Singh Groove Concept Test Report

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Outline of the Project

Objective: To test the claims made for US patent 6237579. Testing will involve analyzing test data gathered from combustion analysis and running on a typical 2-valve head type IC engine. Testing will be accomplished by characterizing combustion, thermal efficiency, exhaust emissions and engine loading of an unmodified engine and a modified engine. Adding a groove as specified by Somender Singh (Patent 6237579 holder) will be the only modification made for this testing. No optimization of spark timing, fuel mapping or camshaft profiles will be done for the modified cylinder head.

Test Engine

A 3 cylinder 1 Liter Geo Metro engine was chosen as the test engine. This is a basic SOHC engine, which easily lends itself to the said modification. These engines are readily available and are cost effective for testing. A test schedule was devised and then performed first with a stock cylinder head and then repeated with a modified cylinder head. The engine and cylinder heads were reconditioned to new condition before the tests were performed. Engine compression and leakdown were checked before each cylinder head was tested to insure engine integrity and overall health. See Appendix A for the results.

Engine Control system

The test engine utilized a MegaSquirt V2.0 fuel control computer to control a throttle body style fuel injection system. A standard mechanical distributor with vacuum advance was used for the ignition system. The EFI was tuned for optimal operation over the load/speed range similar to an OEM system. Sensors such as, TPS, coolant temp, intake air temp, manifold vacuum, O2 and engine speed were fitted to the engine so that the ECU could correctly fuel the engine. Once the fuel table was determined, the ECU was set to open loop operation so that the fuel map was used rather than let the closed loop operation try and adjust the fuel during the test runs.

Dynamometer

A custom built dynamometer was constructed for testing. A hydraulic load cell was used to load the engine. This load cell is basically a hydraulic pump with a restriction valve in the pressure line from the pump. The operator can adjust this valve to give more or less restriction and therefore vary the load on the engine. To help dissipate heat from the load cell a heat exchanger is built into the feed line to the pump and this was circulated with water/antifreeze mixture to a large radiator with an electric fan. The original 5-speed transmission was used to give more flexibility in the ability to load the engine and better match the max speed capability of the load cell. The engine was mounted using the original mounts from the vehicle as well as the original fuel tank and fuel pump. The dynamometer was fitted with sensors to monitor load cell oil temperature, load cell restriction valve setting, load cell torque (via a torque arm assembly), crank and transmission output speeds, engine EGT and a wideband O2 sensor. Safety cutoff switches, alternator voltage and low oil pressure lights were mounted on the user control panel. The dynamometer is controlled manually and the operator controls the cooling fans, throttle position, gear selection and hydraulic load setting. See Appendix B for picture of the dynamometer and the various sensors.

Testing – Engine

To accomplish the desired tests, the engine was configured for both the stock and modified configurations. The bottom end of the engine was checked and found to be in good working condition with no excessive wear on the bearings or piston rings or piston walls. The cylinder heads were configured for each test. The first was a completely stock cylinder head that was remanufactured to factory specification. The second was a modified cylinder head, first remanufactured to factory specification and then had the "groove" modification added. Both heads were then checked for combustion chamber volume and made sure they were nearly identical so that differences in combustion could not be attributed to an increase or decrease in compression ratio.

1. The original cylinder head was rebuilt with resurfaced valves and new seals. Combustion chamber volume, intake runner volume and exhaust runner volume was measured and recorded.
2. Modified cylinder head was rebuilt with resurfaced valves and new seals. After the Singh modification was added, the combustion chamber volume, intake runner volume and exhaust runner volume was measured and recorded.
3. The cylinder head modification (Singh Groove) was performed as instructed by Somender Singh.
4. Engine was assembled and tested for proper operation. Cylinder head leak down tests, cranking compression tests and a normal break were performed for both sets of cylinder heads before tests are performed.

All engine health measurements were documented as well as modifications. See Appendix A for engine health measurements. Appendix C contains photos of the stock and modified cylinder heads.

Testing – Measurements

To gather data on the engine performance, the engine was run at a multitude of engine operating conditions. Tests were run at incremental RPM points as well as throttle opening points. Engine loading, base ignition timing and the EFI air fuel ratio map were varied in these tests to give a broad view of the performance over the entire operating range.

Each test consisted of recording all measurements 10 times per second for 20 seconds. Each test was repeated 10 times. Each set of tests was performed on the stock and modified cylinder head.

Many engine parameters were measured directly with sensors added for the EFI system and for the data acquisition program. Several more measurements were calculated during the tests from the sensor data.

The following parameters were measured directly from either test stand mounted sensors or engine mounted sensors.

1. Engine RPM: measured from a speed sensor on the crankshaft.
2. Output RPM: measured from a speed sensor on one of the transmission outputs
3. Exhaust Gas Temperature: measured using a K type thermocouple in cylinder #2 exhaust stream on exhaust manifold.
4. Air Fuel Ratio: measured from Innovate Wideband AF meter and Bosch wideband O2 sensor about 18 inches downstream from exhaust manifold.
5. Manifold Vacuum: Measured directly by pressure sensor on MegaSquirt EFI controller. Taken off live data stream output of MegaSquirt.

6. Throttle Position: Measured directly by sensor on throttle body by MegaSquirt EFI controller. Taken off live data stream output of MegaSquirt.
7. Engine Torque: Measured by load sensor on torque arm of hydraulic load cell. Assumed efficiencies of drive train used in final calculation.
8. Fuel Flow Rate: Measured by using live data stream from MegaSquirt to report injector duty cycle and measured valve of max flow rate of fuel injector.
9. Manifold Air Temperature: Measured directly by sensor on intake manifold by MegaSquirt EFI controller. Taken off live data stream output of MegaSquirt.
10. Coolant Temperature: Measured directly by sensor on intake manifold by MegaSquirt EFI controller. Taken off live data stream output of MegaSquirt.
11. Load Cell Temperature: Measured by using a coolant temp sensor immersed in the load cell hydraulic fluid reservoir.
12. Load Cell Position: Measured by a sensor coupled to adjustment knob of load cell. Records position of adjustment knob.
13. Barometric Pressure: Measured by MegaSquirt pressure sensor on power up and stored. Value only recorded each time MegaSquirt is powered up before cranking. Taken off live data stream output of MegaSquirt.
14. Outside Air Temperature: Recorded off local weather website.
15. Engine Charging Volts: Measured by MegaSquirt upon each test. Taken off live data stream output of MegaSquirt.
16. HC PPM: Taken from 5 gas EMS gas analyzer.
17. CO2 %: Taken from 5 gas EMS gas analyzer.
18. NOx PPM: Taken from 5 gas EMS gas analyzer.
19. CO %: Taken from 5 gas EMS gas analyzer.
20. O2 %: Taken from 5 gas EMS gas analyzer.

The following parameters we derived as a calculation of the above measurements and assumed constants.

1. Output Ratio: Function of the RPM's.
2. Brake HP: Function of torque and RPM.
3. Corrected HP: Function of Brake HP and air temperature.
4. BSFC: Function of fuel flow rate and horsepower.
5. Volumetric efficiency: Function of airflow into engine and air density.
6. Brake Thermal Efficiency: Function of horsepower and mass of fuel entering engine.

Please refer to the Appendix D for the details on how each parameter was calculated. Appendix E is the test schedule that was performed on both the stock and modified cylinder heads.

Testing – Analysis

The following pages are a summary of the test data. In order to condense the data, the following averaging scheme was utilized on each test set (stock and modified):

1. Each test (20 seconds of data) was compiled into a maximum, minimum and average for each measured or computed parameter of interest.
2. Each of these 10 compiled points (minimum, maximum and average) was again used to get a minimum, maximum and average value. This gives us an overall minimum, maximum and average value for all the readings taken for a particular test.

3. Each of the minimum, maximum and average points can now be compared for the stock head and modified head for each different test. This is compiled in the following tables.
4. Significant differences between the stock and modified head tests are highlighted and an analysis is given after the complied spreadsheets of data.

Testing – Considerations

One of the biggest considerations with this testing was to test the idea as completely as possible while keeping within a reasonable budget. In doing so, some components were chosen that would accomplish that task even if there were some drawbacks to using them.

In terms of loading, a water brake would have been a better choice, but the cost of a suitable water brake exceeded the cost of the entire dynamometer as shown in Appendix B. Therefore the hydraulic load cell was determined to be a more cost effective approach. The main drawback with a hydraulic load cell is that the loading is a function of two items, the restriction valve setting and the temperature of the hydraulic oil. As hydraulic oil becomes hotter, its viscosity decreases and will cause the load cell to load less. Since ambient conditions cannot always be kept the same, keeping the load cell oil temperature constant is very difficult. As we increase the load on the engine and increase the power output of the engine, this power is converted into heat in the oil. The best that can be accomplished is that the oil temperature is left to rise to where it becomes stable (the point where the heat exchanger is removing all excess heat) and then the tests run. During the analysis of the results, one can see this was not always accomplished and in the tests where there was a difference in the oil temperature, we cannot compare torque, power or any numbers based on these between tests as the loading is not exactly the same.

Additionally these tests are only looking at the effect of the added groove. Nothing else has been done to tune the engine in terms of spark timing, fuel mapping or camshaft setup. One of the claims of the groove patent is that it allows a higher compression ratio without exhibiting the effects of higher NOx and detonation that normally becomes an issue. Since the stock and modified heads both have the same combustion chamber volume, the testing did not explore the effects of this either. The bottom line is to start by just looking at the groove and what the effects from it are, without having any other factors come into play.

Test Results – Units

In order to fully understand the test data it is important to know what measurement units the data was recorded in.

Eng RPM – Engine RPM; Revolutions Per minute of the crankshaft of the engine

Ratio – Gear ratio of the Engine RPM divided by the output RPM of the transmission.

EGT – Exhaust Gas Temperature recorded in degrees Fahrenheit.

AFR – Air fuel ratio measured as the ratio mass of air divided by the mass of fuel.

Man VAC – Manifold vacuum of the engine recorded in inches of Mercury.

TPS – Throttle position sensor recorded as a percentage of throttle opening. 0 – fully closed, 100 – fully open.

Meas TQ – Measured torque of the engine. The value read from the torque arm is corrected for the gear ratio of the transmission, length of the torque arm and assumed mechanical efficiency of the transmission. Recorded in foot-pounds.

BK HP – Brake horsepower of the engine. Horsepower calculated from torque and engine rpm. Recorded as horsepower.

Corr HP – Corrected horsepower, brake horsepower value corrected for air temp by SAE standard calculation.

BSFC – Brake specific fuel consumption. Measure of how efficiently the engine is converting the fuel into power. Recorded in lb/HP*hr.

Vol Eff – Volumetric Efficiency, measure of the pumping efficiency of the engine. Recorded as a percentage.

BK TH Eff – Brake thermal efficiency, measure of the thermal efficiency of the engine. Recorded as a percentage.

Fuel Flow – Flow rate of fuel into the engine. Recorded as pounds mass per hour.

Man Air T – Manifold air temperature, measure of the temperature of the air in the intake manifold. Recorded in degrees Fahrenheit.

Load Cell T – Load cell oil temperature, measure of the temperature of the hydraulic fluid used in the loading cell. Recorded in degrees Fahrenheit.

HC (PPM) – Hydrocarbon emissions in the exhaust gases. Recorded in parts per million.

CO2 (%) – Carbon dioxide emissions in the exhaust gases. Recorded as a percentage.

NOx (PPM) – Nitrous oxide emissions in the exhaust gases. Recorded in parts per million.

CO (%) – Carbon monoxide emissions in the exhaust gases. Recorded as a percentage.

O2 (%) – Oxygen in the exhaust gases. Recorded as a percentage.

Appendix D has a detailed explanation of each measured parameter. Included are assumed constants, sensor information and the exact equation used to calculate parameters based upon sensor information.

Overall Analysis:

What can be determined from the following data? If the results are generalized and charted the following picture develops.

IDLE		
	EGT	lower
	NOx	lower
	HC & CO	lower

**EGT = Exhaust Gas Temperature*

MODERATE LOAD	EGT always lower				
LOW RPM			HC same	NOx higher	CO lower
|			HC lower	NOx higher	CO lower
|	Torque, power, & TE	higher			
|			HC lower	NOx lower	CO higher
|	Torque, power, & TE	higher			
HIGH RPM			HC lower	NOx higher	CO lower

**TE = Thermal Efficiency, EGT = Exhaust Gas Temperature*

HIGH LOAD	EGT always lower				
LOW RPM	Torque, power, & TE	lower	HC lower	NOx lower	CO same
|			HC same	NOx lower	
|	Torque, power, & TE	slightly higher		NOx same	CO higher
|			HC same		
|	Torque, power, & TE	same	HC lower	NOx higher	CO higher
HIGH RPM			HC lower	NOx higher	CO higher

**TE = Thermal Efficiency, EGT = Exhaust Gas Temperature*

1. EGT is lower on all tests.
2. Torque, power and thermal efficiencies increased on moderate loads in the higher rpm ranges (and hence lower BSFC). High loads did not have a positive or negative effect on these parameters.
3. HC pollution was generally lower.
4. NOx pollution increased with higher loads and speeds.
5. CO pollution increased with higher loads and speeds.

Points to Remember:

1. Ignition timing can drastically affect the pollutants emitted by an engine. In these tests, the ignition timing was a function of a mechanical distributor with vacuum advance. This gave us a fixed curve that may not have been optimal. This could be a reason why some of the emission numbers varied over rpm ranges.
2. While this is a typical 2-valve head engine, the overall combustion efficiency, swirl and tumble characteristics of the head were not known.
3. This head has a small squish area. Due to this only a small groove could be added to the modified head. With such a small modification, the fact that definite changes are observable is significant.

Idle tests: All data collected over 20 second intervals averaged for a single reading for each test.
Ignition Spark Advance: 6 degrees BTDC

Stock Head

	RPM	EGT	AFR	Man VAC	TPS	VOL EFF	Fuel Flow	Man Air Temp	Coolant Temp	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
1	924.80	716.51	14.80	18.91	0.50	29.58	1.42	104.44	188.13	165.88	13.30	95.07	0.16	2.27
2	924.40	719.30	14.85	18.92	0.50	29.70	1.42	105.00	187.36	157.89	13.30	95.76	0.15	2.28
3	928.01	719.81	14.85	18.88	0.50	29.63	1.42	105.00	190.54	155.09	13.30	95.84	0.16	2.26
4	926.94	720.74	14.86	18.87	0.50	29.65	1.42	105.03	187.56	150.32	13.30	94.00	0.14	2.34
5	927.35	721.58	14.91	18.90	0.50	29.71	1.42	105.80	189.17	149.19	13.30	94.85	0.15	2.28
6	930.02	720.95	14.85	18.95	0.49	29.55	1.42	105.80	188.79	147.00	13.32	93.00	0.15	2.33
7	927.79	721.02	14.80	18.89	0.49	29.53	1.42	106.50	190.35	146.00	13.34	94.00	0.17	2.28
8	925.30	719.75	14.86	18.90	0.50	29.62	1.41	107.24	186.75	145.23	13.30	93.47	0.14	2.31
9	908.68	717.02	15.13	18.76	0.50	30.08	1.39	107.88	188.61	145.00	13.26	92.26	0.15	2.39
10	905.50	713.40	15.17	18.68	0.50	30.09	1.38	108.00	189.66	145.17	12.98	85.00	0.10	2.83
	922.88	719.01	14.91	18.87	0.50	29.72	1.41	106.07	188.69	150.68	13.27	93.32	0.15	2.36

Groove Head

	RPM	EGT	AFR	Man VAC	TPS	VOL EFF	Fuel Flow	Man Air Temp	Coolant Temp	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
1	875.09	727.78	15.61	18.61	0.00	31.01	1.34	110.51	186.70	157.32	12.53	92.88	0.09	3.05
2	874.31	725.91	15.62	18.67	0.00	31.01	1.34	111.10	188.77	150.75	12.43	89.42	0.09	3.16
3	875.04	721.64	15.62	18.65	0.00	30.98	1.34	111.14	189.20	149.72	12.40	87.28	0.09	3.18
4	880.68	717.04	15.67	18.65	0.00	31.05	1.34	111.90	189.20	147.34	12.42	84.83	0.09	3.19
5	880.42	714.55	15.67	18.60	0.00	31.14	1.35	112.49	189.20	145.18	12.40	80.91	0.10	3.22
6	880.14	712.00	15.61	18.67	0.00	31.02	1.35	113.11	189.20	144.00	12.35	78.74	0.09	3.23
7	879.60	708.62	15.57	18.67	0.00	30.80	1.34	113.50	189.20	142.44	12.43	80.00	0.09	3.12
8	879.68	706.81	15.54	18.65	0.00	30.88	1.35	113.50	189.20	141.61	12.44	80.00	0.09	3.13
9	880.72	705.63	15.52	18.67	0.00	30.85	1.35	113.50	189.20	141.00	12.46	79.78	0.09	3.09
10	879.21	701.21	15.51	18.65	0.00	30.81	1.34	112.99	189.20	140.00	12.50	78.22	0.10	3.06
	878.49	714.12	15.59	18.65	0.00	30.96	1.34	112.37	188.91	145.94	12.43	83.21	0.09	3.14

Changes are small, but significant.

1. EGT is generally 10 to 15 degrees F lower on grooved head tests.
2. NOx is generally lower, even though AFR is lower on grooved head tests. AF confirmed leaner by lower fuel flow rate.
3. HC & CO is slightly lower on grooved head tests (could be attributed to leaner AFR).

2000 rpm, 4th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2009.4	3.55	1016.2	14.86	17.23	5.47	16.54	6.30	6.20	0.61
26 degrees	Average	1997.5	3.54	1013.8	14.75	17.14	5.47	16.23	6.17	6.08	0.61
	Low	1988.8	3.53	1011.3	14.58	17.08	5.47	16.05	6.11	6.01	0.60
	Grooved High	2015.9	3.59	959.2	14.30	17.47	5.97	14.21	5.45	5.46	0.70
	Average	2010.1	3.57	957.3	14.20	17.44	5.97	14.15	5.42	5.42	0.69
	Low	2004.6	3.56	955.4	14.13	17.41	5.97	14.06	5.37	5.37	0.69
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2009.6	3.56	1005.7	14.52	17.59	5.97	16.14	6.16	6.07	0.64
26 degrees	Average	2000.6	3.55	1002.4	14.30	17.17	5.94	15.89	6.05	5.96	0.63
	Low	1994.6	3.54	999.0	14.19	17.06	5.79	15.64	5.94	5.85	0.63
	Grooved High	2008.8	3.57	980.9	14.45	17.24	6.01	14.99	5.73	5.74	0.68
	Average	2004.4	3.57	979.3	14.42	17.18	6.00	14.77	5.64	5.64	0.67
	Low	2000.3	3.56	977.0	14.39	17.14	5.99	14.68	5.60	5.61	0.66
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2013.7	3.58	1020.0	14.84	17.18	5.47	16.01	6.10	6.05	0.62
30 degrees	Average	2006.7	3.57	1008.3	14.81	17.03	5.47	15.86	6.06	6.02	0.61
	Low	2000.0	3.56	1003.1	14.79	16.73	5.47	15.72	6.03	5.98	0.61
	Grooved High	2021.6	3.58	945.3	14.13	17.38	5.97	13.81	5.32	5.00	0.74
	Average	2014.9	3.57	942.3	14.06	17.35	5.97	13.66	5.24	4.93	0.73
	Low	2007.5	3.55	937.8	14.01	17.33	5.97	13.46	5.14	4.83	0.72
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2002.6	3.53	1000.2	14.79	17.08	5.47	16.32	6.21	6.11	0.62
29 degrees	Average	1998.6	3.52	998.8	14.72	17.03	5.47	16.10	6.13	6.03	0.62
	Low	1992.7	3.51	997.4	14.62	16.95	5.47	15.85	6.05	5.95	0.61
	Grooved High	2024.8	3.59	955.0	14.48	17.33	5.97	14.44	5.54	5.54	0.70
	Average	2019.3	3.57	951.9	14.43	17.30	5.97	14.24	5.48	5.48	0.69
	Low	2014.3	3.55	948.9	14.36	17.27	5.97	14.02	5.39	5.40	0.68
Humid air, base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2012.4	3.54	991.1	14.08	17.14	5.97	15.36	5.89	5.87	0.67
26 degrees	Average	2008.8	3.53	983.9	13.88	17.10	5.97	15.25	5.83	5.82	0.66
	Low	2005.3	3.52	972.9	13.82	17.07	5.97	15.06	5.75	5.74	0.65
	Grooved High	2024.7	3.50	973.1	13.98	17.18	5.97	15.31	5.90	5.89	0.67
	Average	2021.5	3.49	967.6	13.86	17.14	5.97	15.16	5.83	5.83	0.67
	Low	2016.9	3.48	963.0	13.74	17.10	5.97	15.02	5.79	5.78	0.67

2000 rpm, 4th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	35.8	22.3	3.79	109.6	194.6	109.3	100.2	14.00	1619.0	0.41	1.13
Average	35.6	22.1	3.75	108.8	192.7	105.5	95.5	14.00	1600.2	0.23	0.98
Low	35.4	22.0	3.72	108.0	191.8	102.1	92.3	13.97	1540.3	0.16	0.78
Grooved High	35.2	20.0	3.77	121.0	194.6	118.5	120.0	13.99	1177.7	1.00	0.62
Average	35.0	19.9	3.76	121.0	194.6	117.6	115.8	13.90	1152.1	0.88	0.59
Low	34.9	19.7	3.75	121.0	194.6	116.8	112.0	13.83	1128.3	0.77	0.57
10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	35.3	22.0	3.87	117.6	194.6	101.4	115.3	14.00	1578.0	0.87	0.68
Average	35.1	21.6	3.83	117.2	194.6	100.2	109.0	13.94	1520.7	0.72	0.60
Low	35.0	21.2	3.77	116.8	194.6	99.3	101.0	13.87	1457.5	0.48	0.55
Grooved High	35.9	20.6	3.78	123.7	195.2	111.1	88.0	13.80	1380.2	0.52	0.69
Average	35.8	20.3	3.77	123.1	194.9	110.6	85.7	13.80	1359.7	0.50	0.68
Low	35.7	20.1	3.75	122.8	194.6	110.3	82.2	13.78	1349.2	0.49	0.67
5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	36.0	22.0	3.75	113.5	191.8	110.3	108.0	14.10	1704.7	0.17	0.95
Average	35.9	21.8	3.73	112.8	191.8	108.8	102.9	14.05	1662.2	0.16	0.93
Low	35.6	21.6	3.71	111.9	191.8	107.3	97.3	14.00	1625.8	0.15	0.88
Grooved High	31.8	19.3	3.85	122.4	194.8	111.9	109.1	13.49	1584.2	1.23	0.64
Average	31.7	19.1	3.82	122.0	194.6	111.9	104.5	13.42	1540.7	1.15	0.63
Low	31.6	18.8	3.81	121.9	194.6	111.9	102.0	13.38	1521.6	0.98	0.62
10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	35.9	22.0	3.79	117.6	191.8	100.8	102.1	14.10	2008.9	0.31	0.92
Average	35.7	21.8	3.77	117.0	191.8	99.0	98.9	14.08	1967.8	0.25	0.87
Low	35.5	21.5	3.76	116.2	191.8	97.2	89.8	14.04	1912.4	0.21	0.79
Grooved High	35.9	19.8	3.80	122.1	194.6	111.9	93.6	13.80	1742.5	0.62	0.76
Average	35.8	19.6	3.79	121.9	194.6	111.5	89.0	13.77	1708.8	0.53	0.73
Low	35.6	19.4	3.77	121.9	194.6	111.1	85.0	13.74	1685.5	0.46	0.69
Humid air, base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	35.1	21.5	3.87	111.3	193.0	107.3	150.0	13.90	733.6	1.42	0.50
Average	35.0	21.4	3.86	111.1	192.2	107.3	145.9	13.82	714.3	1.35	0.47
Low	34.9	21.2	3.79	111.1	191.8	107.3	141.6	13.77	684.0	1.25	0.46
Grooved High	35.4	21.4	3.93	121.9	194.6	111.0	139.3	13.60	853.8	1.78	0.59
Average	35.2	21.1	3.90	121.3	194.6	109.6	135.8	13.45	809.2	1.47	0.56
Low	35.1	20.8	3.88	121.0	194.6	108.1	133.0	13.31	760.4	1.17	0.55

Item to note: Humid intake air will increase the octane of the overall air fuel mixture.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 5% lean, 10 deg of base timing, where the EGT dropped by 66 deg F.

HC (PPM):
The drop in HC is small, but the tests showed trend of generally lower HC emissions with the grooved head. It is interesting to note the humid test with a higher-octane air fuel mixture produced higher overall HC emissions.

NOx (PPM):
The change here is more significant. There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx. It is interesting to note how much lower NOx emissions are with the humid test as compared to the rest.

CO (%):
The CO numbers did seem generally higher on the grooved head. However the CO2 (%) follow this inversely. The higher CO numbers could be from the lower CO2.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

2500 rpm, 4th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2496.2	3.53	1129.3	14.31	15.65	9.45	26.7	12.7	12.5	0.43
31 degrees	Average	2483.5	3.53	1123.5	14.12	15.54	9.37	26.6	12.6	12.4	0.42
	Low	2473.7	3.52	1118.1	13.90	15.43	9.23	26.4	12.4	12.2	0.42
	Grooved High	2521.1	3.58	1066.4	13.89	15.96	9.82	23.6	11.3	11.3	0.48
	Average	2508.8	3.56	1062.3	13.83	15.86	9.66	23.3	11.1	11.1	0.47
	Low	2502.2	3.53	1056.7	13.75	15.79	9.45	22.9	10.9	10.9	0.47
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2509.6	3.54	1140.8	14.64	15.69	9.45	26.7	12.7	12.5	0.43
31 degrees	Average	2496.7	3.53	1134.7	14.45	15.34	9.45	26.3	12.5	12.3	0.42
	Low	2475.9	3.51	1126.6	14.32	15.25	9.45	25.7	12.1	11.9	0.42
	Grooved High	2521.0	3.59	1099.1	14.41	15.96	9.45	23.7	11.4	11.4	0.47
	Average	2511.9	3.57	1094.8	14.34	15.91	9.45	23.4	11.2	11.2	0.46
	Low	2503.9	3.55	1092.7	14.27	15.82	9.45	23.1	11.0	11.0	0.45
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2495.4	3.56	1119.8	14.58	15.63	8.98	26.4	12.5	12.4	0.42
34 degrees	Average	2484.8	3.55	1114.8	14.47	15.50	8.96	26.1	12.4	12.3	0.42
	Low	2474.8	3.54	1109.2	14.35	15.28	8.96	25.8	12.2	12.1	0.41
	Grooved High	2519.6	3.57	1064.2	13.94	15.97	9.45	23.2	11.1	10.4	0.48
	Average	2513.4	3.56	1061.9	13.89	15.87	9.45	23.1	11.0	10.4	0.48
	Low	2505.5	3.54	1059.8	13.83	15.81	9.45	23.0	11.0	10.3	0.48
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2513.2	3.52	1124.2	14.76	15.46	9.45	27.9	13.3	13.1	0.43
35 degrees	Average	2492.5	3.51	1121.6	14.67	15.30	9.45	27.5	13.0	12.8	0.40
	Low	2483.9	3.49	1116.3	14.56	15.23	9.45	27.2	12.9	12.7	0.39
	Grooved High	2525.4	3.59	1078.6	14.37	15.76	9.95	23.8	11.4	11.4	0.48
	Average	2518.5	3.57	1072.6	14.31	15.67	9.95	23.5	11.3	11.3	0.46
	Low	2500.6	3.55	1060.0	14.25	15.58	9.94	22.9	10.9	10.9	0.46
Humid air, base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2497.7	3.54	1129.2	13.99	16.03	9.45	24.9	11.8	11.8	0.45
30 degrees	Average	2491.1	3.53	1123.2	13.92	15.72	9.44	24.8	11.8	11.7	0.45
	Low	2481.2	3.52	1111.7	13.80	15.58	9.39	24.6	11.6	11.6	0.44
	Grooved High	2537.2	3.51	1077.9	13.68	15.57	9.95	26.1	12.6	12.5	0.45
	Average	2528.9	3.48	1075.3	13.58	15.47	9.95	26.0	12.5	12.5	0.44
	Low	2520.8	3.47	1072.4	13.52	15.38	9.95	25.7	12.4	12.3	0.44

2500 rpm, 4th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	39.1	33.3	5.34	112.7	197.5	102.9	115.13	13.87	2102.63	1.37	0.62
Average	38.7	32.8	5.30	111.6	196.8	102.6	109.44	13.69	1984.33	1.11	0.56
Low	38.2	32.6	5.27	110.3	194.6	102.1	103.33	13.53	1883.40	0.78	0.53
Grooved High	38.7	30.4	5.32	121.9	197.5	118.7	129.42	13.60	1671.08	1.77	0.52
Average	38.4	29.9	5.27	121.4	197.5	117.6	127.72	13.47	1604.33	1.65	0.48
Low	38.1	29.7	5.21	121.0	197.5	115.9	123.65	13.38	1571.01	1.49	0.47

10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	39.9	32.6	5.37	116.8	197.5	101.4	107.34	14.10	2296.76	0.72	0.71
Average	39.4	31.9	5.30	116.3	197.3	100.6	102.54	14.03	2219.59	0.60	0.60
Low	39.1	31.4	5.17	115.9	196.2	99.2	92.51	13.99	2177.19	0.34	0.55
Grooved High	38.8	30.1	5.17	124.6	197.5	120.9	89.00	13.76	2098.28	0.79	0.63
Average	38.7	29.7	5.14	124.0	197.5	119.8	87.28	13.70	2077.64	0.71	0.60
Low	38.6	29.3	5.10	122.9	197.5	118.9	85.00	13.67	2029.73	0.63	0.57

5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	39.3	32.7	5.21	112.6	194.6	108.0	110.89	14.10	2304.50	0.63	0.63
Average	39.0	32.5	5.15	112.0	194.6	107.2	108.69	14.07	2263.77	0.52	0.61
Low	38.5	32.3	5.03	111.9	194.6	106.5	106.06	14.00	2188.51	0.46	0.57
Grooved High	34.9	29.6	5.32	121.9	197.5	118.3	111.00	13.32	2139.66	1.65	0.53
Average	34.7	29.4	5.29	121.6	197.5	116.4	109.65	13.28	2089.18	1.55	0.53
Low	34.6	29.3	5.27	121.0	197.5	114.3	107.01	13.22	2026.45	1.44	0.52

10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	41.8	34.2	5.49	119.4	197.5	100.0	100.49	14.12	2788.49	0.40	0.83
Average	39.7	33.3	5.26	118.2	197.0	99.1	96.34	14.11	2764.31	0.31	0.76
Low	38.4	31.4	5.12	116.8	194.6	97.2	93.02	14.10	2724.51	0.25	0.69
Grooved High	39.5	29.8	5.26	124.6	197.5	115.9	103.00	13.70	2513.40	0.82	0.65
Average	39.3	29.4	5.24	122.9	197.5	113.9	102.07	13.69	2477.91	0.77	0.63
Low	39.2	28.5	5.22	121.9	197.5	111.8	101.00	13.65	2424.92	0.73	0.61

Humid air, base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	38.9	31.8	5.29	110.8	194.6	111.6	134.00	13.92	1132.15	1.45	0.44
Average	38.5	31.5	5.25	110.4	194.6	110.2	126.78	13.86	1094.51	1.32	0.43
Low	38.2	31.3	5.21	110.3	194.6	108.8	123.37	13.79	1037.66	1.19	0.41
Grooved High	39.4	32.9	5.56	120.7	197.5	109.6	134.05	13.17	1280.25	2.27	0.52
Average	39.2	32.7	5.54	119.8	197.5	108.3	132.51	13.05	1222.10	2.15	0.49
Low	39.0	32.3	5.51	119.1	197.5	107.3	130.95	12.97	1175.28	1.94	0.48

Item to note: Humid intake air will increase the octane of the overall air fuel mixture.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 5% lean, 6 deg of base timing, where the EGT dropped by 61.2 deg F.

NOx (PPM):
The change here is more significant. There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx. It is interesting to note the NOx emissions increased in the humid test although was still at levels lower than the normal non-humid tests.

HC (PPM):
The HC did not show a significant change, some were up and some were down, but all amounts were minimal and a clear correlation could not be determined.

CO (%):
CO was higher on most tests with the grooved head. Since the CO2 numbers were lower on the grooved head, this could be why there is more CO.

AFR vs. Fuel Flow rate:
One interesting thing to note is that AFR numbers were consistently richer on the grooved head, even though fuel flow numbers were not always greater. Since AFR is measured with the Wideband O2 sensor it is dependent upon the leftover oxygen in the exhaust and not on the fuel. The O2 % in the exhaust as measured by the gas analyzer was slightly lower for all tests but the humid test. Higher levels of CO% for most tests could explain where this O2 was going.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

3000 rpm, 4th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3041.0	3.52	1201.9	14.31	13.64	13.88	38.4	22.1	21.8	0.34
34 degrees	Average	3026.5	3.51	1199.4	14.21	13.52	13.47	37.6	21.6	21.3	0.33
	Low	3012.0	3.50	1191.6	14.15	13.30	13.43	37.0	21.4	21.1	0.33
	Grooved High	3031.4	3.59	1152.6	14.04	14.11	13.43	32.5	18.6	18.6	0.39
	Average	3018.8	3.58	1149.5	13.97	14.00	13.43	31.9	18.3	18.3	0.38
	Low	3007.9	3.56	1143.8	13.92	13.87	13.43	31.5	18.2	18.2	0.38
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3061.6	3.53	1216.4	14.79	13.39	13.93	34.4	19.9	19.6	0.37
34 degrees	Average	3040.3	3.51	1213.9	14.72	13.27	13.93	34.2	19.8	19.5	0.36
	Low	3016.5	3.50	1210.6	14.64	13.09	13.93	33.7	19.5	19.2	0.36
	Grooved High	3025.8	3.58	1178.8	14.48	14.04	13.52	28.9	16.6	16.7	0.42
	Average	3016.7	3.56	1176.9	14.45	13.98	13.46	28.8	16.5	16.6	0.42
	Low	3008.7	3.54	1174.5	14.43	13.94	13.43	28.6	16.4	16.5	0.41
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3040.4	3.54	1198.2	14.75	13.73	13.43	36.4	20.8	20.7	0.36
38 degrees	Average	3026.6	3.53	1195.6	14.49	13.63	13.43	35.3	20.3	20.2	0.35
	Low	3008.7	3.52	1189.8	14.38	13.51	13.43	34.0	19.7	19.6	0.34
	Grooved High	3022.2	3.56	1146.2	14.10	14.56	12.94	25.3	14.6	14.6	0.48
	Average	3018.1	3.55	1145.0	14.08	14.52	12.94	25.1	14.4	14.5	0.47
	Low	3012.4	3.53	1143.8	14.06	14.48	12.94	24.9	14.3	14.3	0.47
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3064.9	3.55	1207.1	14.72	13.18	13.93	37.1	21.3	21.0	0.36
38 degrees	Average	3041.0	3.51	1203.7	14.69	13.06	13.93	36.2	21.0	20.7	0.34
	Low	3023.8	3.46	1197.8	14.62	12.90	13.93	34.6	20.2	19.9	0.34
	Grooved High	3020.3	3.58	1162.5	14.42	14.43	13.01	26.1	15.0	15.0	0.46
	Average	3016.7	3.56	1161.0	14.41	14.37	12.95	25.9	14.9	14.9	0.45
	Low	3009.4	3.54	1158.2	14.39	14.33	12.94	25.6	14.7	14.7	0.45
Humid air, base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3046.8	3.54	1195.9	13.95	14.04	13.43	33.8	19.4	19.4	0.39
32 degrees	Average	3032.6	3.53	1194.0	13.86	13.94	13.39	32.9	19.0	18.9	0.38
	Low	3014.5	3.52	1191.3	13.72	13.83	13.36	32.1	18.6	18.6	0.37
	Grooved High	3013.0	3.51	1150.1	13.83	14.33	12.94	26.9	15.4	15.4	0.47
	Average	3003.4	3.50	1149.6	13.80	14.30	12.94	26.6	15.2	15.2	0.46
	Low	2999.5	3.46	1149.1	13.78	14.24	12.94	26.3	15.0	15.0	0.46

3000 rpm, 4th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.1	41.9	7.34	117.6	200.5	109.4	112.22	13.81	2986.31	1.10	0.61
Average	43.6	41.2	7.23	115.6	200.3	106.5	106.17	13.71	2829.47	0.97	0.58
Low	43.3	40.7	7.17	113.5	199.2	103.7	103.68	13.61	2779.00	0.74	0.57
Grooved High	43.4	36.9	7.05	124.6	200.5	127.4	115.40	13.50	2146.31	1.54	0.61
Average	43.0	36.5	7.04	123.5	200.5	124.0	113.89	13.46	2037.17	1.43	0.60
Low	42.7	36.3	7.01	121.9	200.5	120.5	110.62	13.40	1976.56	1.29	0.59

10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	45.0	37.4	7.19	120.2	200.5	110.3	91.96	14.10	3283.07	0.33	0.89
Average	44.4	37.1	7.14	118.9	200.5	107.6	91.13	14.06	3237.24	0.27	0.81
Low	44.1	36.6	7.08	117.6	200.5	104.3	90.52	14.00	3214.00	0.23	0.75
Grooved High	43.8	32.7	6.92	125.6	200.5	125.6	94.90	13.70	2675.29	0.59	0.79
Average	43.6	32.5	6.88	125.5	200.5	123.9	91.01	13.70	2618.07	0.55	0.74
Low	43.3	32.1	6.85	124.6	200.5	121.9	89.00	13.69	2572.92	0.47	0.73

5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.2	40.3	7.04	114.3	197.5	114.7	105.32	14.02	3057.51	0.71	0.71
Average	43.8	39.1	7.01	114.0	197.5	112.2	102.75	13.99	3005.98	0.56	0.68
Low	43.5	38.0	6.95	113.5	197.5	109.8	100.52	13.92	2935.24	0.46	0.65
Grooved High	42.2	29.6	6.86	125.6	200.5	136.6	94.43	13.40	2546.65	1.27	0.64
Average	42.1	29.4	6.84	124.5	200.5	136.1	93.02	13.37	2514.19	1.23	0.64
Low	42.0	29.2	6.80	123.7	200.5	135.5	91.91	13.30	2491.00	1.20	0.64

10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.8	39.9	7.23	124.5	200.5	108.8	96.74	14.13	3699.78	0.32	0.83
Average	44.5	39.2	7.17	122.7	200.5	105.3	95.56	14.10	3668.55	0.29	0.80
Low	44.0	37.4	7.12	121.0	200.5	102.0	94.00	14.10	3632.06	0.26	0.76
Grooved High	42.7	30.1	6.78	126.5	200.5	133.4	91.89	13.70	2893.83	0.65	0.76
Average	42.7	29.8	6.77	126.4	200.5	133.0	90.24	13.70	2872.43	0.64	0.74
Low	42.6	29.5	6.73	125.6	200.1	132.4	89.00	13.70	2856.96	0.60	0.73

Humid air, base fuel, 6deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	43.9	38.4	7.39	111.9	197.5	118.7	126.48	13.80	1724.44	1.56	0.50
Average	43.0	37.5	7.16	111.5	197.5	115.9	125.56	13.67	1652.94	1.48	0.50
Low	42.6	36.4	7.10	111.1	197.5	113.4	124.00	13.60	1629.18	1.27	0.50
Grooved High	42.6	31.2	7.04	119.0	200.5	124.6	117.00	13.20	1666.60	1.81	0.55
Average	42.5	30.8	7.02	118.5	200.3	124.4	116.46	13.16	1636.86	1.78	0.55
Low	42.3	30.4	7.00	118.3	198.4	123.7	115.37	13.10	1609.32	1.75	0.55

Item to note: Humid intake air will increase the octane of the overall air fuel mixture.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 5% lean, 10 deg of base timing, where the EGT dropped by 50.6 deg F.

NOx (PPM):
The change here is more significant. There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx. It is interesting to note that the grooved heads NOx levels were lower on the 10% lean tests than stock 5% lean head.

HC (PPM):
The HC did not show a significant change, some were up and some were down, but all amounts were minimal and a clear correlation could not be determined.

AFR vs. Fuel Flow rate:
One interesting thing to note is that AFR numbers were consistently richer on the grooved head, even though fuel flow numbers were lower on each test for the grooved head. Since AFR is measured with the Wideband O2 sensor it is dependent upon the leftover oxygen in the exhaust and not on the amount of fuel in the system.

CO (%):
Higher CO numbers were also observed for all grooved tests. CO2 was lower for all grooved tests, which could explain why the CO rose.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

** A humid test was not performed for this data set.*

3500 rpm, 4th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3579.5	3.50	1259.3	13.89	11.57	18.91	39.0	26.3	25.9	0.39
36 degrees	Average	3547.4	3.49	1253.5	13.77	11.15	18.65	37.8	25.5	25.1	0.38
	Low	3511.7	3.47	1241.5	13.70	10.89	17.91	36.0	24.1	23.7	0.37
	Grooved High	3544.0	3.58	1208.9	13.59	12.04	17.94	34.0	22.8	22.8	0.43
	Average	3526.0	3.56	1205.6	13.46	11.92	17.92	33.4	22.4	22.5	0.42
	Low	3513.3	3.55	1203.4	13.36	11.79	17.91	33.0	22.1	22.1	0.41
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3571.4	3.52	1281.4	14.53	11.47	18.91	36.3	24.6	24.2	0.40
36 degrees	Average	3539.6	3.50	1276.0	14.29	11.11	18.50	35.8	24.1	23.7	0.39
	Low	3518.8	3.49	1267.7	14.18	10.89	17.91	34.9	23.4	23.0	0.39
	Grooved High	3524.5	3.59	1238.2	14.31	12.07	17.91	32.9	22.1	22.1	0.42
	Average	3516.1	3.57	1236.9	14.24	12.03	17.91	32.6	21.8	21.8	0.41
	Low	3507.1	3.55	1235.3	14.19	11.96	17.91	31.8	21.2	21.3	0.41
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3536.0	3.53	1241.1	13.94	11.77	17.91	36.4	24.5	24.3	0.40
40 degrees	Average	3522.0	3.53	1238.0	13.73	11.44	17.77	36.2	24.3	24.1	0.39
	Low	3507.2	3.52	1234.8	13.65	10.73	17.41	36.1	24.1	24.0	0.39
	Grooved High	3518.9	3.55	1198.3	13.59	12.25	17.90	31.0	20.8	20.8	0.49
	Average	3510.1	3.54	1196.2	13.54	12.14	17.69	29.2	19.5	19.5	0.47
	Low	3500.7	3.53	1194.3	13.50	12.01	17.41	28.3	18.9	18.9	0.45
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3543.8	3.53	1276.6	14.51	11.36	18.91	37.2	25.0	24.7	0.40
40 degrees	Average	3527.8	3.51	1267.6	14.34	10.83	18.61	36.5	24.5	24.1	0.38
	Low	3514.4	3.49	1256.1	14.13	9.75	18.41	35.8	24.1	23.7	0.37
	Grooved High	3539.3	3.58	1232.4	14.37	12.11	17.91	33.4	22.3	22.3	0.42
	Average	3519.5	3.55	1229.5	14.30	11.91	17.91	32.5	21.8	21.8	0.41
	Low	3502.2	3.53	1220.2	14.23	11.72	17.91	31.7	21.2	21.2	0.41

** A humid test was not performed for this data set.*

3500 rpm, 4th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	49.0	38.5	9.86	122.8	207.1	117.6	107.86	13.23	2834.30	2.13	0.50
Average	48.4	37.5	9.72	121.0	205.7	114.3	104.45	13.13	2729.42	1.96	0.45
Low	47.6	36.3	9.37	118.7	203.7	110.7	101.00	13.04	2625.19	1.70	0.42
Grooved High	47.9	35.8	9.43	128.4	208.7	142.8	114.00	12.83	2352.92	2.79	0.56
Average	47.3	35.0	9.39	126.9	206.4	136.4	113.18	12.65	2184.15	2.55	0.50
Low	46.8	34.1	9.33	125.6	203.7	130.8	112.00	12.50	2043.23	2.25	0.47
10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	50.1	35.4	9.56	125.6	207.1	119.9	101.31	14.00	3570.00	1.09	0.54
Average	48.8	35.0	9.42	123.4	206.1	116.2	96.05	13.91	3442.00	0.88	0.49
Low	48.0	34.6	9.25	121.0	203.7	112.7	93.77	13.77	3236.47	0.72	0.46
Grooved High	48.2	33.9	8.98	130.4	210.7	145.4	83.86	13.60	3044.88	1.03	0.63
Average	47.9	33.5	8.95	129.3	208.3	142.1	82.47	13.54	2972.32	0.94	0.60
Low	47.7	32.5	8.93	127.4	207.1	137.2	81.32	13.50	2921.52	0.83	0.59
5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	50.0	37.3	9.69	118.5	203.7	126.5	112.38	13.23	2629.04	2.15	0.48
Average	48.2	36.7	9.49	117.2	203.7	122.2	110.99	13.19	2556.03	2.05	0.47
Low	47.2	36.2	9.30	115.9	203.7	118.5	108.81	13.10	2470.81	1.91	0.43
Grooved High	47.5	32.3	9.34	127.4	207.1	146.9	102.00	12.79	2343.21	2.54	0.52
Average	47.1	30.7	9.24	127.0	207.0	142.9	100.87	12.70	2282.13	2.44	0.51
Low	46.6	29.8	9.17	126.3	205.7	139.5	99.51	12.59	2233.63	2.33	0.51
10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	50.0	36.6	9.68	127.4	207.1	119.8	102.00	14.10	3948.31	1.03	0.58
Average	49.0	35.6	9.40	126.6	206.3	115.9	98.59	13.99	3790.68	0.79	0.52
Low	48.5	34.4	9.23	125.6	203.7	111.1	93.11	13.80	3619.00	0.55	0.49
Grooved High	48.8	33.6	9.10	128.4	209.3	144.6	88.00	13.66	3360.03	0.97	0.65
Average	48.4	33.0	9.01	127.5	206.9	138.6	87.11	13.58	3276.14	0.87	0.63
Low	47.7	32.1	8.90	126.5	203.7	133.8	86.00	13.50	3184.94	0.74	0.61

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 5% lean, 6 deg of base timing, where the EGT dropped by 47.9 deg F.

NOx (PPM):
There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx.

HC (PPM):
The HC did not show a significant change, observed readings were generally lower, but all amounts were minimal and a clear correlation could not be determined.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

10% TPS, 5th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2282.3	2.95	1126.1	14.58	13.46	9.95	34.6	15.0	14.8	0.37
29 degrees	Average	2264.3	2.95	1121.8	14.41	13.40	9.95	34.4	14.8	14.6	0.36
	Low	2250.8	2.94	1115.3	14.13	13.31	9.95	34.2	14.7	14.4	0.36
	Grooved High	2244.7	2.99	1073.6	14.23	14.16	9.95	29.3	12.5	12.5	0.42
	Average	2241.1	2.98	1069.0	14.05	14.05	9.95	29.1	12.4	12.4	0.41
	Low	2235.4	2.96	1061.5	13.85	13.89	9.95	28.9	12.3	12.3	0.41
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2167.0	2.95	1109.5	15.39	13.17	9.95	33.0	13.6	13.4	0.37
29 degrees	Average	2158.4	2.94	1100.1	15.15	13.11	9.95	32.7	13.4	13.2	0.37
	Low	2149.2	2.93	1081.8	15.06	13.03	9.95	32.2	13.2	13.0	0.36
	Grooved High	2207.0	2.98	1079.5	14.65	13.68	9.95	31.7	13.2	13.2	0.39
	Average	2188.9	2.97	1074.0	14.56	13.53	9.95	31.5	13.1	13.1	0.38
	Low	2166.9	2.96	1062.4	14.50	13.38	9.95	31.2	13.0	13.0	0.38
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2283.4	2.95	1110.5	15.11	13.96	9.95	33.9	14.7	14.6	0.37
33 degrees	Average	2220.4	2.95	1108.4	14.85	13.49	9.95	33.3	14.1	13.9	0.36
	Low	2159.7	2.94	1105.8	14.10	13.07	9.95	32.9	13.5	13.3	0.35
	Grooved High	2207.0	2.98	1079.5	14.65	13.68	9.95	31.7	13.2	13.2	0.39
	Average	2188.9	2.97	1074.0	14.56	13.53	9.95	31.5	13.1	13.1	0.38
	Low	2166.9	2.96	1062.4	14.50	13.38	9.95	31.2	13.0	13.0	0.38
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2248.2	2.93	1099.9	15.34	13.67	9.95	33.9	14.3	14.0	0.36
33 degrees	Average	2220.6	2.90	1092.9	15.27	13.36	9.95	33.4	14.1	13.9	0.35
	Low	2198.4	2.89	1088.1	15.21	13.03	9.95	32.9	14.0	13.8	0.35
	Grooved High	2218.5	2.98	1061.2	14.49	13.74	9.95	32.0	13.5	13.5	0.39
	Average	2206.6	2.97	1058.6	14.46	13.67	9.95	31.5	13.2	13.3	0.38
	Low	2193.7	2.95	1055.2	14.44	13.62	9.95	31.1	13.0	13.0	0.38
Humid air, base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2263.2	2.95	1113.1	14.35	13.50	9.95	34.2	14.6	14.6	0.38
28 degrees	Average	2253.7	2.95	1107.2	13.95	13.38	9.95	33.6	14.4	14.4	0.37
	Low	2239.6	2.94	1096.4	13.82	13.09	9.95	33.0	14.2	14.2	0.37
	Grooved High	2214.6	2.90	1065.8	14.01	13.51	9.95	33.4	14.0	14.0	0.38
	Average	2208.1	2.89	1062.0	13.99	13.47	9.95	33.2	14.0	14.0	0.38
	Low	2201.0	2.88	1055.3	13.96	13.43	9.95	33.1	13.9	13.9	0.38
Base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2222.3	2.87	1127.4	14.71	13.84	9.95	32.2	13.6	13.4	0.39
29 degrees	Average	2209.2	2.87	1119.6	14.69	13.43	9.95	32.1	13.5	13.3	0.38
	Low	2192.3	2.87	1103.4	14.68	13.28	9.95	32.0	13.4	13.1	0.38
	Grooved High	2212.5	2.92	1058.3	14.17	13.53	9.95	33.1	13.9	13.8	0.39
	Average	2197.7	2.91	1048.8	13.94	13.44	9.95	33.0	13.8	13.7	0.38
	Low	2177.1	2.90	1031.7	13.77	13.30	9.95	32.9	13.7	13.6	0.38

10% TPS, 5th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.7	38.2	5.50	122.8	195.1	117.9	122.92	13.90	2588.08	1.10	0.73
Average	43.8	37.7	5.36	121.9	194.7	116.0	112.00	13.81	2464.94	0.68	0.68
Low	43.3	36.4	5.28	121.0	194.6	114.3	105.51	13.62	2260.35	0.45	0.59
Grooved High	42.8	34.0	5.20	127.4	197.5	134.0	117.33	13.55	2310.99	1.61	0.58
Average	42.6	33.6	5.15	127.0	195.3	132.1	112.72	13.40	2154.35	1.19	0.55
Low	42.5	33.2	5.10	126.5	194.6	130.4	108.66	13.16	1954.52	0.87	0.52

10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	45.2	36.8	5.03	121.0	197.5	107.3	80.00	13.90	2679.57	0.08	1.51
Average	44.6	36.4	4.94	119.9	195.1	107.0	78.17	13.80	2651.09	0.08	1.33
Low	44.3	35.9	4.89	118.5	194.6	106.5	76.55	13.69	2610.59	0.07	1.20
Grooved High	44.5	35.3	5.06	122.8	197.5	117.5	93.00	13.85	2716.46	0.44	0.81
Average	44.2	35.1	5.03	122.1	197.5	114.8	88.37	13.82	2610.57	0.36	0.73
Low	43.8	34.8	4.99	121.9	197.5	111.9	82.31	13.80	2551.15	0.25	0.69

5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.5	38.8	5.24	119.3	195.6	131.4	109.00	14.00	2824.36	0.64	1.28
Average	43.8	37.4	5.06	118.8	193.4	118.4	90.90	13.92	2711.31	0.25	1.02
Low	42.3	36.5	4.94	118.5	191.8	106.5	78.00	13.80	2616.00	0.08	0.67
Grooved High	44.5	35.3	5.06	122.8	197.5	117.5	93.00	13.85	2716.46	0.44	0.81
Average	44.2	35.1	5.03	122.1	197.5	114.8	88.37	13.82	2610.57	0.36	0.73
Low	43.8	34.8	4.99	121.9	197.5	111.9	82.31	13.80	2551.15	0.25	0.69

10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.7	38.4	5.07	127.4	194.6	121.0	91.00	13.80	3066.39	0.07	1.62
Average	44.1	37.9	4.99	126.7	192.6	117.0	88.76	13.72	3018.63	0.07	1.52
Low	43.6	37.3	4.95	125.6	191.8	113.2	84.34	13.64	2992.65	0.06	1.44
Grooved High	44.0	35.9	5.08	125.6	197.5	120.2	110.63	13.84	2868.27	0.55	0.67
Average	43.9	35.3	5.07	125.3	197.2	118.5	104.21	13.80	2847.50	0.51	0.66
Low	43.7	34.7	5.05	124.6	194.6	116.8	102.00	13.80	2812.49	0.49	0.65

Humid air, base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	45.5	38.3	5.46	113.5	194.8	116.8	132.73	13.90	1448.00	1.46	0.49
Average	43.8	37.5	5.39	113.5	194.6	115.1	129.76	13.75	1373.23	1.32	0.47
Low	43.4	36.0	5.36	113.5	194.6	113.5	127.00	13.64	1317.65	1.14	0.45
Grooved High	44.0	37.3	5.27	118.5	197.5	112.6	127.33	13.50	1714.80	1.41	0.55
Average	43.9	37.2	5.26	117.5	196.4	111.4	123.51	13.48	1664.69	1.36	0.55
Low	43.7	37.0	5.25	116.8	194.6	110.3	119.77	13.44	1624.05	1.32	0.55

Base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	44.7	35.3	5.19	120.2	197.5	107.6	87.51	14.20	2564.65	0.23	0.84
Average	44.4	34.9	5.18	119.3	195.5	105.2	83.81	14.19	2538.97	0.22	0.83
Low	43.9	34.6	5.14	118.5	194.6	102.5	81.00	14.18	2516.50	0.20	0.81
Grooved High	43.7	36.9	5.34	102.1	194.6	109.6	119.49	13.93	2498.13	2.04	0.60
Average	43.6	36.7	5.29	101.6	193.5	106.9	109.53	13.66	2264.69	1.61	0.59
Low	43.3	36.6	5.22	100.7	191.8	104.3	102.35	13.40	2004.89	1.15	0.58

Item to note: Humid intake air will increase the octane of the overall air fuel mixture.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 5% lean, 6 deg of base timing, where the EGT dropped by 52.8 deg F. (The base fuel 6 deg had the largest drop in EGT but, the AFR was significantly richer for the grooved test and therefore some of this drop can be attributed to excess fuel)

NOx (PPM):
There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx.

HC (PPM):
The HC did not show a significant change, observed readings were generally lower, but all amounts were minimal and a clear correlation could not be determined.

Load Cell Temp vs. Torque, Power and Thermal Efficiency:
The load cell temperature was stable on the 10% lean - 10 deg, humid 6 deg and base fuel 6 deg tests. Torque, power and thermal efficiency was down slightly for the grooved head on the lean and humid air tests, but was up on the base fuel test.

15% TPS, 5th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2730.3	2.94	1187.8	13.98	10.71	14.93	44.49	22.83	22.48	0.34
31 degrees	Average	2713.7	2.92	1180.9	13.88	10.63	14.93	42.59	22.00	21.66	0.34
	Low	2694.8	2.91	1174.9	13.83	10.27	14.93	41.77	21.68	21.35	0.32
	Grooved High	2782.6	3.00	1151.9	13.91	11.49	14.93	36.04	19.09	19.11	0.39
	Average	2773.1	2.98	1150.4	13.86	11.45	14.93	35.67	18.83	18.85	0.38
	Low	2763.2	2.94	1148.3	13.81	11.41	14.93	35.18	18.58	18.60	0.38
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2704.4	2.93	1212.5	14.82	10.60	14.93	42.44	21.42	21.09	0.34
32 degrees	Average	2681.1	2.92	1208.6	14.67	10.47	14.93	41.71	21.29	20.96	0.33
	Low	2650.5	2.91	1200.7	14.58	10.36	14.93	41.04	21.13	20.80	0.33
	Grooved High	2728.9	2.97	1165.4	14.31	11.17	14.93	38.33	19.72	19.74	0.38
	Average	2712.6	2.95	1163.9	14.28	11.07	14.93	36.99	19.10	19.12	0.37
	Low	2699.9	2.93	1161.1	14.23	10.93	14.93	35.98	18.58	18.60	0.36
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2836.3	2.95	1178.6	13.89	11.06	14.93	42.61	23.00	22.84	0.34
37 degrees	Average	2832.7	2.94	1177.0	13.83	10.94	14.93	42.31	22.82	22.66	0.33
	Low	2829.4	2.93	1175.3	13.75	10.61	14.93	41.94	22.59	22.44	0.33
	Grooved High	2738.3	2.96	1126.5	13.66	11.11	14.93	34.72	17.87	17.89	0.42
	Average	2720.3	2.95	1124.8	13.63	11.03	14.93	34.27	17.75	17.77	0.41
	Low	2698.2	2.94	1122.0	13.60	10.90	14.93	33.66	17.44	17.45	0.41
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2759.9	2.91	1209.7	14.84	10.89	14.93	39.98	21.01	20.68	0.34
37 degrees	Average	2750.4	2.89	1206.2	14.77	10.82	14.93	39.53	20.70	20.38	0.34
	Low	2742.3	2.88	1202.8	14.69	10.76	14.93	39.13	20.43	20.12	0.34
	Grooved High	2707.0	2.97	1151.6	14.46	11.20	14.93	37.12	19.08	19.09	0.38
	Average	2688.0	2.95	1148.6	14.30	11.12	14.93	36.59	18.72	18.74	0.37
	Low	2665.4	2.94	1142.5	14.21	11.01	14.93	35.46	18.16	18.18	0.37
Humid air, base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2763.5	2.95	1182.1	13.80	11.07	14.93	42.24	22.15	22.09	0.34
33 degrees	Average	2738.0	2.94	1176.7	13.63	10.88	14.93	41.98	21.89	21.83	0.34
	Low	2714.9	2.93	1169.4	13.56	10.50	14.93	41.75	21.58	21.53	0.33
	Grooved High	2733.1	2.91	1131.4	13.50	10.83	14.93	39.37	20.18	20.16	0.39
	Average	2706.3	2.88	1126.6	13.48	10.76	14.93	38.44	19.81	19.79	0.38
	Low	2674.0	2.87	1119.2	13.45	10.60	14.93	37.60	19.53	19.51	0.37
Base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2787.3	2.86	1200.6	14.00	10.73	15.42	39.00	20.39	20.00	0.38
31 degrees	Average	2771.2	2.86	1199.4	13.91	10.62	15.42	38.34	20.23	19.84	0.38
	Low	2746.3	2.85	1197.7	13.69	10.50	15.42	37.46	19.87	19.49	0.37
	Grooved High	2690.5	2.93	1122.5	13.28	11.10	14.93	38.35	19.58	19.41	0.39
	Average	2668.7	2.92	1119.9	13.27	10.96	14.93	38.04	19.33	19.16	0.39
	Low	2640.4	2.90	1115.2	13.25	10.79	14.93	37.66	19.04	18.88	0.38

15% TPS, 5th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	49.1	43.7	7.46	121.9	200.5	117.1	128.0	13.41	2685.4	2.13	0.48
Average	48.7	41.9	7.42	121.6	200.0	115.6	124.3	13.30	2550.7	1.75	0.46
Low	48.5	41.0	7.37	121.0	197.5	113.5	120.7	13.08	2324.4	1.53	0.44
Grooved High	47.7	37.4	7.25	129.4	203.7	148.4	111.0	13.20	2467.1	1.75	0.53
Average	47.6	37.0	7.21	129.4	203.7	148.3	109.3	13.14	2417.5	1.65	0.52
Low	47.4	36.5	7.18	129.4	203.7	147.2	107.0	13.10	2360.4	1.55	0.52
10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	49.9	40.9	7.11	120.1	200.5	114.9	98.4	14.10	3492.7	0.39	0.72
Average	49.6	40.5	7.06	119.0	199.6	111.3	96.5	14.10	3466.1	0.34	0.70
Low	49.4	39.9	6.94	118.5	197.5	107.3	94.4	14.09	3434.2	0.30	0.65
Grooved High	49.2	38.4	7.06	126.5	200.5	132.7	104.2	13.61	2898.2	0.90	0.62
Average	48.9	37.2	7.04	126.5	200.5	129.4	98.4	13.60	2863.8	0.85	0.60
Low	48.7	36.1	7.01	126.5	200.5	126.5	93.5	13.59	2833.2	0.80	0.59
5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	48.2	43.4	7.62	121.0	200.5	144.6	126.0	13.37	2825.4	2.00	0.51
Average	47.8	43.0	7.52	120.9	200.5	143.9	125.7	13.28	2732.0	1.76	0.51
Low	47.6	42.4	7.48	120.3	200.5	143.4	125.0	13.10	2563.0	1.64	0.51
Grooved High	48.9	35.1	7.36	122.8	200.5	133.4	106.0	12.90	2200.3	2.32	0.51
Average	48.5	34.9	7.33	122.8	200.5	129.6	104.8	12.84	2173.9	2.25	0.51
Low	48.3	34.2	7.29	122.8	200.5	125.5	104.4	12.80	2142.4	2.19	0.51
10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	48.8	39.9	7.08	128.4	203.7	131.4	98.0	14.10	3876.7	0.30	0.90
Average	48.5	39.4	7.04	128.4	202.8	129.5	96.8	14.09	3857.7	0.26	0.82
Low	48.1	39.1	7.01	128.4	200.5	127.9	95.4	14.04	3820.7	0.23	0.76
Grooved High	49.5	37.3	7.01	125.6	200.5	130.4	97.7	13.67	3203.4	1.09	0.63
Average	49.0	36.7	6.98	125.1	200.5	126.8	96.0	13.61	3098.3	0.86	0.61
Low	48.6	35.7	6.92	124.6	200.5	123.2	91.9	13.49	2928.0	0.67	0.59
Humid air, base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	48.7	43.3	7.47	113.5	199.4	125.4	132.1	13.30	1681.9	2.19	0.42
Average	48.3	42.7	7.39	112.8	197.8	121.7	130.6	13.25	1653.3	2.10	0.42
Low	47.3	41.5	7.18	112.7	197.5	118.5	128.4	13.20	1614.9	2.04	0.41
Grooved High	49.6	39.5	7.57	117.6	200.5	119.2	126.3	12.80	1598.7	2.62	0.52
Average	49.3	38.5	7.52	116.4	199.5	115.7	125.2	12.75	1563.7	2.56	0.49
Low	48.8	37.8	7.49	115.9	197.5	112.7	123.8	12.70	1530.3	2.49	0.48
Base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	49.7	38.7	7.65	120.2	200.5	121.1	113.7	13.77	2636.5	1.72	0.53
Average	49.2	37.5	7.60	119.2	200.5	116.6	111.1	13.62	2494.3	1.51	0.51
Low	47.8	36.8	7.51	118.5	200.5	111.4	107.0	13.50	2358.0	1.26	0.49
Grooved High	48.5	39.0	7.50	105.0	197.5	116.4	108.0	12.80	1668.9	3.24	0.53
Average	48.2	38.6	7.46	104.4	197.5	113.9	106.0	12.73	1642.1	3.19	0.51
Low	47.8	38.1	7.43	103.6	197.5	111.7	103.5	12.70	1609.5	3.15	0.51

Item to note: Humid intake air will increase the octane of the overall air fuel mixture.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the base fuel, 6 deg of base timing, where the EGT dropped by 79.5 deg F. AFR numbers showed a richer mix on the grooved test, but fuel flow numbers were lower for the grooved test. There was slightly higher manifold vacuum on the grooved test, which would account for the lower fuel flow and richer mixture.

NOx (PPM):
There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx. NOx levels did rise significantly with the leaner mixture settings. The grooved head showed significant decrease in NOx at these leaner mixtures.

HC (PPM):
The HC did not show a significant change, observed readings were generally lower, but all amounts were minimal and a clear correlation could not be determined.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

20% TPS, 5th gear, max load

5% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3158.8	2.93	1232.8	13.74	8.12	19.90	44.80	26.94	26.52	0.38
33 degrees	Average	3140.7	2.92	1229.4	13.68	7.93	19.90	43.85	26.22	25.81	0.37
	Low	3111.6	2.91	1221.4	13.63	7.21	19.90	43.30	25.88	25.48	0.36
	Grooved High	3115.9	2.98	1193.5	13.55	8.82	20.29	43.08	25.25	25.27	0.38
	Average	3099.1	2.97	1186.2	13.51	8.68	20.01	41.87	24.70	24.73	0.38
	Low	3067.5	2.94	1169.7	13.46	8.45	19.90	41.26	24.39	24.42	0.37
10% lean, 6 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3146.1	2.91	1258.3	14.38	8.03	19.90	45.06	26.62	26.21	0.37
33 degrees	Average	3119.0	2.90	1253.5	14.27	7.89	19.90	43.91	26.07	25.67	0.36
	Low	3083.3	2.89	1246.8	14.14	7.67	19.90	42.45	25.36	24.97	0.35
	Grooved High	3142.6	2.98	1224.1	14.15	8.95	19.90	41.59	24.56	24.58	0.38
	Average	3122.9	2.97	1219.8	14.11	8.86	19.90	40.59	24.13	24.15	0.37
	Low	3101.2	2.95	1212.6	14.09	8.78	19.90	39.73	23.77	23.80	0.36
5% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3193.9	2.94	1218.4	13.61	8.44	19.90	46.26	27.98	27.79	0.36
38 degrees	Average	3179.0	2.93	1215.8	13.57	8.21	19.90	45.71	27.67	27.48	0.35
	Low	3163.7	2.93	1213.2	13.50	7.61	19.90	44.52	26.82	26.63	0.34
	Grooved High	3171.8	2.96	1192.6	13.59	9.01	19.90	40.84	24.67	24.69	0.40
	Average	3150.8	2.95	1187.4	13.56	8.89	19.90	40.14	24.08	24.10	0.39
	Low	3135.3	2.93	1182.0	13.53	8.82	19.90	39.07	23.36	23.39	0.38
10% lean, 10 deg Base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3143.4	2.91	1244.7	14.27	8.08	19.90	45.81	27.41	26.99	0.36
38 degrees	Average	3129.7	2.90	1240.7	14.20	7.97	19.90	44.90	26.76	26.34	0.35
	Low	3112.0	2.90	1233.0	14.08	7.86	19.90	43.41	25.84	25.44	0.34
	Grooved High	3151.7	2.97	1213.0	14.12	8.84	19.90	41.67	25.01	25.03	0.38
	Average	3133.6	2.96	1209.7	14.09	8.75	19.90	40.41	24.11	24.13	0.38
	Low	3117.1	2.95	1205.5	14.05	8.66	19.90	39.57	23.48	23.51	0.36
Base fuel, 6deg base timing		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3233.6	2.85	1245.4	13.75	8.46	20.40	44.57	27.41	26.89	0.38
32 degrees	Average	3215.0	2.85	1242.3	13.62	8.13	20.40	44.15	27.03	26.51	0.37
	Low	3176.5	2.85	1237.2	13.51	7.79	20.40	43.36	26.23	25.72	0.36
	Grooved High	3174.0	2.93	1202.0	13.30	8.68	20.40	43.46	26.26	26.03	0.40
	Average	3144.1	2.92	1194.7	13.26	8.42	20.40	42.44	25.41	25.19	0.39
	Low	3116.5	2.91	1186.7	13.22	8.15	20.40	41.93	24.94	24.72	0.38

20% TPS, 5th gear, max load

5% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	55.8	39.9	9.95	123.7	207.1	127.4	114.0	13.20	2533.6	2.27	0.42
Average	54.3	38.8	9.71	122.6	206.0	122.5	110.7	13.10	2449.5	2.15	0.42
Low	53.8	37.6	9.63	121.9	203.7	118.7	108.2	13.00	2370.8	2.02	0.42
Grooved High	54.3	39.3	9.40	128.4	207.1	147.1	110.0	12.77	2213.0	2.49	0.53
Average	53.6	38.7	9.31	127.4	205.5	140.2	105.0	12.69	2125.3	2.41	0.51
Low	53.1	38.3	9.27	126.5	200.5	132.6	99.3	12.60	2065.3	2.29	0.50
10% lean, 6 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	55.0	39.5	9.35	122.8	207.1	123.8	94.7	14.00	3374.0	0.93	0.50
Average	54.6	38.5	9.29	121.6	206.4	118.8	93.1	13.90	3298.9	0.88	0.50
Low	54.2	37.3	9.17	120.2	203.7	115.9	91.7	13.88	3237.4	0.79	0.50
Grooved High	53.6	38.2	8.97	133.3	214.6	154.1	85.3	13.48	2881.1	1.20	0.56
Average	53.4	37.4	8.94	132.1	211.6	150.2	80.7	13.42	2867.0	1.16	0.55
Low	53.2	36.7	8.92	131.4	210.7	145.8	78.7	13.40	2845.0	1.13	0.55
5% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	54.5	42.2	9.77	121.9	207.1	142.9	114.7	13.05	2282.3	2.43	0.47
Average	53.8	41.5	9.67	121.4	206.7	138.6	110.3	12.99	2214.7	2.35	0.47
Low	53.3	40.4	9.60	121.0	205.4	133.4	105.6	12.90	2175.0	2.22	0.47
Grooved High	53.4	38.0	9.40	129.4	210.7	157.2	99.0	12.80	2366.2	2.44	0.51
Average	53.2	37.3	9.37	129.1	210.0	153.2	96.2	12.74	2304.4	2.35	0.50
Low	53.0	36.2	9.30	128.4	207.1	148.9	94.0	12.70	2248.1	2.27	0.50
10% lean, 10 deg Base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	54.3	40.9	9.33	128.4	210.7	129.6	102.2	13.99	3586.1	1.10	0.48
Average	53.9	39.9	9.26	128.4	209.3	125.4	100.2	13.89	3495.5	0.97	0.48
Low	53.4	38.9	9.14	128.4	207.1	122.8	98.0	13.80	3364.0	0.87	0.48
Grooved High	54.0	38.4	9.08	131.4	214.6	153.8	91.0	13.40	3123.7	1.31	0.58
Average	53.7	37.0	9.05	129.9	211.2	149.8	88.1	13.38	3080.6	1.23	0.57
Low	53.4	36.1	9.00	128.5	208.1	145.8	84.7	13.33	3041.9	1.15	0.56
Humid air, base fuel, 6deg base timing	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	54.8	40.0	10.07	123.7	210.7	133.5	101.2	13.37	2404.8	2.50	0.47
Average	54.3	39.2	9.95	122.6	209.0	128.3	99.4	13.20	2256.5	2.21	0.47
Low	53.7	38.1	9.82	121.0	204.0	123.1	98.0	13.01	2098.8	1.93	0.46
Grooved High	54.8	39.6	9.96	110.3	200.5	136.2	93.3	12.80	1810.9	3.34	0.51
Average	54.2	38.4	9.89	108.1	200.3	127.4	83.9	12.73	1739.8	3.20	0.50
Low	53.6	37.6	9.83	105.8	198.8	119.4	77.4	12.63	1658.7	3.08	0.50

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the base fuel map, 6 deg of base timing, where the EGT dropped by 47.6 deg F.

NOx (PPM):
There is a noticeable drop in NOx emissions on the grooved head. This would correspond with the lower EGT's as higher temps produce more NOx. The effects of the AFR on both overall NOx and effectiveness of the groove can be seen by comparing the three 6 deg runs. The base fuel (~13.6 AFR) displayed the lowest NOx and largest reduction with the grooves.

HC (PPM), CO (%) & O2 (%):
The HC, CO and O2 did not show a significant change, observed readings were generally lower, but all amounts were minimal and a clear correlation could not be determined.

Load Cell Temp vs. Torque, Power and Thermal Efficiency:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison. The humid air test is the only one with a temperature stable enough to make a comparison. In this test there is a slight decrease in torque, power and thermal efficiency, similarly to the 10% TPS.

Low/Moderate RPM

1500 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	1525.8	3.56	910.3	14.76	18.43	2.49	5.93	1.70	1.69	1.63
18 degrees	Average	1511.2	3.53	907.8	14.74	18.34	2.49	5.75	1.65	1.64	1.57
	Low	1500.8	3.51	905.7	14.71	18.26	2.49	5.50	1.60	1.58	1.52
	Grooved High	1522.6	3.55	873.8	15.12	18.23	2.88	6.88	1.98	1.97	1.46
	Average	1519.0	3.54	867.2	15.08	18.19	2.74	6.47	1.87	1.86	1.40
	Low	1513.5	3.53	855.4	15.05	18.14	2.51	6.20	1.79	1.78	1.32
1500 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	1524.7	2.95	931.0	14.79	18.16	2.99	7.36	2.11	2.10	1.42
18 degrees	Average	1504.1	2.94	916.5	14.72	18.05	2.93	6.99	2.00	1.99	1.32
	Low	1488.5	2.93	906.9	14.63	17.96	2.84	6.48	1.84	1.83	1.26
	Grooved High	1489.3	2.95	869.0	14.80	18.08	2.99	8.98	2.53	2.50	1.09
	Average	1476.7	2.94	866.5	14.66	18.01	2.99	8.67	2.44	2.42	1.07
	Low	1459.8	2.93	864.1	14.52	17.90	2.99	8.53	2.39	2.37	1.04
2000 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2012.9	3.51	981.3	14.19	18.58	4.98	9.78	3.75	3.72	0.95
27 degrees	Average	2010.7	3.49	976.4	14.17	18.55	4.98	9.70	3.71	3.69	0.94
	Low	2005.4	3.48	967.6	14.16	18.51	4.98	9.57	3.66	3.63	0.93
	Grooved High	2021.0	3.53	952.8	14.66	18.28	4.98	12.28	4.72	4.67	0.81
	Average	2011.1	3.50	945.7	14.57	18.25	4.98	12.00	4.59	4.55	0.77
	Low	2000.9	3.48	932.3	14.44	18.22	4.98	11.47	4.38	4.34	0.76
2000 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2029.0	2.92	988.8	14.12	18.17	4.98	14.42	5.57	5.53	0.69
27 degrees	Average	2019.1	2.91	974.2	13.82	17.95	4.98	14.23	5.47	5.44	0.68
	Low	2007.2	2.91	964.7	13.54	17.88	4.98	14.09	5.39	5.35	0.66
	Grooved High	2016.7	2.92	958.4	14.22	17.78	5.47	17.05	6.54	6.48	0.58
	Average	2012.4	2.91	952.0	14.13	17.76	5.47	16.80	6.44	6.38	0.58
	Low	2007.8	2.90	939.6	14.01	17.74	5.47	16.64	6.37	6.32	0.57
2500 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2556.0	3.52	1125.3	14.34	17.69	7.96	15.89	7.70	7.65	0.62
31 degrees	Average	2542.5	3.49	1118.1	14.28	17.65	7.96	15.80	7.65	7.60	0.61
	Low	2514.9	3.48	1098.5	14.18	17.57	7.95	15.53	7.44	7.39	0.61
	Grooved High	2570.3	3.52	1076.0	14.46	17.44	8.46	20.66	10.10	10.01	0.50
	Average	2542.6	3.50	1068.2	14.34	17.36	8.45	20.32	9.84	9.75	0.49
	Low	2529.9	3.46	1062.2	14.23	17.16	8.40	19.97	9.62	9.53	0.48
2500 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2553.0	2.91	1112.6	13.97	16.83	8.46	21.45	10.43	10.36	0.50
30 degrees	Average	2541.5	2.90	1103.5	13.82	16.73	8.46	21.22	10.27	10.20	0.49
	Low	2530.0	2.90	1098.9	13.66	16.67	8.46	21.02	10.13	10.06	0.49
	Grooved High	2553.9	2.92	1070.4	14.08	16.84	8.95	27.44	13.34	13.22	0.40
	Average	2535.3	2.90	1065.6	13.98	16.74	8.92	26.65	12.86	12.75	0.39
	Low	2516.4	2.88	1055.7	13.87	16.62	8.86	25.87	12.39	12.28	0.38

Low/Moderate RPM

1500 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	33.0	8.8	2.60	110.3	192.3	103.6	94.1	14.14	398.2	0.19	1.23
Average	32.9	8.6	2.59	109.3	191.7	100.4	90.5	14.10	392.1	0.18	1.17
Low	32.8	8.2	2.58	108.8	191.1	97.2	87.0	14.10	385.1	0.17	1.14
Grooved High	33.8	10.1	2.63	112.7	192.2	108.8	96.4	13.57	448.7	0.12	1.67
Average	33.8	9.6	2.62	112.0	191.5	106.7	92.1	13.52	427.8	0.12	1.63
Low	33.7	9.2	2.61	111.1	190.2	103.6	88.0	13.50	411.1	0.12	1.60
1500 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	34.4	10.7	2.74	116.8	191.8	126.1	109.1	14.20	495.0	0.27	1.35
Average	33.7	10.2	2.64	112.2	191.5	115.5	101.4	14.12	455.1	0.22	1.24
Low	33.4	9.5	2.60	108.8	189.2	107.5	98.0	14.10	407.8	0.17	1.14
Grooved High	34.1	12.9	2.65	128.4	194.6	103.7	94.4	13.90	591.4	0.37	1.31
Average	33.8	12.5	2.62	126.8	193.9	101.2	90.0	13.85	573.5	0.28	1.14
Low	33.5	12.3	2.58	125.6	191.8	98.6	85.5	13.80	548.8	0.18	1.02
2000 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	32.2	14.8	3.51	110.3	194.2	95.8	111.5	14.02	849.4	0.92	0.76
Average	32.1	14.7	3.49	109.0	192.6	95.5	109.7	14.00	836.7	0.87	0.74
Low	32.0	14.5	3.49	108.0	191.8	94.8	107.9	13.97	810.2	0.80	0.73
Grooved High	33.6	17.7	3.59	116.8	194.6	102.1	91.9	13.90	1021.0	0.45	0.97
Average	33.5	17.4	3.56	114.1	193.5	101.7	89.2	13.90	999.8	0.35	0.89
Low	33.3	16.6	3.53	111.9	192.7	100.7	87.9	13.90	983.7	0.27	0.78
2000 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	33.4	22.3	3.79	108.0	193.1	105.8	134.0	14.10	1064.7	2.28	0.63
Average	33.1	21.0	3.71	107.2	192.0	104.6	128.8	13.74	927.5	1.60	0.60
Low	32.3	20.6	3.63	106.5	191.8	103.6	120.0	13.32	778.3	0.99	0.59
Grooved High	34.1	24.4	3.76	124.6	194.6	98.9	106.1	13.89	1321.0	1.16	0.63
Average	33.9	24.0	3.72	124.6	194.6	98.1	100.8	13.81	1253.7	0.94	0.61
Low	33.8	23.7	3.70	124.6	194.3	97.2	95.6	13.67	1189.7	0.75	0.59
2500 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	34.3	22.6	4.68	111.9	194.6	100.7	92.5	14.01	1114.3	0.90	0.67
Average	34.2	22.4	4.67	111.2	194.4	98.6	88.0	13.98	1078.5	0.77	0.64
Low	34.0	22.0	4.63	110.4	193.0	95.2	82.2	13.91	1059.1	0.68	0.60
Grooved High	35.5	28.5	4.87	118.5	197.5	106.5	81.4	13.80	1534.6	0.89	0.71
Average	35.2	27.9	4.80	118.3	195.2	105.9	75.1	13.77	1480.0	0.70	0.67
Low	35.0	27.4	4.76	116.8	194.6	102.1	68.1	13.70	1438.3	0.55	0.63
2500 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	36.2	29.3	5.10	108.0	194.6	108.0	115.1	13.99	1428.3	1.95	0.51
Average	35.9	28.8	5.06	107.7	194.6	106.3	113.0	13.81	1334.9	1.64	0.48
Low	35.6	28.4	5.02	107.3	194.5	104.1	109.8	13.60	1262.2	1.34	0.47
Grooved High	36.4	37.0	5.11	125.6	197.5	105.8	102.5	13.74	1989.4	1.55	0.57
Average	36.1	35.7	5.05	124.7	196.9	103.1	99.7	13.61	1886.1	1.31	0.55
Low	35.8	34.5	5.01	124.6	194.7	100.0	96.2	13.41	1774.2	1.05	0.53

Note: Load cell position sensor gives off a voltage from 0 to 5 V. 0.08V is the maximum load setting. As the valve is opened the voltage increases. In the above tests the valve was opened to a position of 0.30 and 0.36V.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 1500 RPM in 5th gear with 0.36 load, where the EGT dropped by 50.0 deg F.

NOx (PPM):
There is an increase NOx emissions on the grooved head. While the increase was not large, all tests showed a slight increase in a condition where the engine was only partly loaded.

HC (PPM)& CO (%):
The HC and CO numbers were consistently lower for all tests.

Load Cell Temp:
The load cell temperature was lower on most of the non-grooved tests. As a result the torque (and power) numbers are higher in the non-grooved tests. This is the drawback with a hydraulic load cell. This lower temperature of the oil directly affects its viscosity and therefore it's ability to load. The cooler oil will load more than the warmer oil, which causes this difference in torque and power numbers. These numbers need to be within a couple degrees to do any meaningful comparison.

High RPM, 4th Gear, Load at 0.30

3000 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3075.6	3.49	1207.1	14.76	16.89	10.45	20.45	11.98	11.90	0.51
35 degrees	Average	3055.2	3.47	1201.0	14.62	16.84	10.45	20.16	11.73	11.65	0.50
	Low	3030.5	3.44	1185.8	14.50	16.73	10.45	19.92	11.49	11.42	0.49
	Grooved High	3019.6	3.52	1145.6	14.34	16.96	10.95	24.81	14.25	14.12	0.43
	Average	3009.1	3.48	1141.6	14.28	16.89	10.85	24.51	14.04	13.92	0.42
	Low	2999.2	3.46	1130.5	14.20	16.84	10.45	23.85	13.62	13.50	0.42
3500 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3564.5	3.49	1269.0	14.12	15.95	12.95	24.01	16.06	15.95	0.47
37 degrees	Average	3530.3	3.46	1255.2	14.05	15.85	12.94	23.70	15.93	15.83	0.46
	Low	3502.2	3.45	1215.9	13.92	15.74	12.94	23.50	15.77	15.67	0.46
	Grooved High	3542.4	3.50	1224.4	13.92	15.93	13.43	27.29	18.40	18.24	0.42
	Average	3523.4	3.48	1221.2	13.81	15.82	13.43	27.18	18.24	18.08	0.41
	Low	3500.4	3.46	1217.0	13.69	15.68	13.43	26.94	18.03	17.88	0.41
4000 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	4058.4	3.48	1340.4	14.27	14.80	16.42	33.84	26.02	25.85	0.36
39 degrees	Average	4043.0	3.46	1327.1	13.95	14.65	16.07	33.32	25.65	25.48	0.35
	Low	4023.2	3.44	1313.4	13.70	14.39	15.92	32.47	25.09	24.93	0.35
	Grooved High	4025.7	3.53	1296.5	14.21	14.79	17.87	36.29	27.65	27.41	0.36
	Average	4015.2	3.50	1290.9	14.02	14.61	17.02	34.54	26.41	26.17	0.35
	Low	4001.5	3.47	1280.5	13.87	14.50	16.43	32.55	24.89	24.68	0.33
4500 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	4565.3	3.49	1339.4	13.54	13.38	19.40	35.30	30.35	30.15	0.39
41 degrees	Average	4535.1	3.47	1331.3	13.45	13.12	19.16	34.00	29.36	29.16	0.38
	Low	4506.8	3.45	1314.0	13.41	12.93	18.91	33.16	28.61	28.42	0.36
	Grooved High	4556.2	3.51	1307.8	13.85	13.13	19.93	38.26	32.90	32.61	0.35
	Average	4523.8	3.48	1296.6	13.71	12.94	19.78	37.36	32.18	31.90	0.35
	Low	4503.2	3.45	1286.9	13.56	12.74	19.44	36.63	31.47	31.19	0.34
5000 rpm 4th gear load @ 0.30		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	5056.0	3.45	1350.9	13.44	11.55	22.89	37.76	36.11	35.87	0.38
43 degrees	Average	5038.7	3.43	1346.4	13.32	11.35	22.89	36.81	35.32	35.08	0.37
	Low	5022.0	3.40	1332.8	13.25	11.20	22.89	35.91	34.48	34.25	0.37
	Grooved High	5029.2	3.47	1336.7	14.06	10.65	24.38	40.96	39.22	38.87	0.37
	Average	5009.8	3.44	1323.1	13.91	10.54	24.28	39.84	38.01	37.67	0.35
	Low	4982.6	3.39	1293.7	13.78	10.42	24.09	38.37	36.53	36.21	0.34

High RPM, 4th Gear, Load at 0.30

3000 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	36.9	27.1	5.94	118.5	200.0	106.5	81.0	14.01	1741.7	0.48	1.07
Average	36.7	26.8	5.89	113.4	197.4	104.6	73.7	14.00	1720.2	0.37	0.98
Low	36.5	26.4	5.85	110.3	194.6	101.5	68.6	14.00	1689.9	0.26	0.89
Grooved High	36.8	32.6	5.99	124.8	200.5	107.3	76.3	13.57	1544.7	0.97	0.85
Average	36.7	32.3	5.96	122.3	198.2	106.7	75.1	13.51	1520.5	0.86	0.84
Low	36.6	31.4	5.90	120.2	196.9	106.2	74.0	13.48	1482.2	0.75	0.82
3500 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	38.5	30.3	7.51	122.2	200.9	113.5	181.4	13.90	2002.3	1.50	0.61
Average	38.2	30.1	7.37	119.1	199.0	110.3	115.9	13.82	1845.2	1.18	0.57
Low	37.8	29.9	7.31	111.9	194.6	106.7	99.7	13.64	1676.4	1.04	0.53
Grooved High	38.9	34.8	7.62	128.4	201.2	115.1	93.0	13.30	1606.2	1.94	0.56
Average	38.5	34.3	7.57	126.4	200.1	112.1	90.2	13.18	1522.4	1.69	0.54
Low	38.1	33.8	7.51	125.6	197.5	109.4	85.6	13.01	1471.2	1.47	0.52
4000 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	41.4	40.7	9.17	115.9	202.9	123.3	200.9	14.20	2774.4	2.02	0.51
Average	40.8	39.8	9.07	111.9	200.8	119.0	162.1	13.91	2247.7	1.47	0.43
Low	40.3	39.1	8.89	108.4	200.5	114.5	134.2	13.65	1946.3	0.83	0.37
Grooved High	41.9	41.9	9.19	131.1	210.7	126.7	77.8	13.63	2223.1	1.58	0.50
Average	41.3	40.5	9.10	129.1	206.9	121.3	73.6	13.50	2161.1	1.27	0.43
Low	40.7	38.3	8.96	128.4	200.5	117.1	66.2	13.35	2085.8	0.98	0.40
4500 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	43.5	39.9	11.23	117.6	206.6	137.0	146.8	13.48	2041.5	2.73	0.29
Average	43.0	38.7	11.13	116.7	203.3	131.7	136.8	13.32	1917.9	2.60	0.28
Low	42.6	37.8	11.07	114.8	199.6	126.0	129.6	13.20	1848.0	2.36	0.28
Grooved High	44.5	41.8	11.30	127.4	218.4	136.6	93.7	13.68	2611.3	2.36	0.38
Average	44.0	41.2	11.19	125.2	209.7	132.1	91.2	13.47	2518.7	1.98	0.35
Low	43.5	40.6	11.01	123.7	203.2	126.0	88.5	13.26	2327.8	1.62	0.33
5000 rpm 4th gear load @ 0.30	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	45.8	40.7	13.34	121.9	214.7	149.1	120.1	13.30	2166.4	3.16	0.26
Average	45.6	39.6	13.23	120.5	211.2	145.2	113.7	13.12	2074.5	2.94	0.24
Low	45.4	38.6	13.12	118.5	202.8	141.0	106.0	12.99	2001.5	2.66	0.23
Grooved High	49.1	41.1	13.57	133.5	230.0	138.4	82.6	13.95	3376.8	1.79	0.37
Average	48.2	40.1	13.37	130.8	218.2	132.7	78.0	13.76	3224.6	1.50	0.32
Low	47.5	38.6	13.20	128.7	203.5	124.2	75.2	13.60	3078.8	1.20	0.29

Note: Load cell position sensor gives off a voltage from 0 to 5 V. 0.08V is the maximum load setting. As the valve is opened the voltage increases. In the above tests the valve was opened to a position of 0.30 and 0.36V.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 3000 RPM in 4th gear with 0.30 load, where the EGT dropped by 59.4 deg F.

NOx (PPM):
There was a decrease in NOx emissions on the grooved head until the higher rpms, then an increase was observed.

HC (PPM):
The HC numbers were consistently lower for most tests.

CO (%):
The CO numbers were higher for the lower rpms and then decreased for the higher rpms.

Load Cell Temp vs. Torque, Power and Thermal Efficiency:
The load cell temperature was stable for most of these tests. The torque, power and thermal efficiency numbers show a significant increase on all tests.

BSFC:
The BSFC numbers also showed improvement (decrease in value) on the grooved head over the stock head.

Moderate/High RPM, 5th Gear, Load at 0.36

2500 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	2553.0	2.91	1112.6	13.97	16.83	8.46	21.45	10.43	10.36	0.50
30 degrees	Average	2541.5	2.90	1103.5	13.82	16.73	8.46	21.22	10.27	10.20	0.49
	Low	2530.0	2.90	1098.9	13.66	16.67	8.46	21.02	10.13	10.06	0.49
	Grooved High	2553.9	2.92	1070.4	14.08	16.84	8.95	27.44	13.34	13.22	0.40
	Average	2535.3	2.90	1065.6	13.98	16.74	8.92	26.65	12.86	12.75	0.39
	Low	2516.4	2.88	1055.7	13.87	16.62	8.86	25.87	12.39	12.28	0.38
3000 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3071.3	2.90	1195.0	13.99	15.61	11.94	29.62	17.32	17.21	0.42
33 degrees	Average	3054.7	2.89	1180.0	13.78	15.50	11.94	28.46	16.56	16.45	0.40
	Low	3033.1	2.88	1165.4	13.64	15.11	11.92	26.90	15.53	15.43	0.38
	Grooved High	3027.6	2.93	1164.0	14.14	15.69	11.94	34.11	19.66	19.49	0.34
	Average	3014.8	2.91	1159.2	14.10	15.58	11.94	33.55	19.26	19.09	0.34
	Low	3002.6	2.90	1152.4	14.04	15.48	11.94	33.13	18.95	18.79	0.33
3500 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3589.2	2.91	1273.0	14.18	14.19	15.42	36.34	24.45	24.29	0.35
36 degrees	Average	3553.5	2.90	1258.0	13.74	13.95	15.37	35.63	24.11	23.95	0.35
	Low	3508.9	2.88	1245.5	13.44	13.74	14.93	34.69	23.18	23.03	0.34
	Grooved High	3544.3	2.93	1233.5	14.06	14.23	15.92	44.81	30.24	29.98	0.29
	Average	3521.3	2.91	1226.3	13.95	14.01	15.55	43.71	29.31	29.05	0.28
	Low	3504.1	2.88	1214.8	13.82	13.75	15.42	42.58	28.48	28.23	0.28
4000 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	4058.5	2.91	1328.4	13.78	12.66	18.91	39.95	30.42	30.21	0.37
39 degrees	Average	4024.9	2.90	1319.7	13.72	12.37	18.86	38.39	29.42	29.22	0.35
	Low	3998.1	2.89	1310.6	13.56	12.22	18.41	36.57	27.86	27.68	0.34
	Grooved High	4066.3	2.90	1293.2	13.83	12.52	19.40	45.64	34.86	34.55	0.33
	Average	4023.2	2.89	1287.2	13.72	12.20	19.29	43.75	33.51	33.22	0.31
	Low	4001.1	2.88	1281.2	13.58	12.03	18.91	41.16	31.41	31.13	0.30
4500 rpm 5th gear load @ 0.36		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	4567.6	2.91	1331.9	13.47	10.73	22.89	39.18	33.69	33.47	0.40
41 degrees	Average	4535.3	2.90	1329.4	13.36	10.15	22.89	37.28	32.19	31.98	0.39
	Low	4511.1	2.88	1326.6	13.27	10.00	22.89	36.45	31.60	31.39	0.38
	Grooved High	4532.3	2.93	1314.5	13.82	9.99	23.88	44.09	38.05	37.72	0.34
	Average	4509.6	2.89	1305.9	13.67	9.87	23.58	43.54	37.38	37.05	0.34
	Low	4494.1	2.86	1288.5	13.48	9.61	23.38	42.93	36.78	36.46	0.34

Moderate/High RPM, 5th Gear, Load at 0.36

2500 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	36.2	29.3	5.10	108.0	194.6	108.0	115.1	13.99	1428.3	1.95	0.51
Average	35.9	28.8	5.06	107.7	194.6	106.3	113.0	13.81	1334.9	1.64	0.48
Low	35.6	28.4	5.02	107.3	194.5	104.1	109.8	13.60	1262.2	1.34	0.47
Grooved High	36.4	37.0	5.11	125.6	197.5	105.8	102.5	13.74	1989.4	1.55	0.57
Average	36.1	35.7	5.05	124.7	196.9	103.1	99.7	13.61	1886.1	1.31	0.55
Low	35.8	34.5	5.01	124.6	194.7	100.0	96.2	13.41	1774.2	1.05	0.53
3000 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	39.9	37.2	6.73	109.6	197.5	116.8	116.9	14.00	2058.0	2.01	0.59
Average	38.9	35.6	6.62	108.7	197.5	113.5	113.5	13.68	1838.8	1.69	0.58
Low	38.6	33.7	6.51	107.8	197.5	109.6	107.0	13.50	1719.3	1.05	0.58
Grooved High	39.8	42.1	6.53	125.6	197.9	114.4	105.6	13.70	2276.7	1.22	0.71
Average	39.5	41.2	6.50	124.6	197.5	111.0	101.1	13.60	2217.2	1.13	0.71
Low	39.2	40.5	6.47	123.7	197.5	107.3	92.0	13.50	2147.7	1.05	0.71
3500 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	42.9	41.2	8.58	114.3	200.5	127.4	123.2	14.10	2374.5	2.33	0.59
Average	42.6	40.7	8.45	112.3	200.3	123.1	118.8	13.56	2099.2	1.92	0.50
Low	41.9	39.9	8.02	110.3	198.6	118.5	105.4	13.30	1939.0	1.04	0.49
Grooved High	43.3	50.5	8.53	123.4	200.5	124.6	105.0	13.70	2530.1	1.81	0.61
Average	42.8	49.4	8.33	122.2	199.2	120.7	99.5	13.55	2447.8	1.48	0.59
Low	42.4	48.5	8.16	121.0	197.5	115.9	94.7	13.35	2343.4	1.26	0.58
4000 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	46.3	42.3	10.36	116.8	203.7	141.4	113.0	13.69	2435.2	2.38	0.40
Average	45.9	40.8	10.32	115.8	202.0	135.6	110.4	13.58	2334.1	2.04	0.39
Low	45.0	39.7	10.19	115.0	200.5	129.4	108.3	13.40	2115.6	1.85	0.38
Grooved High	46.7	47.5	10.52	130.6	218.7	136.6	94.2	13.59	2675.1	2.21	0.43
Average	46.1	46.1	10.41	127.3	213.9	132.1	92.3	13.41	2575.3	2.02	0.42
Low	45.2	44.3	10.23	124.6	207.1	127.0	91.0	13.31	2491.0	1.75	0.40
4500 rpm 5th gear load @ 0.36	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
	49.3	38.9	12.78	119.3	214.6	158.5	103.0	13.28	2189.2	3.03	0.29
	48.8	37.5	12.70	118.2	211.9	153.1	100.7	13.15	2064.1	2.88	0.27
	48.4	36.7	12.64	116.8	207.1	146.1	98.2	13.10	1997.0	2.62	0.26
	50.7	42.8	12.83	133.4	227.6	148.6	92.9	13.56	2780.7	2.56	0.36
	49.8	42.5	12.66	131.9	222.3	140.4	86.0	13.39	2672.9	2.15	0.33
	49.3	42.0	12.46	130.6	208.9	131.3	80.9	13.18	2449.1	1.81	0.31

Note: Load cell position sensor gives off a voltage from 0 to 5 V. 0.08V is the maximum load setting. As the valve is opened the voltage increases. In the above tests the valve was opened to a position of 0.30 and 0.36V.

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 2500 RPM in 5th gear with 0.36 load, where the EGT dropped by 37.9 deg F.

NOx (PPM):
There was an increase in NOx emissions on the grooved head.

HC (PPM):
The HC numbers were consistently lower for all tests.

CO (%):
The CO numbers were lower for all tests.

Load Cell Temp vs. Torque, Power and Thermal Efficiency:
The load cell temperature was stable for most of these tests. The torque, power and thermal efficiency numbers show a significant increase on all tests.

BSFC:
The BSFC numbers also showed improvement (decrease in value) on the grooved head over the stock head.

High RPM, High Load

3000 rpm, 5th gear load max		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3104.2	2.92	1203.7	13.41	8.80	19.40	43.39	25.65	25.42	0.38
33 degrees	Average	3077.6	2.91	1200.6	13.25	8.61	19.40	42.67	25.01	24.79	0.37
	Low	3038.8	2.90	1199.1	13.15	8.48	19.40	42.15	24.39	24.17	0.37
	Grooved High	3057.7	2.92	1172.8	13.36	9.42	19.40	44.25	25.55	25.33	0.37
	Average	3032.6	2.90	1170.7	13.33	9.19	18.69	42.95	24.80	24.58	0.37
	Low	3014.3	2.88	1168.5	13.27	8.67	18.41	41.76	24.03	23.82	0.36
3500 rpm, 5th gear load max		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3545.4	2.92	1315.3	13.51	6.53	27.37	45.27	30.52	30.25	0.41
28 degrees	Average	3532.2	2.92	1301.6	13.40	5.99	25.57	44.95	30.23	29.96	0.39
	Low	3521.3	2.91	1289.4	13.18	5.13	24.88	44.48	29.84	29.57	0.39
	Grooved High	3545.2	2.91	1254.3	13.36	6.46	26.71	45.10	30.29	30.02	0.41
	Average	3518.9	2.88	1249.7	13.30	6.21	25.51	44.67	29.93	29.66	0.40
	Low	3500.0	2.87	1236.1	13.22	5.75	24.88	43.92	29.33	29.07	0.39
25% TPS 4th gear load max		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	4309.5	3.41	1353.6	13.56	8.19	24.88	38.78	31.15	30.55	0.45
38 degrees	Average	4269.6	3.41	1345.1	13.45	8.03	24.88	37.79	30.71	30.13	0.44
	Low	4211.5	3.40	1341.0	13.36	7.86	24.88	36.82	30.14	29.56	0.42
	Grooved High	4229.1	3.50	1299.6	13.53	8.49	24.88	37.82	30.41	30.14	0.44
	Average	4198.6	3.48	1297.1	13.45	8.42	24.88	37.45	29.94	29.68	0.43
	Low	4162.3	3.46	1291.5	13.36	8.33	24.88	36.92	29.26	29.00	0.43
30% TPS, 5th gear load max		Eng RPM	Ratio	EGT	AFR	Man VAC	TPS	Meas TQ	BK HP	Corr HP	BSFC
Ignition Spark Adv:	Stock High	3716.8	2.91	1353.1	13.53	4.65	30.35	44.43	30.96	30.36	0.44
25 degrees	Average	3681.8	2.88	1341.0	13.39	4.55	30.35	43.54	30.52	29.94	0.43
	Low	3648.8	2.85	1326.4	13.33	4.47	30.35	42.88	30.11	29.53	0.43
	Grooved High	3757.6	2.94	1302.6	13.27	4.85	30.35	44.18	31.38	31.10	0.44
	Average	3708.8	2.94	1289.6	13.15	4.73	30.35	43.82	30.94	30.67	0.44
	Low	3653.0	2.92	1275.0	13.06	4.59	30.35	43.45	30.68	30.41	0.43

High RPM, High Load

3000 rpm, 5th gear load max	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	52.8	40.9	9.47	112.2	200.5	133.6	121.0	13.01	1667.4	3.37	0.42
Average	52.3	39.9	9.36	111.1	199.9	127.9	117.9	12.86	1568.6	3.20	0.41
Low	51.9	38.7	9.23	109.6	198.1	121.9	113.1	12.76	1502.0	2.94	0.41
Grooved High	53.0	40.9	9.33	124.3	201.3	133.6	120.7	12.97	1929.4	3.09	0.50
Average	51.9	40.4	9.10	122.6	199.1	127.9	117.3	12.90	1902.0	2.95	0.50
Low	51.5	39.5	8.96	121.9	197.5	121.3	114.5	12.80	1813.4	2.89	0.49
3500 rpm, 5th gear load max	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	60.3	38.1	12.47	118.5	207.1	164.9	98.3	13.30	1866.9	3.24	0.35
Average	58.4	37.6	11.86	116.3	206.1	156.2	91.8	13.17	1741.4	2.76	0.35
Low	57.2	36.6	11.58	113.5	203.7	138.6	89.1	12.90	1461.2	2.54	0.35
Grooved High	60.1	38.0	12.28	133.0	228.0	159.7	107.6	13.04	2125.6	3.20	0.43
Average	58.5	37.4	11.92	129.2	220.9	152.4	98.3	12.93	2001.0	3.00	0.41
Low	57.6	36.2	11.70	124.6	209.3	139.2	93.8	12.76	1847.6	2.83	0.41
25% TPS 4th gear load max	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	55.7	34.3	13.75	127.4	239.0	150.3	89.0	13.11	2531.3	2.94	0.30
Average	54.4	33.6	13.40	125.4	233.7	141.3	86.4	12.93	2333.6	2.74	0.30
Low	53.9	33.0	13.17	123.3	227.1	132.4	84.9	12.80	2224.2	2.40	0.29
Grooved High	54.1	34.7	12.97	126.5	223.2	162.9	102.0	13.30	2404.4	2.87	0.37
Average	53.7	34.0	12.90	121.9	218.2	152.5	98.6	13.23	2351.2	2.69	0.35
Low	53.1	33.2	12.84	118.5	212.1	136.4	96.4	13.13	2241.5	2.57	0.33
30% TPS, 5th gear load max	Vol Eff	BK TH Eff	Fuel Flow	Man Air T	Coolant T	Load Cell T	HC (PPM)	CO2 (%)	NOx (PPM)	CO (%)	O2 (%)
Stock High	63.1	34.5	13.47	130.4	218.7	158.8	83.1	13.07	1850.1	2.93	0.37
Average	62.1	34.0	13.25	128.2	217.0	148.3	78.6	12.91	1741.2	2.78	0.35
Low	61.6	33.6	13.16	124.7	214.6	138.3	74.3	12.80	1672.8	2.51	0.35
Grooved High	63.3	34.6	13.72	114.8	214.6	169.8	72.9	12.80	1731.8	3.67	0.42
Average	62.6	34.4	13.58	113.2	211.6	158.9	60.8	12.62	1559.1	3.46	0.39
Low	62.0	34.1	13.50	111.9	205.7	144.6	51.8	12.50	1468.1	3.16	0.37

EGT:
EGT numbers from the grooved head are consistently lower in all tests. The largest was on the 3500 RPM in 5th gear max load, where the EGT dropped by 51.9 deg F.

NOx (PPM):
There was an increase in NOx emissions on the grooved head.

HC (PPM):
The HC numbers were only lower for the 30% TPS test (this test was close to the max torque point for this engine).

CO (%):
The CO numbers began to rise as the RPM increased.

Thermal Efficiency:
The thermal efficiency numbers only saw an increase at moderate speed. As the speed increased no real increase or decrease in thermal efficiency was observed.

Appendix A

Engine Specifications and Health Measurements

Engine Specifications:

3 Cylinder Geo Metro XFI

61 cubic inches (1.0L)
Bore & Stroke: 74 x 77 mm
Head gasket thickness: 1.27 mm
Head gasket diameter: 76 mm
Combustion Chamber volume: 30.8 cc
Piston Dish Volume: 5.4 cc
Deck Clearance: 0 mm

Total Displacement Volume: 41.96 cc
Compression Ratio: 8.89:1

Stock Head Measurements:

Cylinder #1:
- Combustion chamber: 30.9 cc
- Intake runner: 65.0 cc
- Exhaust runner: 53.4 cc

Cylinder #2:
- Combustion chamber: 30.8 cc
- Intake runner: 65.0 cc
- Exhaust runner: 53.3 cc

Cylinder #3:
- Combustion chamber: 30.6 cc
- Intake runner: 65.2 cc
- Exhaust runner: 52.6 cc

Grooved Head Measurements:

Cylinder #1:
- Combustion chamber: 30.0 cc
- Intake runner: 63.8 cc
- Exhaust runner: 53.6 cc

Cylinder #2:
- Combustion chamber: 29.9 cc
- Intake runner: 64.0 cc
- Exhaust runner: 53.4 cc

Cylinder #3:
- Combustion chamber: 30.2 cc
- Intake runner: 64.4 cc
- Exhaust runner: 52.8 cc

Engine Health Measurements (13 May 2007, Stock head rebuilt)

Crank Comp Test, WOT, 3 engine pumps:

Cylinder #1
1 pump: 120 PSI
2 pumps: 165 PSI
3 Pumps: 190 PSI

Cylinder #2
1 pump: 125 PSI
2 pumps: 165 PSI
3 Pumps: 190 PSI

Cylinder #3
1 pump: 125 PSI
2 pumps: 165 PSI
3 Pumps: 190 PSI

Leakdown Test

Cylinder #1
80 PSI In, 78.5 PSI Out (1.9%)

Cylinder #2
80 PSI In, 78.0 PSI Out (2.5%)

Cylinder #3
80 PSI In, 78.0 PSI Out (2.5%)

Engine Health Measurements (16 June 2007, Grooved head rebuilt)

Crank Comp Test, WOT, 3 engine pumps:

Cylinder #1
1 pump: 125 PSI
2 pumps: 165 PSI
3 Pumps: 190 PSI

Cylinder #2
1 pump: 120 PSI
2 pumps: 165 PSI
3 Pumps: 190 PSI

Cylinder #3
1 pump: 120 PSI
2 pumps: 160 PSI
3 Pumps: 185 PSI

Leakdown Test

Cylinder #1
80 PSI In, 77.0 PSI Out (3.8%)

Cylinder #2
80 PSI In, 78.0 PSI Out (2.5%)

Cylinder #3
80 PSI In, 76.0 PSI Out (5.0%)

Appendix B

Dynamometer Test Stand and Test Stand Sensing

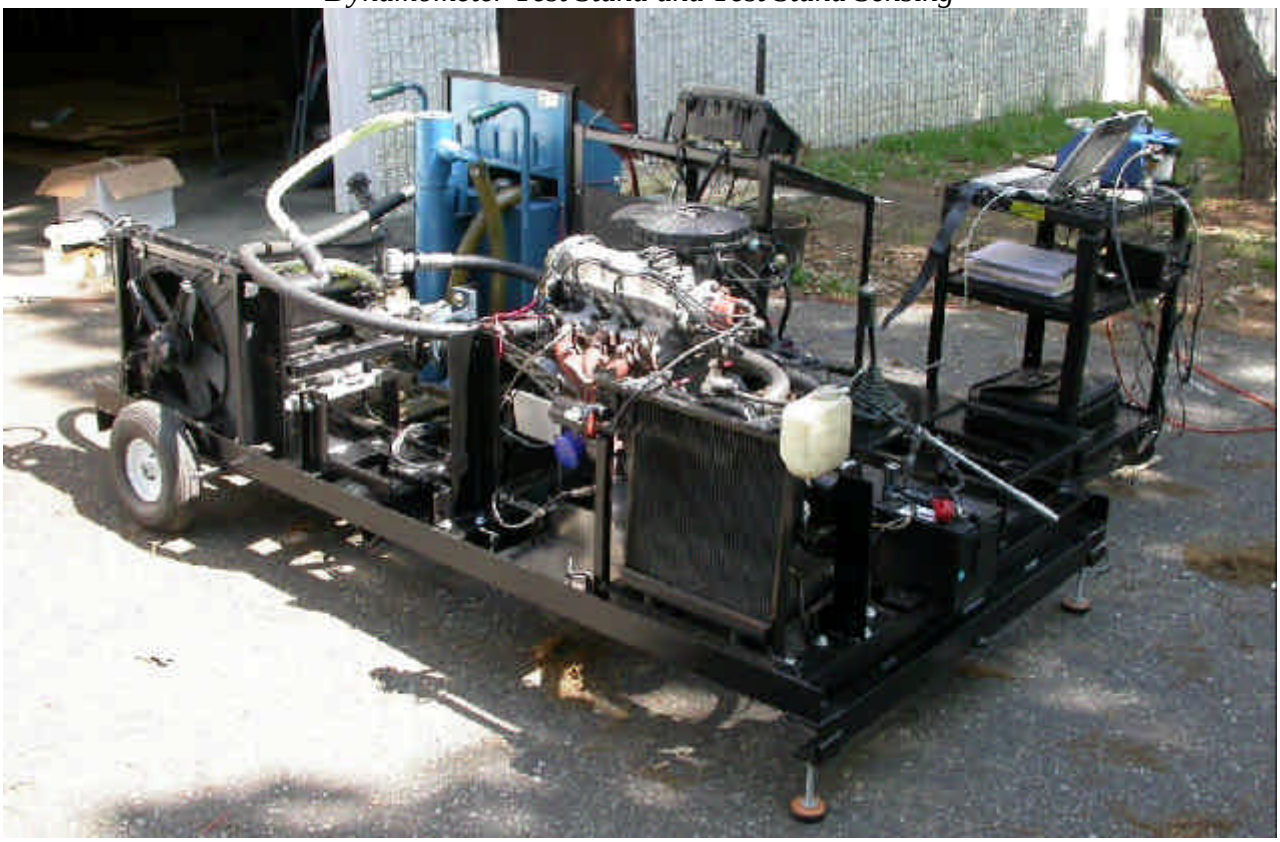

Figure 1. Dynamometer test stand, engine side

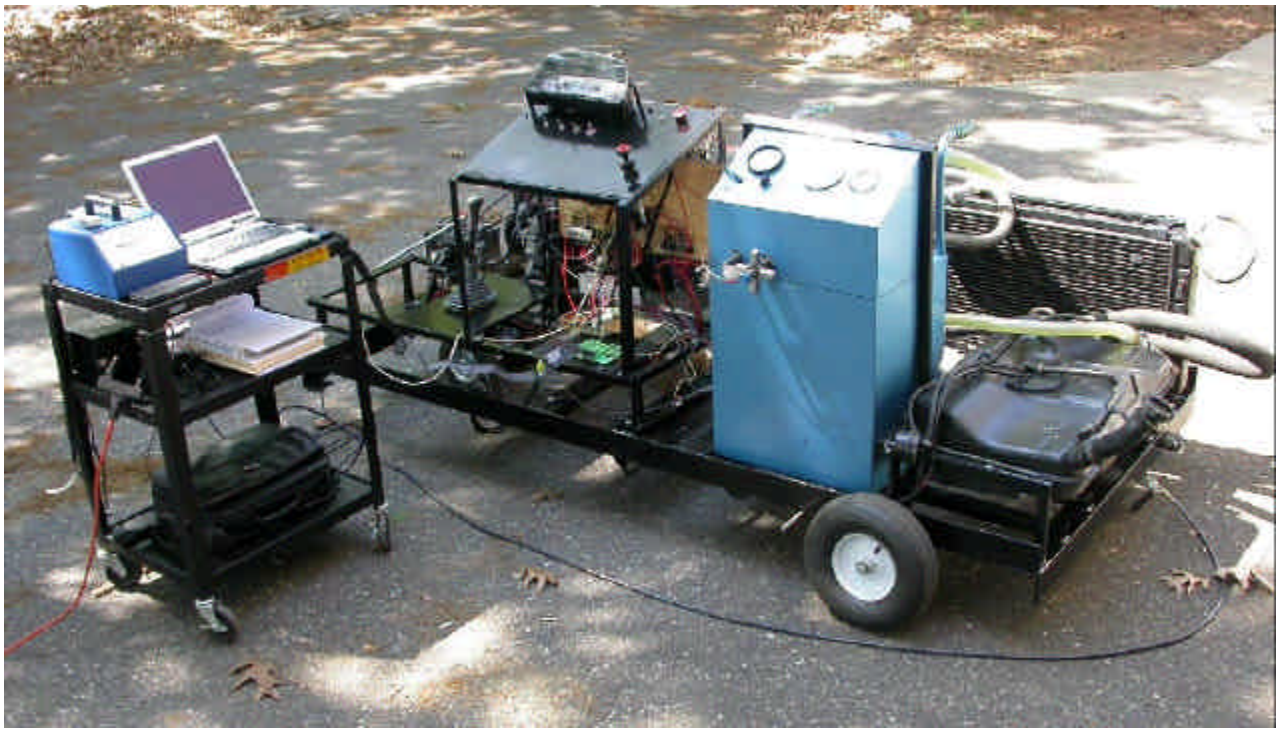

Figure 2. Dynamometer test stand, operator side.

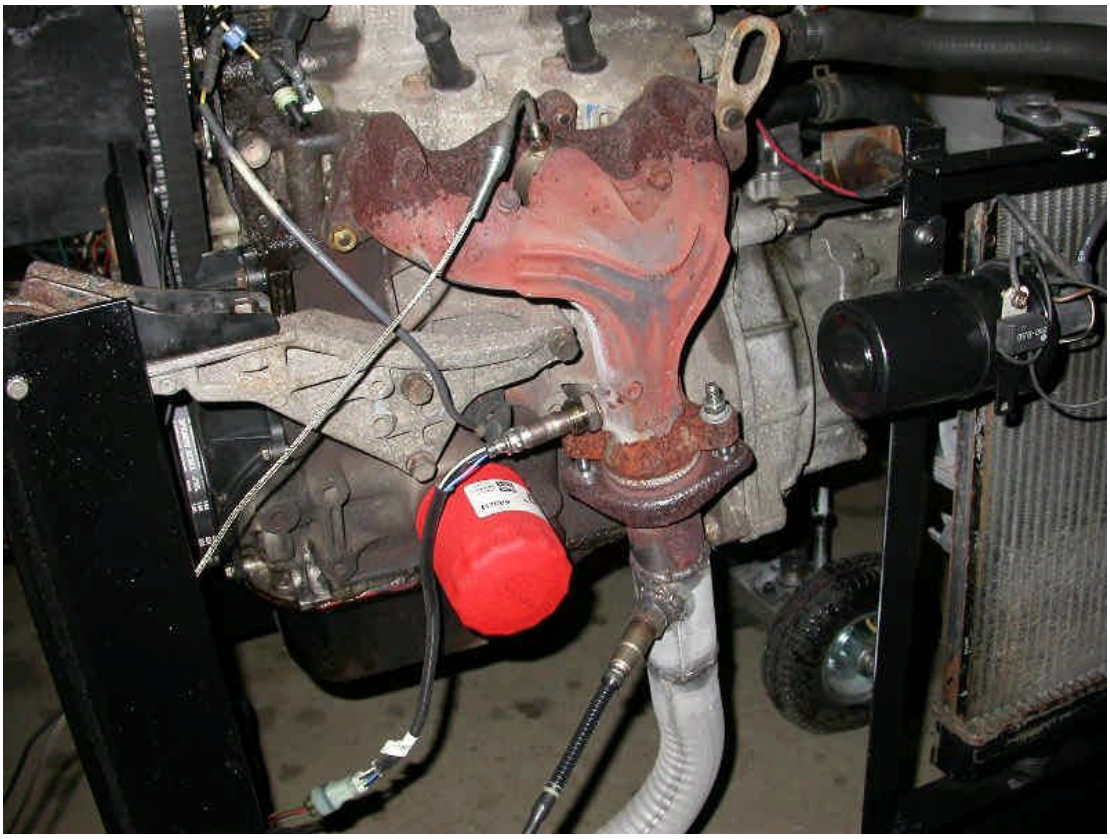

Figure 3. EGT, narrow band O2 and wideband O2 sensors.

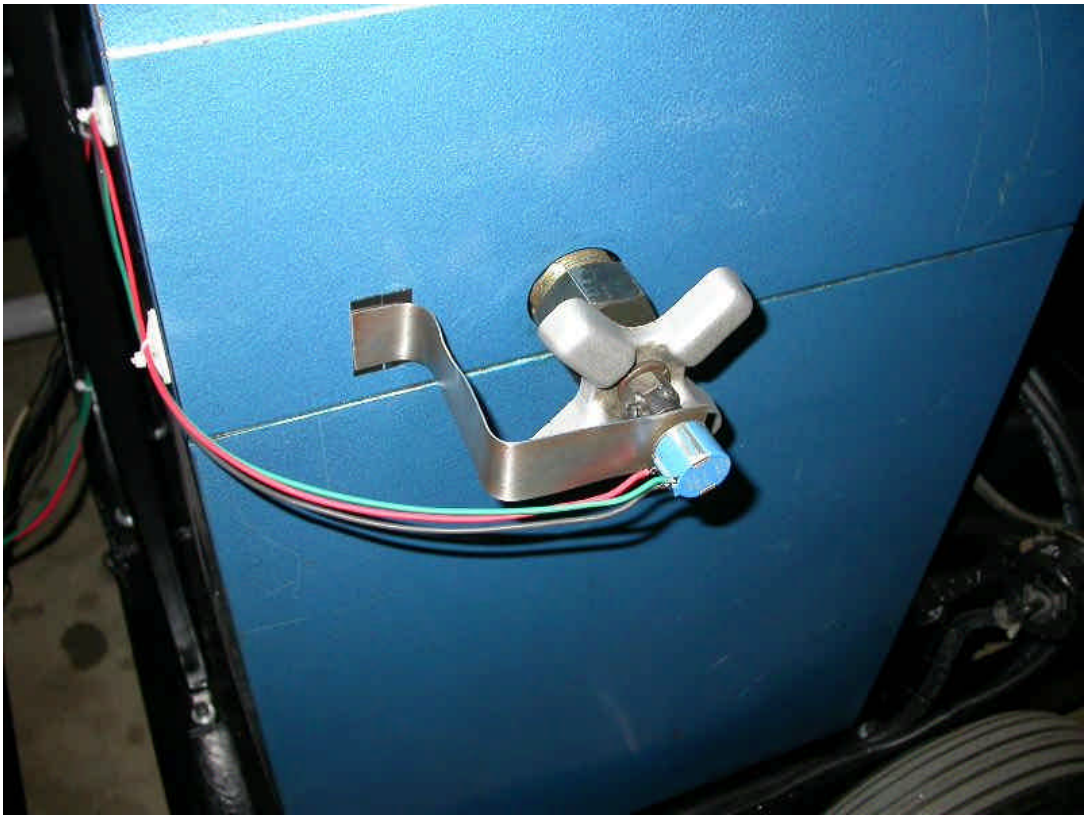

Figure 4. Load cell restriction valve with position sensor.

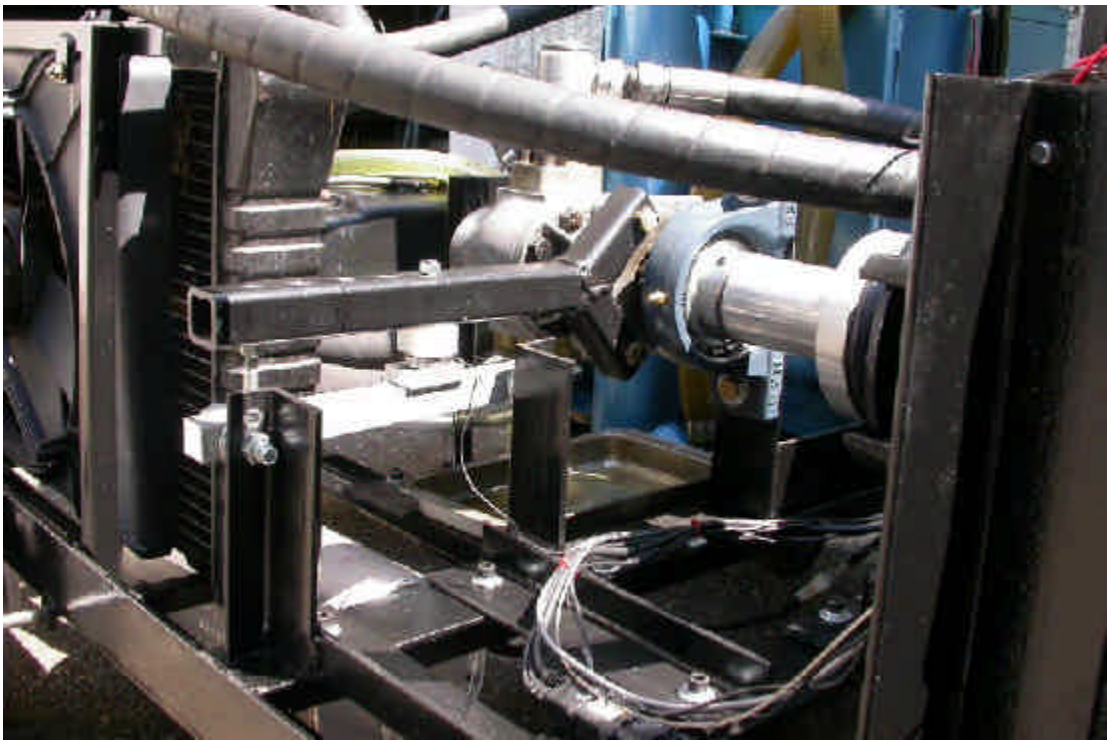

Figure 5. Torque arm and load sensor.

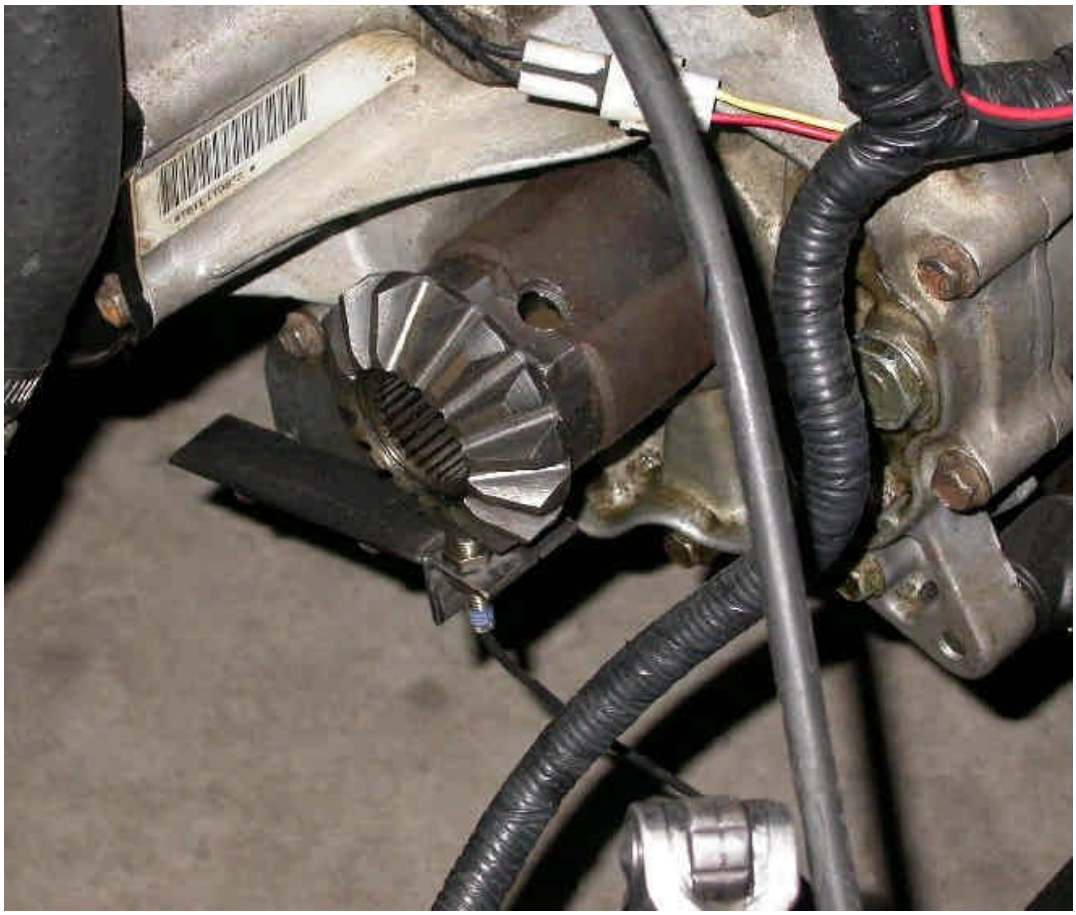

Figure 6. Transmission output speed sensor.

Appendix C

Stock and Modified Cylinder Heads

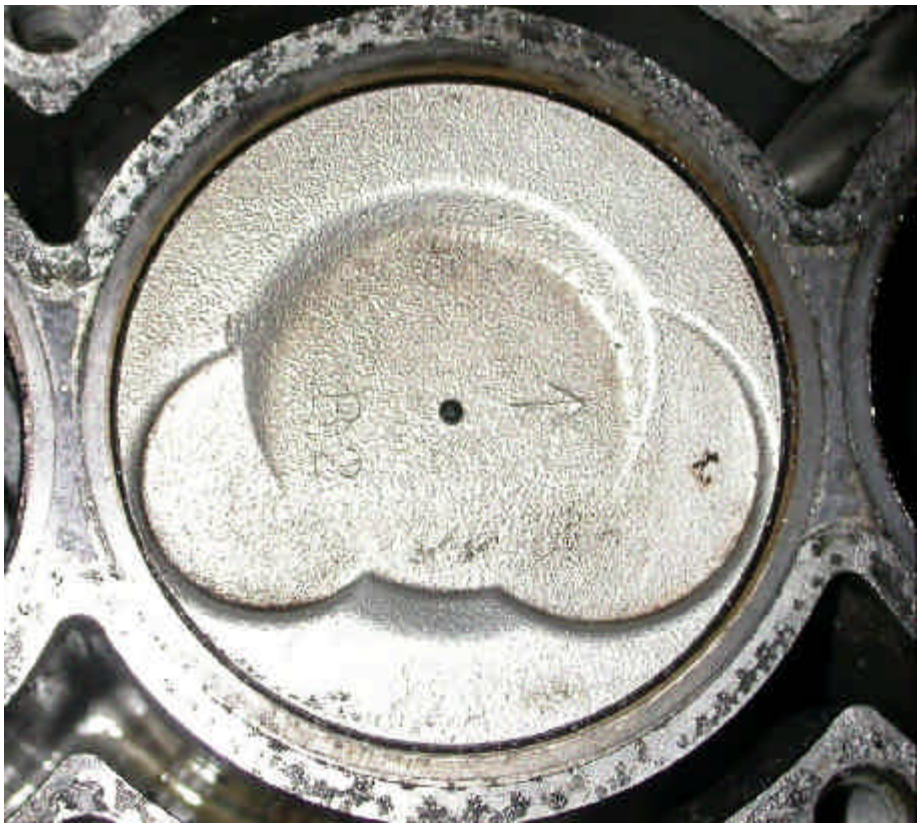

Figure 1. Piston dish.

Figure 2. Piston dish.

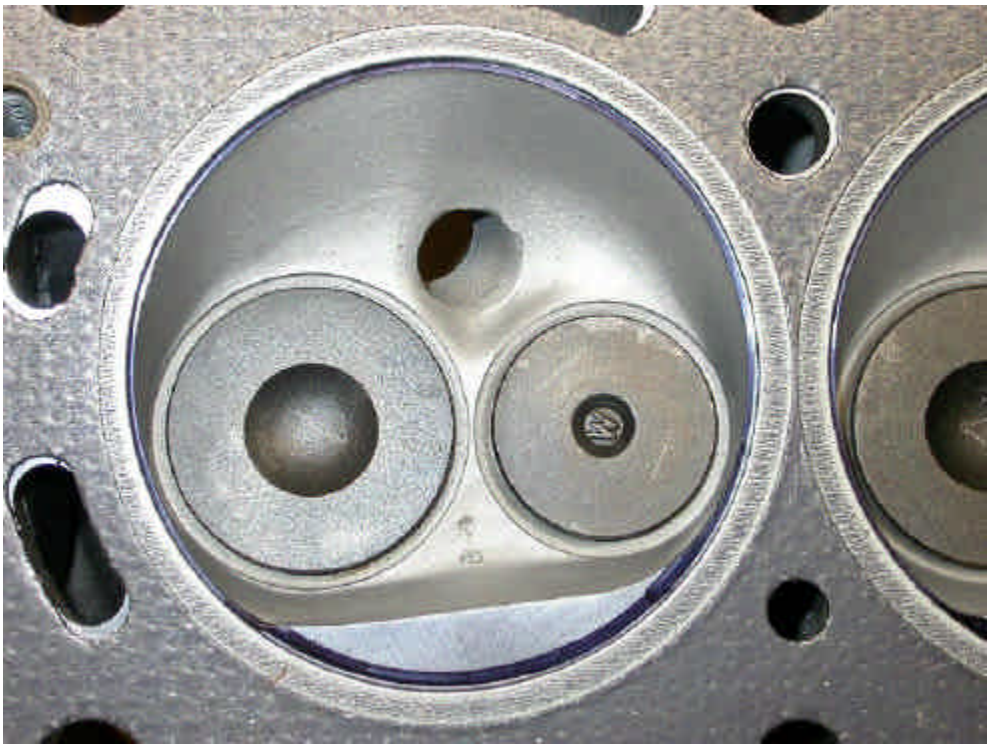

Figure 3. Stock combustion chamber.

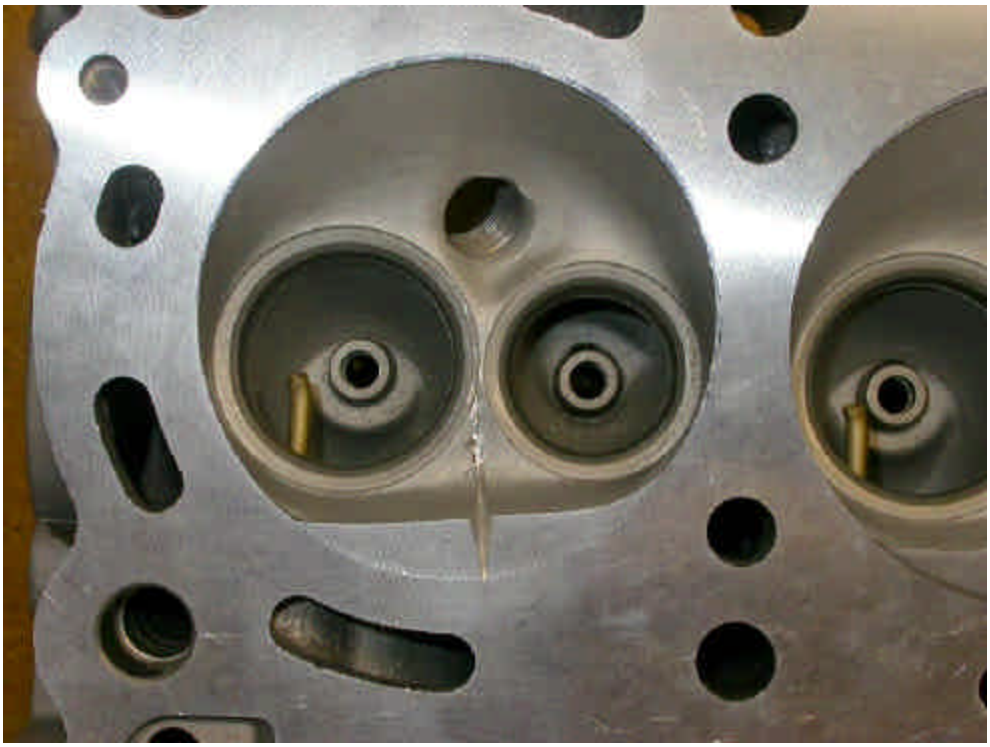

Figure 4. Grooved combustion chamber.

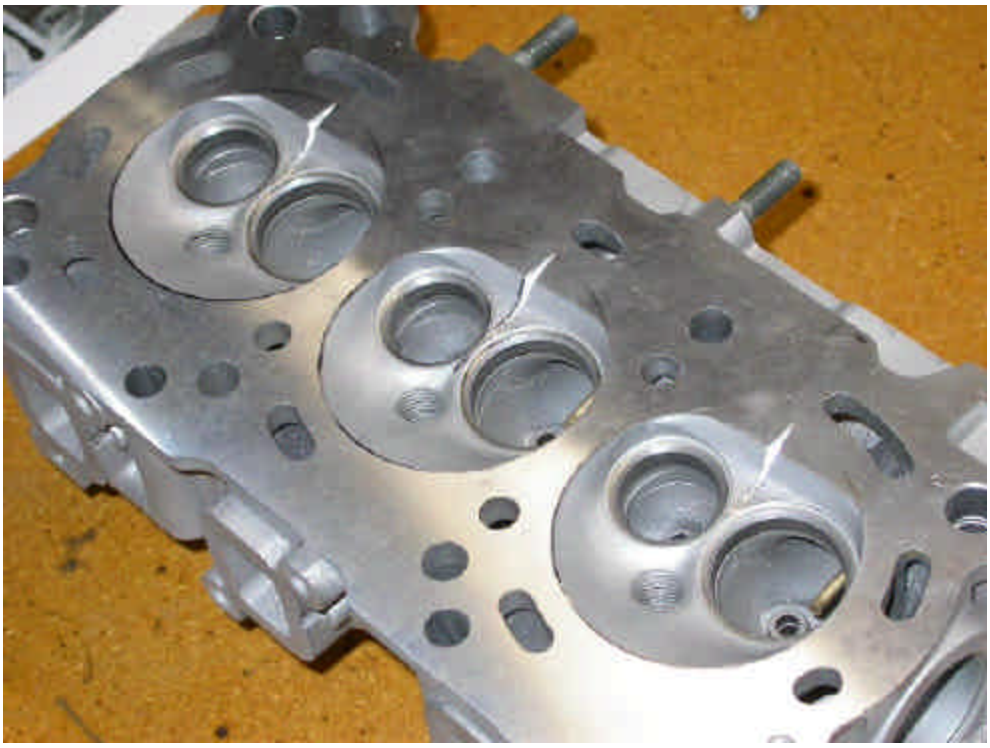

Figure 5. Grooved test head before assembly.

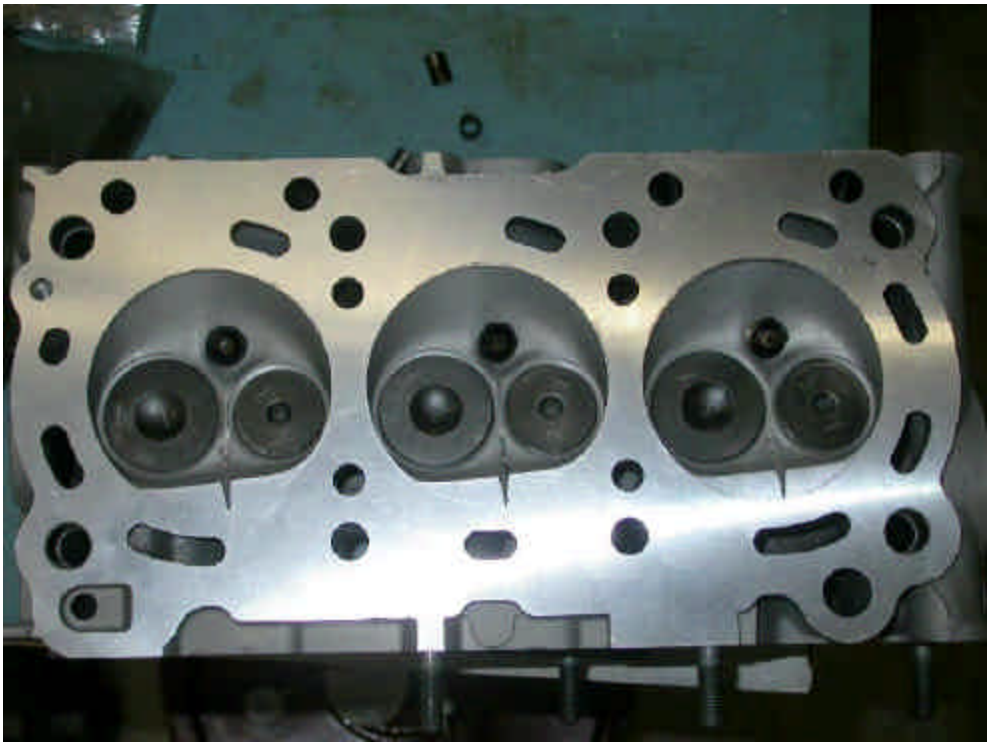

Figure 6. Grooved test head after assembly.

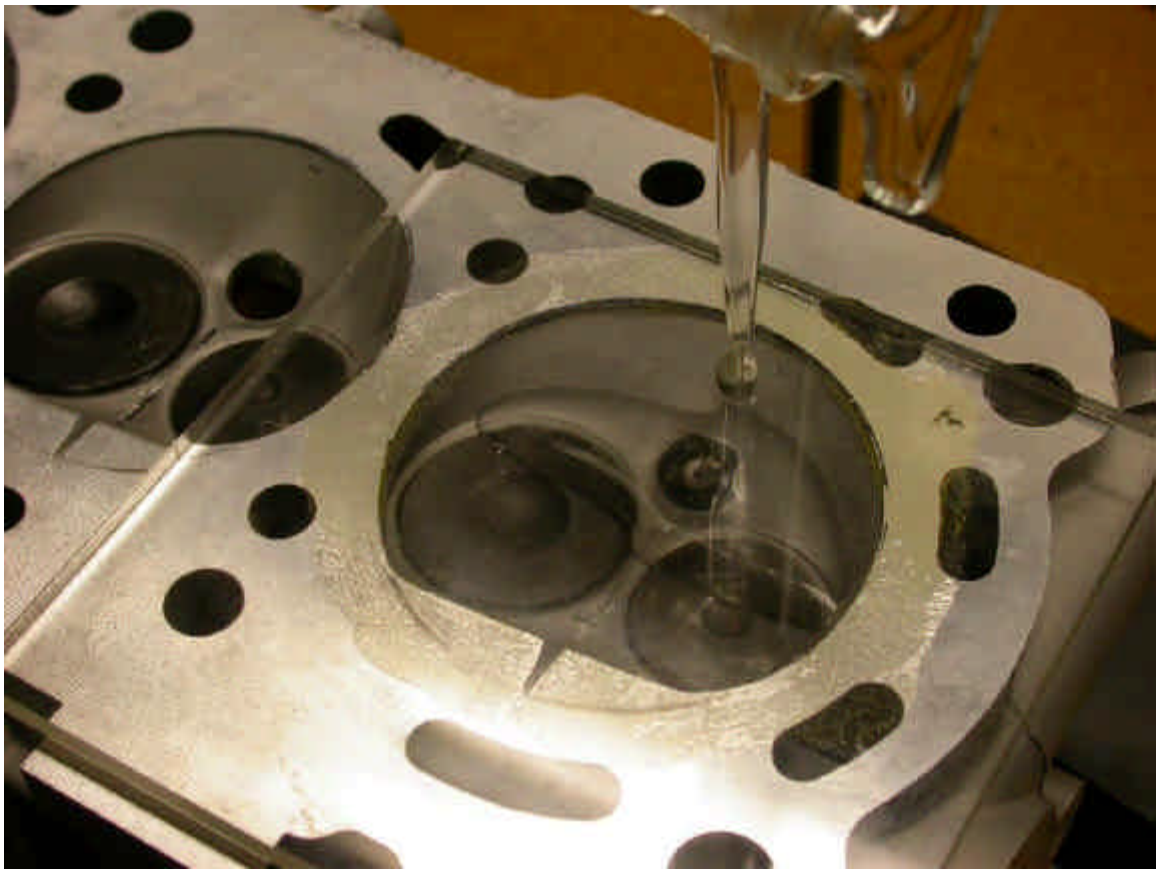

Figure 7. Measuring volume of grooved combustion chamber on test head.

Appendix D

Measurements, Calculations and Assumed Values

Injector Flow Rate

Method: Measured time taken to fill a 100 cc container with fuel pump running with normal alternator voltage applied and fuel injector fully open. The top of the throttle body assembly was used so that normal fuel pressure regulator was kept in system. Gasoline was used rather than a test fluid to keep results as accurate as possible.

Errors: There are two primary sources of error. The first is from evaporation. The second is from timing errors as both beginning filling and time measurements were made manually.

Determined Flow Rate: 45.55 lbm/hr (7.97 cc/sec)

Heating Value of Gasoline

Method: Value was found in Table A-2, Pg 380 of "Engineering Fundamentals of the Internal Combustion Engine" by Willard W. Pulkrabek. ISBN 0-13-570854-0, 1997.

Errors: A range is given for all gasoline, from a high heating value to a low heating value. The average of the high and low is used. There is no information on if this changes from manufacturer to manufacturer or for different octane readings.

Determined Heating Value: 45150 KJ/kg

Drivetrain Efficiency

Method: The value was found by applying max load to the engine, setting the throttle for the peak torque point and adjusting the efficiency factor until the rated torque of the engine was observed. Since we have losses through the transmission gear train as well as the hydraulic pump acting as a load cell we must include an efficiency factor.

Errors: Efficiency may not be constant over rotation speed in drivetrain. Method also assumed we can fully load the engine at a constant point. Temperature of load cell hydraulic fluid changes viscosity and therefore loading capacity.

Determined Drivetrain Efficiency: 75%

Engine RPM

Method: A sensor was used to generate a frequency signal off the crank pulley that would produce 18 pulses per revolution. This was then fed into a circuit that converts frequency to a linear voltage to be read by the computer DAQ system. Reading was calibrated to insure accuracy.

Errors: The main source for error was from the frequency to voltage circuit. This circuit relies on a resistor and capacitor for the output voltage. Capacitors can their value quite a bit with temperature, which will in turn affect the output voltage of the circuit. Since we are working with a HOT engine with lots of air blowing around, it is safe to assume the temperature of the circuit will vary some. Calibration was performed to keep accurate with the change in outside air temperature and a small cooling fan placed directly on the circuit to help keep the temperature constant.

Output RPM

Method: A sensor was used to generate a frequency signal off one of the output drive axles of the transmission. A gear was welded that would produce 15 pulses per revolution. This was then fed into a circuit that converts frequency to a linear voltage to be read by the computer DAQ system. Reading was calibrated to insure accuracy.

Errors: The main source for error was from the frequency to voltage circuit. This circuit relies on a resistor and capacitor for the output voltage. Capacitors can their value quite a bit with temperature, which will in turn affect the output voltage of the circuit. Since we are working with a HOT engine with lots of air blowing around, it is safe to assume the temperature of the circuit will vary some. Calibration was performed to keep accurate with the change in outside air temperature and a small cooling fan placed directly on the circuit to help keep the temperature constant.

Output Ratio

Calculated Equation:

Ratio = Input RPM / Output RPM

Errors: Dependent upon the ratio of the errors of the two measured RPM parameters.

EGT

Method: Measured from a K-type thermocouple placed in the exhaust manifold directly in exhaust flow on exit from cylinder head. A Linear Technology LTK001 thermocouple cold junction compensator and matched amplifier were used to process and amplify the raw signal. This signal was calibrated at 32 deg F (freezing) and at 212 deg F (boiling) to obtain the linear equation for the amplifier and compensator.

Errors: Linear Technology literature lists an accuracy of 0.75 Deg C. Any error in the calibration of the freezing and boiling points would also have an effect on the linear equation. Calibration was performed several times to guarantee accuracy.

Wideband AFR

Method: An Innovate Motorsports LC1 Digital Air/Fuel Sensor controller and Bosch LSU4.2 5 wire wideband O2 sensor was used to monitor AF ratio. The analog output, which gave a linear signal from 0 to 5V for AFR 7.35 to 22.39, was used to monitor AFR.

Errors: Innovate lists the accuracy of the controller as +/- 0.1 AFR. Additional errors can be introduced in the form of a misfire in the engine, since this sensor uses the leftover oxygen in the exhaust stream to generate the AFR signal.

Brake Specific Fuel Consumption

Calculated Equation:

$$bsfc = \dot{m}_f \Big/ \dot{W} = \frac{45.55 * DC}{2 * p * N * t} \quad \text{lb/HP*hr}$$

DC = Duty cycle from Injector (data read from MegaSquirt data stream output)
45.55 lb/hr max flow rate of injector
N = Engine RPM
τ = Engine Torque

Errors: Dependent upon accuracy of all measured parameters.

Fuel Flow Rate

Calculated Equation:

$$\dot{m}_f = 45.55 * DC \quad \text{lbm/hr}$$

DC = Duty cycle from Injector (data read from MegaSquirt data stream output)
45.55 lb/hr max flow rate of injector

Errors: Dependent upon accuracy of all measured parameters.

Engine Torque

Method: Engine torque was measured by placing a FC23 compression load cell (Measurement Specialties) where a torque arm from the hydraulic load cell could apply a load to it as the output from the transmission tried to turn it. The hydraulic pump was mounted so that its center of rotation was concentric with the rotation of one of the drive axles. A torque arm was mounted to the hydraulic pump housing to stop the rotation of the pump. The compression load cell was placed a known distance from the center of the pump shaft along the torque arm. As the engine tried to spin the pump it puts a load on the compression load cell. The compression load cell is a strain gage, which outputs a small voltage linear with loading. A 10x amplifier was used to amplify this signal into a useful voltage range. Sensor signal was calibrated to determine linear volts to force relation using measured weights placed up the torque arm.

Calculated Equation:

$$t = \frac{LD}{ratio * h_{DRIVE}} \text{ ft-lbs}$$

LD = measured load from the compression load cell
ratio = ratio of output rpm to input rpm
η_{DRIVE} = efficiency of drivetrain (75%)

Errors: Dependent upon accuracy of all measured parameters.

Brake Horsepower

Calculated Equation:

$$\dot{W} = \frac{t * EngRPM}{5252} \text{ HP}$$

τ = Engine Torque
EngRPM = Engine RPM

Errors: Dependent upon accuracy of all measured parameters.

Corrected Horsepower

Calculated Equation:

$$\dot{W}_{Corr} = \dot{W} * \left(1.180 * \left[\left(\frac{990}{P_d} \right) * \left(\frac{T_c + 273}{298} \right)^{0.5} \right] - 0.18 \right) \text{ HP}$$

P_d = Pressure of dry air in hPa
T_c = Air temp in degrees Celsius

Errors: Dependent upon accuracy of all measured parameters.

Volumetric Efficiency

Calculated Equation:

$$h_v = \frac{m_a}{r_a * V_d} = \frac{n * \dot{m}_a}{r_a * V_d * N}$$

$\dot{m}_a = \dot{m}_f$ * AFR = Steady State Air Flow into engine (mass of air)

$\dot{m}_f$ = Mass of fuel into engine
AFR = Air fuel ratio (from Innovate Wideband sensor)
n = number of revolutions per engine cycle
$r_a = \frac{P_o}{R * T_o}$ = Air density at atmospheric conditions
P_o = barometric pressure (Megasquirt reads when powered up before engine cranking)
T_o = Temperature of Air
R = Gas constant for Air = 0.287 kJ/kg-K = 53.33 ft-lbf/lbm-^oR
V_d = Displacement Volume (1.0L)
N = Engine Speed (RPM)

Errors: Dependent upon accuracy of all measured parameters.

Brake Thermal Efficiency

Calculated Equation:

$$(n_t)_{BRAKE} = \frac{\dot{W}_b}{\dot{m}_f * Q_{HV} * n_c}$$

$\dot{W}_b$ = Horsepower (converted to kW)
Q_{HV} = Heating Value of Gasoline = 45150 kJ/kg
$\dot{m}_f$ = mass flow of fuel into engine
n_c = combustion efficiency (see Note 1)

Combustion efficiency was taken from graph given on Figure 4-1, Pg 126 of "Engineering Fundamentals of the Internal Combustion Engine" by Willard W. Pulkrabek. ISBN 0-13-570854-0, 1997.

Errors: Dependent upon accuracy of all measured parameters.

Load Cell Fluid Temperature

Method: The temperature of the hydraulic fluid in the load cell was measured by submerging a standard GM coolant temperature sensor in the fluid reservoir. A voltage divider was used to condition the signal and a lookup table for the resistance to temperature relation of the sensor used to give the temperature.

Errors: Dependent upon the accuracy of the lookup table as well as the resistance values used in the voltage divider.

Load Cell Dial Position

Method: The multi-turn potentiometer was affixed to the adjustment knob on the load cell so it would turn with the knob. A voltage divider was used to condition the signal and a voltage from 0 to 5V was read to reference the position of the adjustment knob from fully closed to fully open.

Errors: Accuracy of the position dependent upon the accuracy of the resistance values used in the voltage divider.

Battery Volts

Method: The battery voltage value monitored by the Megasquirt EFI controller was read from the output data stream on its serial port interface.

Errors: Accuracy dependent upon the Megasquirt EFI controller's measurement accuracy.

Engine Manifold Vacuum

Method: The manifold vacuum value monitored by the Megasquirt EFI controller was read from the output data stream on its serial port interface. The Megasquirt uses a Freescale semiconductor MPX4250AP integrated pressure sensor to determine the manifold air pressure. This is a 20 to 250 kPA sensor.

Sensor Equation:

$$V_{out} = V_s\left(P * 0.004 - 0.04\right)$$

Errors: Freescale data sheets give a max error of sensor as 1.5% over temperature range. Additional errors can come from measurement circuitry and rounding errors of Megasquirt micro code.

Engine Coolant Temperature

Method: The coolant temperature value monitored by the Megasquirt EFI controller was read from the output data stream on its serial port interface. A lookup table internal to the Megasquirt table was used to convert the resistance to a temperature.

Errors: Accuracy dependent upon the Megasquirt EFI controller's measurement accuracy as well as the accuracy of the lookup table to the resistance relation of the sensor.

Manifold Air Temperature

Method: The manifold air temperature value monitored by the Megasquirt EFI controller was read from the output data stream on its serial port interface. A lookup table internal to the Megasquirt table was used to convert the resistance to a temperature.

Errors: Accuracy dependent upon the Megasquirt EFI controller's measurement accuracy as well as the accuracy of the lookup table to the resistance relation of the sensor.

Throttle Position

Method: The coolant temperature value monitored by the Megasquirt EFI controller was read from the output data stream on its serial port interface. A standard 10k GM throttle position sensor was mounted on the throttle body so that it could read the full range of motion of the throttle.

Errors: Accuracy dependent upon the Megasquirt EFI controller's measurement accuracy. Sensor range was calibrated for min and max.

Hydrocarbon PPM

Method: An Emissions Systems, Inc. model 8000 5-gas analyzer was used to monitor the tailpipe emissions. Software was written to communicate directly with the analyzer through its serial interface. Readings could be taken from 0-2000 PPM.

Errors: The emissions bench is certified to meet or exceed the following standards: CA Bar 97, ISO 3930, OIML R99 Class 0 and OIML R99 Class 1. The bench was calibrated at the manufacturer with periodic re-zeroing during testing.

CO %

Method: An Emissions Systems, Inc. model 8000 5-gas analyzer was used to monitor the tailpipe emissions. Software was written to communicate directly with the analyzer through its serial interface. Readings could be taken from 0-10%.

Errors: The emissions bench is certified to meet or exceed the following standards: CA Bar 97, ISO 3930, OIML R99 Class 0 and OIML R99 Class 1. The bench was calibrated at the manufacturer with periodic re-zeroing during testing.

NOx PPM

Method: An Emissions Systems, Inc. model 8000 5-gas analyzer was used to monitor the tailpipe emissions. Software was written to communicate directly with the analyzer through its serial interface. Readings could be taken from 0-5000 PPM.

Errors: The emissions bench is certified to meet or exceed the following standards: CA Bar 97, ISO 3930, OIML R99 Class 0 and OIML R99 Class 1. The bench was calibrated at the manufacturer with periodic re-zeroing during testing.

CO2 %

Method: An Emissions Systems, Inc. model 8000 5-gas analyzer was used to monitor the tailpipe emissions. Software was written to communicate directly with the analyzer through its serial interface. Readings could be taken from 0-25%.

Errors: The emissions bench is certified to meet or exceed the following standards: CA Bar 97, ISO 3930, OIML R99 Class 0 and OIML R99 Class 1. The bench was calibrated at the manufacturer with periodic re-zeroing during testing.

O2 %

Method: An Emissions Systems, Inc. model 8000 5-gas analyzer was used to monitor the tailpipe emissions. Software was written to communicate directly with the analyzer through its serial interface. Readings could be taken from 0-25%.

Errors: The emissions bench is certified to meet or exceed the following standards: CA Bar 97, ISO 3930, OIML R99 Class 0 and OIML R99 Class 1. The bench was calibrated at the manufacturer with periodic re-zeroing during testing.

Equipment & Literature References:

Emission Systems, Inc.
P.O. Box 7
Algonquin, IL 60102
Phone: 847-854-8483
www.emsgas.com

Innovate! Technology, Inc.
5 Jenner, Suite 100
Irvine, CA 92618
Phone: 949-502-8400
Fax: 949-502-8439
www.innovatemotorsports.com

Linear Technology Corporate Headquarters
1630 McCarthy Blvd.
Milpitas, CA 95035-7417
Phone: 408-432-1900
Fax: 408-434-0507
http://www.linear.com/pc/productDetail.jsp?navId=H0,C1,C1154,C1073,P1181

MegaSquirt EFI computer
http://www.bgsoflex.com/megasquirt.html

Measurement Specialties, Inc.
460 E. Swedesford Rd. Suite 2010
Wayne, PA 19087
Phone: 610-971-9893
http://www.meas-spec.com/myMeas/default/index.asp
http://www.meas-spec.com/myMeas/download/pdf/english/sensors/LoadCellFC23.pdf

Freescale Semiconductor
800-521-6274
http://www.freescale.com/
http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MPX4250&fsrch=1

"Engineering Fundamentals of the Internal Combustion Engine" by Willard W. Pulkrabek.
ISBN 0-13-570854-0, 1997.

Appendix E

Singh Dynamometer Test Schedule

1. The following is the test schedule that will be followed for testing the Singh grooves.
2. Ionization current tests will record the ionization current and a waveform that can be used to determine the mechanical position of the engine.
3. Running tests will log all gas analyzer readings, pertinent EFI controller readings and direct sensor data. All data will be logged 10 times per second for the duration of the test (about 20 seconds). All tests will be repeated 10 times so that any anomalous readings can be discarded from the test set.

Engine has been set to the following specs.

- Base ignition timing 6 deg BTDC (unless otherwise specified in test).
- Thermostat regulates coolant temp 180 to 210 Deg F
- EFI AFR set to 14.7:1 at idle and low loads, with a gradual increase in AFR to 13.5:1 as load and speed is increased.
- Engine checked for even compression (pass)
- Engine checked for low leakdown (pass, <3%)
- Standard summer blend 87 octane Citgo gasoline, purchased within a week of testing.
- EGR valve off.
- XFI camshaft installed.

It should be noted that the hydraulic load cell increases it loading with speed. At low rpm, max pressure setting will only provide a small to moderate load. As speed increases and higher gears are used the loading will increase. Currently the load cell will load the engine to max capacity in 5^{th} gear at about 3500 rpm.

Ionization Current Tests:

Ionization current graphs (Record 20 graphs at each of the following conditions), will note relative consistency of the graphs, i.e. how regular, or erratic is the combustion on a cycle-to-cycle basis. (Please see separate report for ionization current analysis)

- Idle (900 rpm)
  - engine at operating temp, cooling fan on & no load.
- Light load, low rpm
  - 2000 rpm, 4th gear, cooling fan on, engine at operating temp.
  - load cell on with light load, load cell oil at stable temp, load coolant fan on.
- Light load, high rpm
  - 4500 rpm, 3rd gear, cooling fan on, engine at operating temp.
  - load cell on with light load, load cell oil at stable temp load coolant fan on.
- High load, moderate rpm
  - 2500 rpm, 5th gear, cooling fan on, engine at operating temp
  - load cell on with high load, load cell oil at stable temp, load coolant fan on.
- High load, high rpm
  - 3500 rpm, 5th gear, cooling fan on, engine at operating temp (near WOT)
  - load cell on with near max load, load cell at stable temp, load coolant fan on.
- Light load, low rpm **(humid air intake on stock head only)**
  - 2000 rpm, 4th gear, cooling fan on, engine at operating temp.
  - load cell on with light load, load cell oil at stable temp, load coolant fan on.

Note:

Humid air test used as a comparison test. The high humidity will increase the octane of the air fuel mix significantly and we can see the effects of octane increase on a stock head.

Normal Running Test; engine RPM incremented (each point will be run for 20 seconds and repeated 10 times, all sensor information recorded (EFI, gas analyzer, and sensors) for later analysis)

4th gear tests, Incremented by engine RPM, load at 0.30V position

- Idle
  - 900 rpm, engine at operating temp, cooling fan on, no load
- Engine at 1500 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 2000 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 4000 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 4500 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on
- Engine at 5000 rpm
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on 80% load, load cell oil at a stable temp, load coolant fan on

5th gear tests, Incremented by engine RPM, load at 0.26V position

- Engine at 1500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 2000 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 4000 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on
- Engine at 4500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on 75% load, load cell oil at a stable temp, load coolant fan on

5th gear tests, Incremented by engine RPM, load at 0.08V position

- Engine at 1500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2000 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

Normal Running Tests; TPS incremented (keeps TPS position and fueling the same to look for Torque, HP and RPM differences), (Each point will be run for 20 seconds and repeated 10 times, all sensor information recorded for later analysis)

4th gear tests, Incremented by TPS, load at 0.08V position

- Engine at 2% TPS
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 5% TPS
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 25% TPS
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

5th gear tests, Incremented by TPS, load at 0.08V position

- Engine at 2% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 5% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 30% TPS
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

Lean Run Tests; engine RPM & TPS incremented. Fuel table is scaled 5% and 10% leaner, 6 degree base timing. (Each point will be run for 20 seconds and repeated 10 times, all sensor information recorded for later analysis).

4th gear tests, Incremented by engine RPM & TPS, load at 0.08V position

- Engine at 2000 rpm, fueling 5% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm, fueling 5% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm, fueling 5% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm, fueling 5% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS, fueling 5% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS, fueling 5% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS, fueling 5% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

4th gear tests, Incremented by engine RPM & TPS, load at 0.08V position

- Engine at 2000 rpm, fueling 10% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm, fueling 10% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm, fueling 10% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm, fueling 10% leaner
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS, fueling 10% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS, fueling 10% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS, fueling 10% leaner
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

Lean Run Tests; engine RPM & TPS incremented. Fuel table is scaled 5% & 10% leaner, 10 degree base ignition timing. (Each point will be run for 20 seconds and repeated 10 times, all sensor information recorded for later analysis).

4th gear tests, Incremented by engine RPM & TPS, load at 0.08V position

- Engine at 2000 rpm, fueling 5% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm, fueling 5% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm, fueling 5% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm, fueling 5% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS, fueling 5% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS, fueling 5% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS, fueling 5% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

4th gear tests, Incremented by engine RPM & TPS, load at 0.08V position

- Engine at 2000 rpm, fueling 10% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm, fueling 10% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm, fueling 10% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3500 rpm, fueling 10% leaner, 10 Deg BTDC base ign
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS, fueling 10% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS, fueling 10% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 20% TPS, fueling 10% leaner, 10 Deg BTDC base ign
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

Humid Run tests. Fogger unit is used to add water vapor to intake air to simulate a 100% humidity condition. (Each point will be run for 20 seconds and repeated 10 times, all sensor information recorded)

- Engine at 2000 rpm, base fuel map, 6 deg static timing
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 2500 rpm, base fuel map, 6 deg static timing
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 3000 rpm, base fuel map, 6 deg static timing
  - 4th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 10% TPS, base fuel map, 6 deg static timing
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on
- Engine at 15% TPS, base fuel map, 6 deg static timing
  - 5th gear, engine at operating temp, cooling fan on
  - load cell on max load, load cell oil at a stable temp, load coolant fan on

Low idle test

Adjust idle screw to lowest point at which engine will idle without stalling & record RPM.

Cold warm up test

Start engine cold (75 deg ambient) and take time for coolant to reach 160 Deg (fast idle off set point).