP Active	49:OK
OverBoost	73:OK
UEGOS Fail	13:OK
Oil Pressure	74:OK
Inj DutyCycle	75:OK

ECU Internal	
COP	55:OK
Interrupt	55:OK
Analog	55:OK
Execution	55:OK
Clocks	55:OK
Stack	55:OK
RAM	51:OK

GEM Lean Burn Control System Diagnostics

Fault	High	Low	Miscellaneous Faults		Engine Parameters			
FPP	21:OK	22:OK	UEGOS Fail	13:OK	Speed	0	rpm	
TPS	16:OK	17:OK	Spark Input	42:OK	MAP	14.4	psia	15.1 Des
TPSExp	18:OK	19:OK	TPS_Cal	29:OK	PTP	14.2	psia	1.63 V
MAT	23:OK	25:OK	MAT_HiExp	24:OK	MAT	122	°F	1.37 V
MAP	33:OK	34:OK	OverBoost	73:OK	ECT	128	°F	1.43 V
PTP	35:OK	36:OK	PTP_Active	37:OK	NGP	93.1	psia	2.37 V
ECT	26:OK	27:OK	ECT_HiExp	28:OK	NGT	106	°F	1.96 V
NGT	14:OK	15:OK	Oil_Press	74:OK	FPP	0.41	V	0.41 Min
NGP	38:OK	39:OK	Inj_DutyCyc	75:OK	TPS	1.99	VCmd	0.02 FB
NGPExp	41:OK	43:OK	EBP_Hi	:OK	EBP	14.41	psia	2.41 V
BPExp	35:OK	34:OK	EBP_Lo	:OK	Phi	1.022	Act	1.000 Des
NGTT	64:OK	65:OK	EBP_HiExp	:OK	NGTP	0	psig	0.02 V
NGTP	66:OK	67:OK	EBP_LoExp	:OK	NGTT	-50	°F	5.00 V
UEGOP	63:OK	62:OK	Interrupts	55:OK	Batt	14.2	V	
UEGOH	58:OK	59:OK	COP	55:OK	IgnAdv	5.0	°BTDC	
UEGOR	68:OK	69:OK	Execution	55:OK	PW	19.5	ms	
Volts	53:OK	52:OK	Clocks	55:OK	CL_Mult	+0.00	%	
Boost	71:OK	72:OK	Stack	55:OK	AL_Mult	+0.00	%	
ALlim	46:OK	47:OK	Analog	55:OK	Control	OPEN LOOP		
CLlim	44:OK	45:OK	RAM	51:OK	RunTime	00:00:00		

GEM Lean Burn Control System - Drive-By-Wire Parameters

Speed	0	rpm	RPMdt	0	rpm/s	StartTPS	2.00	Volts
MAP 10.0	14.4	psia	RPMdt_dz	150	rpm/s	StartRPMOffst	75	rpm
ECT	128	°F	RPMdt_max	0	rpm/s	StartRPMDecay	10	rpm/s
FPPn	0.51	Volts	RPMdt_dcy	156	rpm/s/s			
TPSc	1.99	Volts						
RunTime	00:00:00		FPPmin/max	0.41 3.51 V		1.022		
GovControl	MIN-MAX		FPPactual	0.41 V				

Min Governor:	Idle	Fast	
RPM_target	675		rpm
RPM_targ_def	600	1200	rpm
RPM_enable	300	400	rpm
RPM_dz	75	10	rpm
Kp	0.001	0.003	V/rpm
Ki	0.002	0.006	V/rpm/s
Kd	0.0001	0.0002	V/rpm*s
K_I_init	0.10	0.00	V/100rpm/s
I_init	0.00		Volts
Min_TPSc	0.00		Volts

Max Governor:

Droop	
RPM	TPS
1975	4.50
2005	3.50
2050	2.90
2200	2.60
2300	2.10
2330	1.55
2350	1.20
2400	0.50

Max_TPSc 4.50 Volts

GEM Lean Burn Control System - ECT Based Modification Tables

ECT (°F)	Idle Offset (rpm)	Adv Offset (CAD BTDC)	Max Boost (psia)	Phi Cold (%)
-40	50	+5.0	30.0	100
-20	50	+5.0	30.0	100
0	50	+5.0	30.0	100
32	50	+5.0	30.0	100
50	50	+5.0	30.0	75
70	50	+3.0	30.0	75
90	50	+0.0	30.0	60
110	50	+0.0	32.1	50
130	50	+0.0	35.1	30
155	0	+0.0	35.1	30
160	0	+0.0	45.0	0
190	0	+0.0	45.0	0
200	0	+0.0	45.0	0
210	0	+0.0	45.0	0
220	0	+0.0	45.0	0
230	0	+0.0	45.0	0

ECT	128	°F
Speed	0	rpm
Idle	675	rpm
Idle_def	600	rpm
IgnAdv	5.0	°BTDC
IgnOffst	+0.0	°BTDC
MAP	14.4	psia
Max_boost	15.1	psia
Max_boost_s	15.1	psia
PhiECT	32	%

GEM Lean Burn Control System - Miscellaneous Calibrations

UEGO Calibration

Volts	UEGO_Phis
0.647	1.100
1.000	1.000
1.627	0.912
1.902	0.872
2.196	0.828
2.431	0.800
2.647	0.770
2.863	0.743
3.098	0.710
3.235	0.691
3.412	0.671
3.549	0.650
3.725	0.630
3.882	0.609
4.020	0.588
4.274	0.537
UEGO	0.922 Volts
UEGO_Phis	1.022
UEGO_Phi	1.022

GEM Lean Burn Control System - Closed Loop Activation Map

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
400	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
600	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
800	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1000	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1100	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1250	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1500	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1700	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1950	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
2000	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0

Closed Loop Selection (1=ClosedLoop, 0=OpenLoop)

Speed	0	rpm	CL_select	0	(0-1)	ControlMode	OPEN LOOP
MAP	14.4	psia	Phi	1.000		CL_Mult	+0.00 %
FSO_on	1150	rpm	UEGO_Phi	1.022		Adpt_Mult	+0.00 %
FSO_off	850	rpm	FSO_TPS_min	4.51	V	Block_Mult	100.0 %

GEM Lean Burn Control System - Manifold Filling Calibration

TPS (Volts)	Acceleration Multiplier (psi/V)	Acceleration Decay (ms)	Deceleration Multiplier (psi/V)	Deceleration Decay (ms)
0.0	0.98	3	0.00	5
0.5	0.98	3	0.00	5
1.0	0.98	3	0.00	5
1.5	0.00	5	0.00	5
2.0	0.00	5	0.00	5
3.5	0.00	5	0.00	5
3.0	0.00	5	0.00	5
3.5	0.00	5	0.00	5
4.0	0.00	5	0.00	5
4.5	0.00	5	0.00	5

ControlMode	OPEN LOOP		FSO_on	1150	rpm	MAP_dt_mg	0.0 mg/inj
Phi	1.000		FSO_off	850	rpm	CPM_mg	0.0 mg/inj
Phi_delay	1.000		FSO_TPS_min	4.51	V	EvsTempCF	+2.3 %
UEGO_Phi	1.022		FSO_TPS_off	1000	rpm	CL_Mult	+0.00 %
Fuel_In	129.8	mg/inj	EvsTemp_C	0.251	%	Adpt_Mult	+0.00 %
PW	24.1	ms	Tau_idle	40.0	sec	Block_Mult	100.0 %

Speed	0	rpm
MAP	14.4	psia
PTP	14.2	psia
PTP_dt	+0.0	psi/s
TPS	0.41	Volts
TPS_dt	+0.0	V/sec
TPS_dtTrig	12.0	V/sec
TPSdt->MAPdt	0.00	psi/V
MAP_dtPrdct	+0.0	psi/s
MAP_dt_f	+0.0	psi/s
MAP_dtTrig_f	70.1	psi/s
MAP_dt_s	+0.0	psi/s
MAP_dtTrig_s	8.8	psi/s
MAP_dt_mg	0.0	mg/inj
CPM_mg	0.0	mg/inj
EvsTempCF	+2.3	%
CL_Mult	+0.00	%
Adpt_Mult	+0.00	%
Block_Mult	100.0	%

GEM Lean Burn Control System - Turbo Lag Compensation Screen

TPSc (volts)

RPM	2.00	2.51	2.75	3.00	3.39	3.80	4.06	4.29
650	15.1	15.9	15.9	16.5	17.0	17.0	17.0	17.0
900	15.1	15.9	17.0	18.1	18.9	20.0	22.1	25.1
1100	15.1	17.0	20.0	22.1	24.0	25.1	26.1	28.7
1200	15.1	18.1	22.1	25.1	28.0	31.0	34.5	35.2
1250	15.1	17.0	20.0	23.0	25.9	28.0	30.7	37.0
1400	15.1	15.9	17.5	20.0	24.0	26.5	30.3	35.9
1600	15.1	15.9	17.5	18.9	23.0	25.9	30.1	35.2
1800	15.1	15.9	17.0	18.9	22.1	25.1	29.4	34.9
1820	15.1	15.9	17.0	18.9	22.1	24.0	26.5	31.0
2150	15.1	15.1	15.1	15.1	15.1	15.4	15.9	16.3
2200	15.1	15.9	15.1	15.1	15.1	15.1	15.1	15.1
2700	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1

Maximum Desired Boost (psia)

K_enrich	2.20	%/psi
K_retard	1.50	°ATDC/psi
TLC_enrich	0	%
TLC_retard	0.0	°ATDC
TLC_enable	0	%
TLC_MAP_dz	3.0	psi
TLC_On	4000	ms
TLC_Reset	3000	ms
TLC_Slew	500	ms
TLC_TPS	0.51	+/- volts
TLC_enr_max	10	%
TLC_ret_max	8.0	°ATDC
TLC_range	1050	1700 rpm

Speed	0	rpm	Phi	1.000	
PTP	14.2	psia	UEGO_Phi	1.022	
MAT	122	°F	IgnAdv	5.0	°BTDC
TPS	0.41	volts	IgnOffset	+0.0	°BTDC
TPSc	1.99	volts			

MAP	14.4	psia
Max_boost	15.1	psia
Max_boost_s	15.1	psia
Min_boost	26.6	psia
Boost_PWM	0.0	%

GEM Lean Burn Control System - BASE Boost Control Calibration Screen

RPM	TPS (volts) 2.00	2.51	2.75	3.00	3.39	3.80	4.06	4.29	Boost (psia)	MaxInt (%)	Speed (rpm)	Kd_PTP (%s/p)
650	15.1	15.9	15.9	16.5	17.0	17.0	17.0	17.0	15.1	80.0	1250	0.0
900	15.1	15.9	17.0	18.1	18.9	20.0	22.1	24.0	18.1	80.0	1700	0.0
1100	15.1	17.0	20.0	22.1	24.0	25.1	26.1	27.5	20.0	80.0	1800	2.0
1200	15.1	18.1	22.1	25.1	28.0	31.0	34.5	35.2	22.1	80.0	2000	2.0
1250	15.1	17.0	20.0	23.0	25.9	28.0	30.8	33.8	25.9	80.0	BP	Derate
1500	15.1	15.9	17.5	20.0	24.0	26.5	29.6	32.4	28.9	80.0	10.0	5.0
1700	15.1	15.9	17.5	18.9	23.0	25.9	27.5	31.2	31.0	80.0	11.5	0.0
1950	15.1	15.9	17.0	18.9	22.1	25.1	28.0	31.0	35.1	80.0	0.0	%Derate
1970	15.1	15.9	17.0	18.9	22.1	24.0	25.9	28.9				
2150	15.1	15.1	15.1	15.1	15.1	15.4	15.9	16.3				
2200	15.1	15.9	15.1	15.1	15.1	15.1	15.1	15.1				
2700	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1				

BASE Maximum Desired Boost (psia)

Speed	0	rpm	Phi	1.000		MAP	14.4 psia
PTP	14.2	psia	UEGO_Phi	1.022		Max_boost	15.1 psia
MAT	122	°F	IgnAdv	5.0	°BTDC	Max_boost_s	15.1 psia
FPPn	0.51	volts	IgnOffset	+0.0	°BTDC	Min_boost	26.6 psia
TPSc	1.99	volts	EBP	14.41	psia	PhiMAP_C	0.8 dPhi/dMAP
						Kp_MAP	12.00 %/psi
						Ki_MAP	6.00 %/psi/sec
						Kd_MAP	2.00 %/psi*sec
						Kd_PTP	0.00 %/psi*sec
						Boost_PWM	0.0 %

GEM Lean Burn Control System - COLD Phi Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
400	95	95	95	95	95	90	83	83	83	83	83	83	83	83	83	80
600	95	95	95	95	95	90	80	79	78	78	78	78	78	78	78	70
800	95	95	95	95	95	90	80	79	78	78	73	73	71	71	71	68
1000	95	95	95	95	90	85	80	80	80	77	71	71	71	71	71	64
1100	93	82	82	80	80	80	80	80	80	80	80	77	73	69	69	64
1250	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1500	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1700	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
1950	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64
2000	93	82	77	74	72	69	67	67	67	67	67	67	67	67	67	64

COLD Equivalence Ratio (Phi*100)

Speed	0	rpm	Phi	1.000		ControlMode	OPEN LOOP	
MAP	14.4	psia	UEGO_Phi	1.006		CL_Mult	+0.00	%
IgnAdv	5.0	°BTDC	PhiECT	32	%	Adpt_Mult	+0.00	%
IgnOffset	+0.0	BTDC	PhiMAP_C	0.8	dP/dMAP	Block_Mult	100.0	%

GEM Lean Burn Control System - BASE Phi Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.23	38.03	42.06	45.04
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
400	91	86	83	83	83	81	81	81	81	81	81	81	81	81	81	81
600	91	86	83	83	81	77	77	77	76	76	76	76	76	76	76	71
800	91	86	83	83	81	77	77	77	76	76	71	71	69	69	69	69
1000	91	81	77	74	74	74	78	78	78	75	69	69	69	69	69	69
1100	91	80	77	74	74	74	74	78	78	78	78	75	71	67	67	66
1250	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1500	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1700	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
1950	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65
2000	91	80	75	72	70	67	65	65	65	65	65	65	65	65	65	65

BASE Equivalence Ratio (Phi*100)

Speed	0	rpm	Phi	1.000		ControlMode	OPEN LOOP	
MAP	14.4	psia	UEGO_Phi	1.022		CL_Mult	+0.00	%
IgnAdv	5.0	°BTDC	PhiECT	32	%	Adpt_Mult	+0.00	%
IgnOffset	+0.0	BTDC	PhiMAP_C	0.8	dP/dMAP	Block_Mult	100.0	%

GEM Lean Burn Control System - Ignition Advance Calibration Screen

MAP (psia)

RPM	0.00	4.03	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.93	38.03	42.06	45.04
270	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
300	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
400	13	13	13	13	13	13	12	12	12	12	12	12	12	12	12	5
600	13	13	13	13	13	13	12	11	10	10	10	10	10	10	10	5
800	16	16	16	15	16	15	15	13	12	12	12	10	10	10	10	5
1000	26	26	26	20	20	18	14	14	13	13	13	12	10	10	10	5
1100	27	27	27	24	21	18	16	15	14	13	13	13	10	10	10	5
1250	26	26	26	24	21	18	17	17	16	14	14	13	13	13	10	5
1500	26	26	26	24	21	18	17	17	17	16	16	16	16	14	10	5
1700	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5
1950	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5
2100	27	27	27	24	21	18	17	17	17	16	16	16	16	16	10	5

Ignition Advance (°BTDC)

Speed	0	rpm	IgnAdv	5.0	°BTDC	ControlMode	OPEN LOOP		
MAP	14.4	psia	IgnOffset	+0.0	°BTDC	CL_Mult	+0.00	%	
PTP	14.2	psia	TLC_retard	0.0	°ATDC	Adpt_Mult	+0.00	%	
UEGO_Phi	1.022		Phi	1.000		Block_Mult	100.0	%	

GEM Lean Burn Control System - VE Calibration Screen

MAP (psia)

RPM	0.00	2.80	4.56	5.96	8.94	11.92	14.72	18.05	21.03	24.01	26.99	29.97	32.95	35.93	39.08	42.06
200	40	40	55	60	65	70	80	85	88	88	88	88	88	88	88	88
400	40	40	55	60	65	70	80	85	88	88	88	88	88	88	88	88
600	50	50	55	60	65	70	80	85	88	88	88	88	88	88	88	88
775	50	50	55	60	65	71	80	90	90	90	90	90	90	90	90	90
950	50	50	60	63	65	72	77	87	90	90	90	90	90	90	89	89
1100	50	50	60	63	68	74	80	84	88	90	91	91	91	91	90	90
1300	50	50	60	63	67	69	78	82	86	87	89	91	91	91	90	90
1500	50	50	60	63	66	68	77	81	85	86	87	88	88	91	90	90
1700	50	50	60	63	66	68	77	79	81	83	85	86	87	88	88	87
1900	45	45	60	63	66	68	74	77	80	82	84	84	85	86	86	86
2100	45	45	60	63	66	68	74	77	80	82	82	82	82	82	82	82
3000	45	45	60	63	66	68	74	77	80	82	82	82	82	82	82	82

Volumetric Efficiency (%)

Speed	0 rpm	VE_std	78.7 %	ControlMode	OPEN LOOP
MAP	14.4 psia	VE_mod	100.3 %	CL_Mult	+0.00 %
PTP	14.2 psia	VE_act	80.8 %	Adpt_Mult	+0.00 %
UEGO_Phi	1.017	Phi	1.000	Block_Mult	100.0 %

GEM Lean Burn Control System - Adaptive Parameter Table

Speed	0	rpm
MAP	14.4	psia
PTP	14.2	psia
TPS	0.41	Volts
MAT	122	°F
ECT	128	°F
NGP	58.8	psia
NGT	106	°F
PW	30.3	ms
PWtiming	0.0	°ATDC
IgnAdv	5.0	°BTDC
IgnOffst	+0.0	°BTDC

CL_Mult	+0.00	%
K_CL	20	%
CL_step	5.00	%
CL_switch	0	
CL_max	+40.00	%
CL_min	-35.00	%
BlockMult	100.0	%

MAP (psia)

	4.56	6.13	9.99	15.07	19.98	25.06	31.02	38.03
560	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
R 900	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
P1200	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
M1600	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
2000	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0

Adaptive Parameters (%)

Adpt_Mult	+0.00	%
K_Adapt	5	%
Adpt_step	2.00	%
Adpt_dzone	1.00	%
Adpt_max	+35.00	%
Adpt_min	-30.00	%
Adpt_valid	3.00	%
T_delay	4096	ms
UEGO_Phi	1.017	
Phi	1.000	
Phi_delay	1.000	

RunMode	STOPPED
ControlMode	OPEN LOOP
RunTime	00:00:00
EBP	14.41 psia
EBP_est	14.71 psia
BP	14.71 psia
VE_act	78.7 %
Fuel_In	164.5 mg/inj
MAPdt_mg	0.0 mg/inj

GEM Lean Burn Control System Monitor PROM ID: 2570-008- 09/11/98

Speed	0	rpm	Raw Voltages:			Diagnostics:	
MAP	14.4	psia	MAP raw	1.57	volts	NORMAL	
ECT	128	°F	ECT raw	1.43	volts		
MAT	122	°F	MAT raw	1.37	volts	Spark:	
PTP	14.2	psia	PTP raw	1.63	volts	(firing order)	
EBP	14.41	psia	EBP raw	2.41	volts	1 - ENABLED	
NGP	57.8	psia	NGP raw	1.67	volts	2 - ENABLED	
NGT	106	°F	NGT raw	1.96	volts	3 - ENABLED	
NGTP	0	psig	NGTP raw	0.02	volts	4 - ENABLED	
NGTT	-50	°F	NGTT raw	5.00	volts	5 - ENABLED	
UEGO	1.006	phi	UEGO raw	0.94	volts	6 - ENABLED	
FPP	0.51	%	FPP raw	0.41	volts	7 - ENABLED	
TPS_Command	1.99	volts				8 - ENABLED	
TPS_Feedbck	0.02	volts	RunTime	00:00:00			
Baro	14.71	psia	ControlMode	OPEN LOOP		Injector:	
Battery	14.2	volts	RunMode	STOPPED		1 - ENABLED	
SparkAdv	5.0	°BTDC				2 - ENABLED	
PW	30.7	ms				3 - ENABLED	
CL_Mult	+0.00	%	FPP Minimum	0.41	volts	4 - ENABLED	
AL_Mult	+0.00	%	FuelGauge	0	%		

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13. ABSTRACT *(Maximum 200 words)* The goal of this project was to install a production-ready, state-of-the-art engine control system on the Mack E7G natural gas engine to improve efficiency and lower exhaust emissions. In addition, the power rating was increased from 300 brake horsepower (bhp) to 325 bhp. The emissions targets were oxides of nitrogen plus nonmethane hydrocarbons of less than 2.5 g/bhp-hr and particulate matter of less than 0.05 g/bhp-hr on 99% methane. Vehicle durability and field testing were also conducted. Further development of this engine should include efficiency improvements and oxides of nitrogen reductions.

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