Under Hood Temperature Measurements of Four Vehicles

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Preface

This report constitutes the final deliverable for the work proposed under Biokinetics Proposal P04-60 v02 to measure the under hood temperatures of vehicles.

The opinions expressed herein are those of Biokinetics and Associates Ltd. and do not necessarily reflect those of the Motor Vehicle Fire Research Institute.

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1. Introduction

Due to its volatility, spilled gasoline in the presence of an ignition source posses the greatest threat of a post crash vehicle fire occurring. However, other automotive fluids such as, engine oil, transmission oil, brake fluid, coolant and power steering fluid are also flammable and similarly, if exposed to an ignition source can result in a vehicle fire. The ignition source need not be a spark or flame. If hot enough, contact with engine or exhaust components may also cause each of the fluids listed to self ignited.

Under normal vehicle operating conditions automotive fluids are well contained and do not pose a fire threat as they are not exposed to excessively hot surfaces. However, the risk of fire increases if the fluids are spilled, as is possible, following a crash in which fluid reservoirs may be damaged. Fire may result if the spilled fluids are exposed to sufficiently hot surfaces.

The testing reported on herein attempts to identify the range of under hood temperatures that spilled fluids may be exposed to by directly measuring the temperature of hot under hood engine and exhaust components. Comparison are then made to the auto ignition temperatures of various automotive fluids' auto ignition temperatures. The temperature measurements were conducted with the vehicles loaded to their rated capacity for both level road driving and driving uphill.

2. Vehicle Selection

The under hood temperatures were measured for four vehicles selected to represent various vehicle types with sales numbers in excess of 50,000 units in the North American market. The test vehicles were obtained through rental agencies.

For testing purposes, the vehicles were ballasted to their rated cargo capacity. The power to weight ratio for each was calculated based the rated engine horse power (HP) and on their test weight which included the weight of the vehicle, ballast, driver and instrumentation technician.

A summary of the tested vehicles is presented in Table 1 below.

Table 1: Vehicle selection for under hood temperature measurements.

Manufacturer	**Model**	**Sales (units)**	**HP**	**Vehicle Weight Including Ballast (lb)**	**Power/Weight (HP/lb)**
Chrysler	Neon (SX2.0)	64,098	132	3415	0.039
Chrysler	Caravan	131,397	180	5063	0.036
General Motors	Silverado	322,907	200	6091	0.033
Ford	Focus	118,807	130	3346	0.039

3. Test Matrix and Procedure

The vehicle under hood temperatures were measured under three loading conditions that were achieved when the vehicle was stationary, driving on a level road and uphill. For both driving conditions the vehicles were loaded to the rated capacity indicated on the door sill and tested at several driving speeds. For the stationary tests the engine speed was selected as a multiple of the base engine idling speed expressed in revolutions per minute (rpm).

The complete test matrix is summarized in Table 2.

Table 2: Test matrix for under hood temperature measurements.

Test Condition	Speed
Stationary	Base idle rpm
	Base idle rpm x 2
	Base idle rpm x 3
	Base idle rpm x 4
Level road driving	48 km/h (30 mph)
	64 km/h (40 mph)
	80 km/h (50 mph)
	96 km/h (60 mph)
	112 km/h (70 mph)
Driving uphill	64 km/h (40 mph)
	80 km/h (50 mph)
	96 km/h (60 mph)
	112 km/h (70 mph)

All the testing was performed with a minimum ambient temperatures of 22 ºC.

For the stationary tests, the vehicles were allowed to idle at a given engine speed until the temperature reading stabilized at which point the engine speed was increased to the next increment.

Under level road driving conditions at the speeds indicated in the test matrix, the vehicle was driven until the temperatures stabilized at which point the vehicle was brought to a stop and the engine turned off. This procedure was designed to represented a vehicle crash in which the vehicle may come to a sudden halt. Temperature measurements continued for a period of 20 minutes or until the maximum temperature recorded by any of the temperature transducers dropped below 200 ºC.

A stretch of highway approximately 1.6 km (1 mile) in length with a 7% grade was selected for the uphill driving tests. The length of the hill was insufficient to allow the vehicle temperatures to stabilize, consequently the procedure of steady state driving was modified as per the following :

1. Ascend hill at steady state speed.
2. Continue over crest off hill and descend the back side for 0.7 km to the stop at the bottom.
3. At the bottom, turn around and accelerated to steady state speed up the back side of the hill (also 7% grade).
4. Continue over crest to the bottom of the test hill.
5. Turn around, accelerate to steady state speed and repeat.

Steps 1 through 5 were repeated 3 times. On the third ascension of the test hill the vehicle was pulled off to the side of the road and the engine was turned off. The repeated process of ascending and descending the hill several times stabilized the peak temperatures achieved at the crest of the hill prior to the engine being turned off. Similarly to the level road testing the temperature measurements were continued for a period of 20 minutes or until the maximum temperature dropped below 200 ºC.

For the uphill driving tests, it was initially considered desirable to have a low vehicle speed of 48 km/h for comparison with the level road conditions. However, this was deemed to be potentially hazardous due to faster moving traffic on the highway. Consequently the 48 km/h hill test was not conducted.

4. Instrumentation

K-type thermocouples from Omega® were used to measure vehicle temperatures at eleven location under the hood and along the exhaust system. The locations are summarized in Table 3 below.

Table 3: Thermocouple locations.

Thermocouple No.	**Location**	**Note**
1	Catalytic Converter 1	Immediately adjacent the converter on the upstream side.
2	Catalytic Converter 2	Immediately adjacent the converter on the downstream side.
3	Catalytic Converter 3	On the mid body of the catalytic converter.
4	Exhaust Manifold 1	On one pipe closest to the engine block.
5	Exhaust Manifold 2	At the union of all manifold pipes.
6	Exhaust 1	Location along the exhaust system closest to the gas tank.
7	Exhaust 2	Immediately prior to the muffler.
8	Oil Pan	The oil dip stick was replaced with a thermocouple.
9	Coolant Intake	Adjacent the radiator.
10	Centre of the Hood	A thermo couple was suspended over the engine at the centre of the hood.
11	Coolant Outlet	Adjacent the radiator.
Note: Thermo couple 11 was added following the completion of the first test series with the Ford Focus.		

The vehicles were obtained from rental agencies which precluded the use of spot welding or adhesives for affixing the thermo couples. Instead, the K-type thermocouples were secured to each location with stainless steel hose clamps. The thermocouples were aligned so as to ensure maximum surface contact with the matting surface. In instances where a heat shield was installed, such as on the manifold or the catalytic converter, the thermocouple was placed directly on the component beneath the shield.

Omega four channel and eight channel data loggers recorded the temperatures at five second intervals. The two data loggers were synchronized and the data points were time and date stamped.

5. Results and Discussion

Reference temperatures were measured with the vehicles stationary at four engine idle speeds. An example of the temperatures measured during a stationary test with Chevrolet Silverado is shown in Figure 1. These temperatures are not reflective of actual driving conditions but without the benefits of convective cooling they do represent the worst case scenario for the unloaded engine.

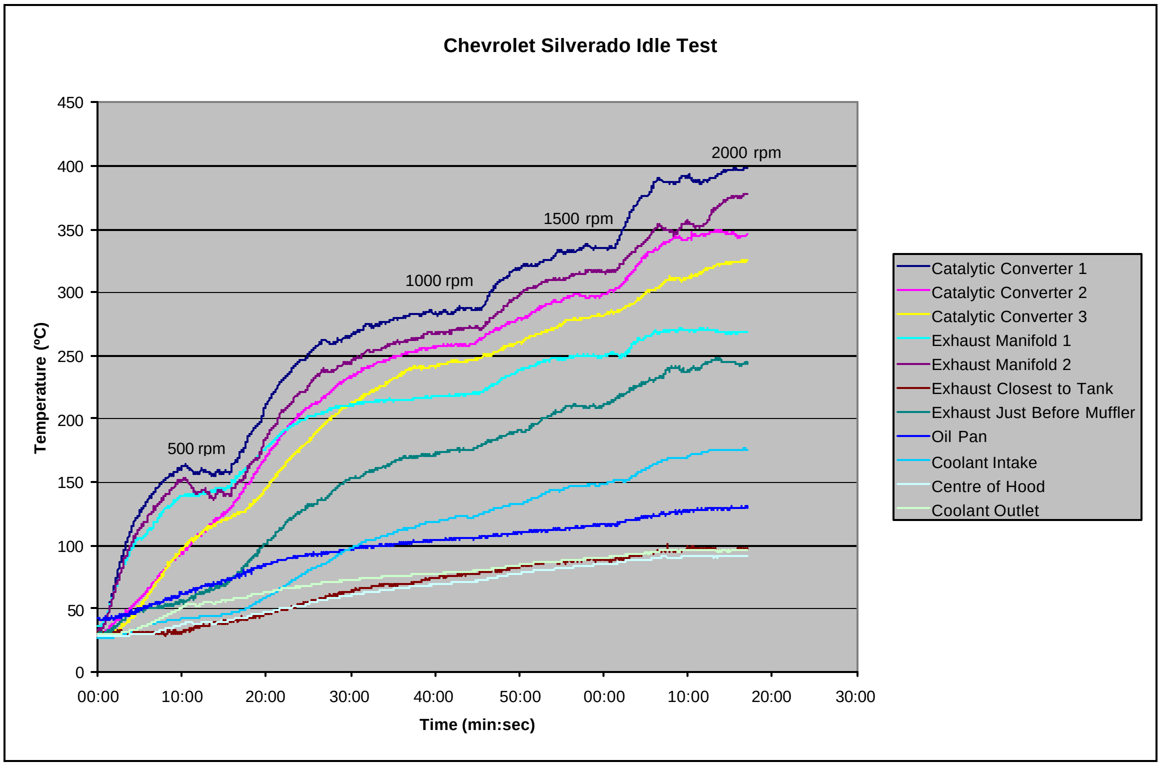


Figure 1: Temperature measurements on a stationary Chevrolet Silverado.

For both the level road and the hill tests the temperature increased after the vehicle was pulled to the side of the road and the engine turned off. While moving the convective cooling moderated the temperature especially with respect to the catalytic converter and the exhaust manifold. During level road driving a slight dip in the road would be identified with a decrease in temperature and a slight incline would result in an increase in temperature. Similar effects were seen to a greater degree when driving on hilly roads.

Examples of the temperature rise seen after the vehicles' ignition was turned off following the level road and the uphill driving are shown in Figure 2 and Figure 3. The data traces for all the tests are contained in Appendix A to Appendix D.

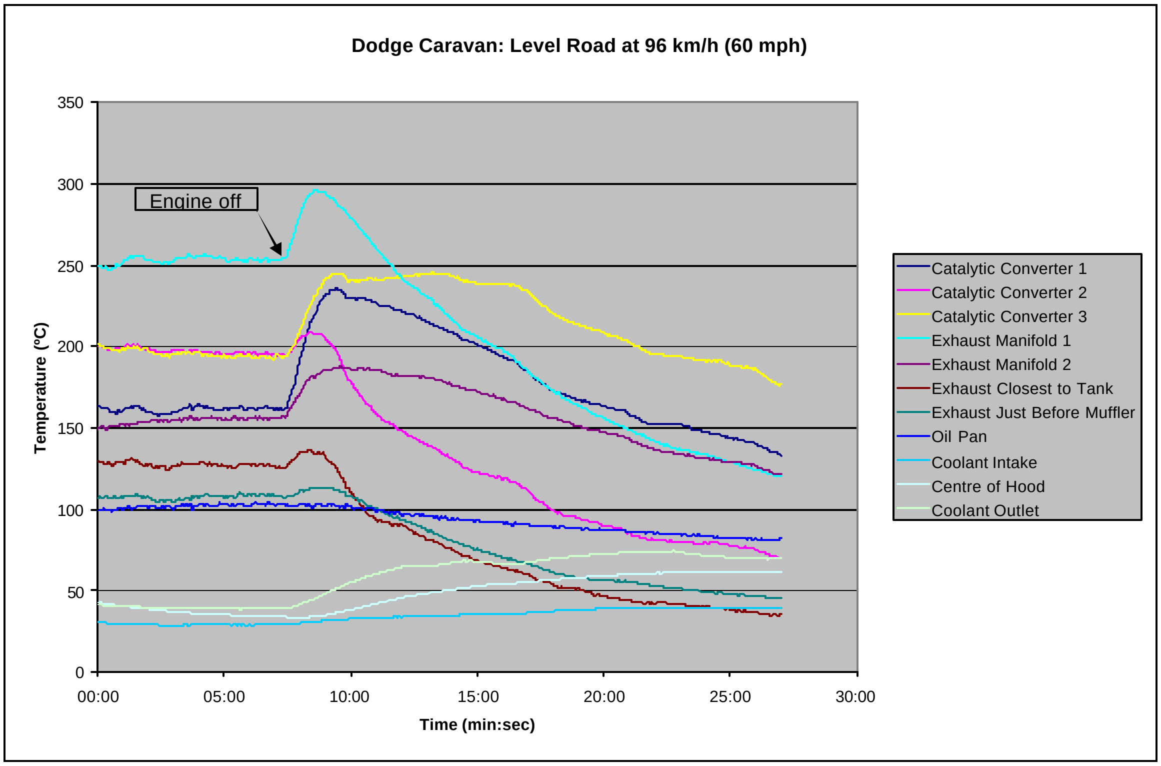


Figure 2: Example of the temperature rise subsequent to the vehicle ignition being turn off in a level road test at 96 km / h with the Dodge Caravan.

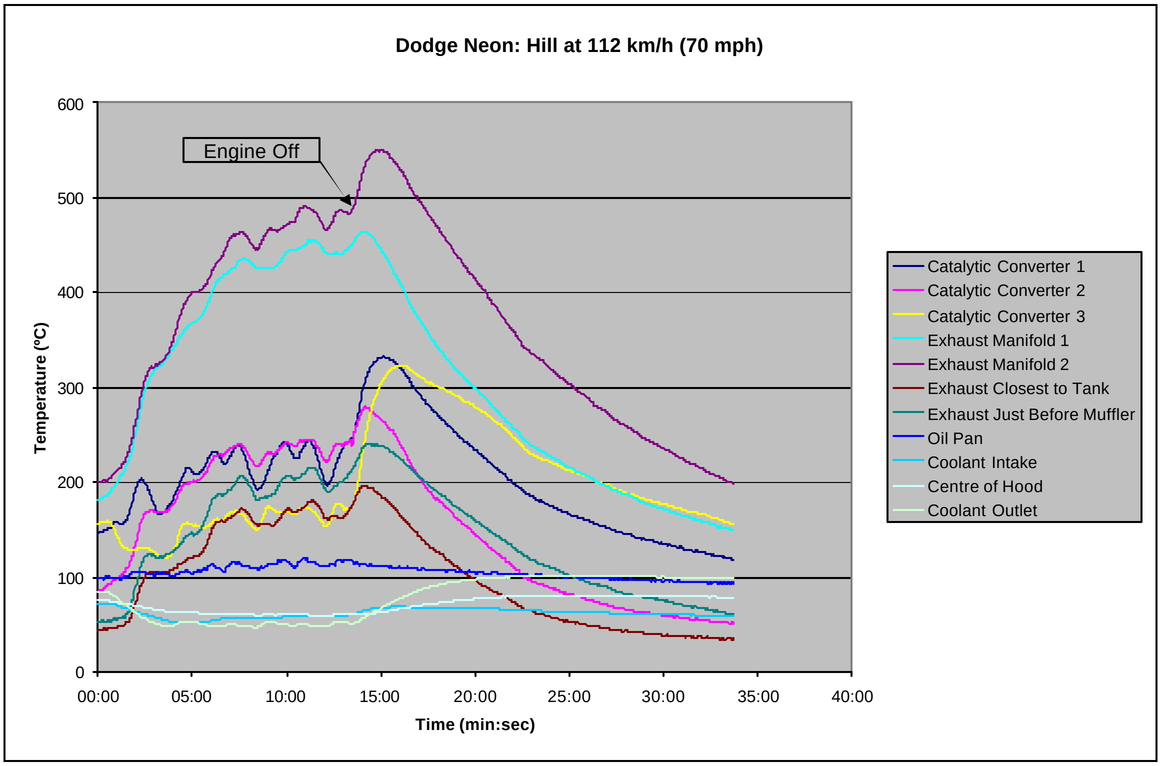


Figure 3: Example of the temperature rise subsequent to the vehicle ignition being turn off in a hill test at 112 km / h with the Dodge Neon.

It should be noted that the data traces from the level road measurements do not necessarily exhibit constant lead in temperature as seen in Figure 2. Best efforts were made to ensure several minutes of steady driving such that the engine temperatures had the opportunity to stabilize. However, road or traffic conditions could not be controlled and slight changes in either of these parameters influenced the temperatures observed. Nevertheless, the temperatures at which the ignitions were turned off were representative of the steady state temperatures observed by the testers prior to any influence caused the by road or traffic conditions.

The temperatures measured during the hill test with the Dodge Neon at 112 km / h, shown in Figure 3, represents the hottest temperatures measured from all the tests with the four vehicles.

In a scenario involving a vehicle crash, the risk of ignition of spilled fluids would depend on whether they came into contact with a hot surface. Surface temperatures which exceed the fluids auto ignition temperature would increase the likelihood of ignition. Testing performed by Santrock and Kononen [Ref. 1] determined the auto ignition temperatures for many engine compartment fluids other than gasoline. Samples of the fluids were poured onto a heated crucible and the probability of ignition at a given temperature was established. Table 4 below summarizes the lowest temperatures at which ignition was certain to occur for the various fluids tested.

Table 4: Summary of the lowest temperature at which auto ignition was certain to occur.

Fluid Type	**Auto Ignition Temperature [1] (°C)**
Unused Motor Oil	320 to 335
Used Motor Oil	315 to 335
Unused Synthetic Motor Oil	320 to 370
Used Synthetic Motor Oil	335 to 365
Brake Fluid	280 to 340
Power Steering Fluid	325 to 345
Automatic Transmission Fluid	315 to 320
Antifreeze and Engine Coolant	550 to 675
Gasoline[2]	260 to 280

Notes: 1- The temperature range indicated the upper and lower auto ignition temperatures for the various brands and compositions of fluids tested.

2- The auto ignition temperatures for gasoline were not reported in Santrock and Kononen's report. The values presented here were obtained from: "Ignition Temperature of Gasoline" at http://hypertextbook.com/facts/2003/ShaniChristopher.shtml

The temperatures indicated in Table 4 were the lowest temperatures measured and were dependent on the test methodology. If the fluids were poured onto a cast iron hemisphere instead of a crucible, the minimum temperatures required for auto ignition increased by a minimum of 30ºC. Increases in minimum auto ignition temperatures were also observed if airflow was present over the test apparatus. For the purposes of this report the lowest auto ignition temperatures will be referenced as they represent the worst case.

The peak under hood temperatures from the hottest vehicle components are summarized in Table 5 to Table 7. The exhaust manifold, exhaust and muffler pipes, and the catalytic converter registered the hottest temperatures and only their peaks values are presented in the tables as the other measured temperatures were insufficient to promote auto ignition of the vehicle fluids. The cells containing temperatures that exceed the lowest auto ignition temperature for the fluids listed in Table 4 are shaded.

Table 5: Summary of measured temperatures from the hottest vehicle components during the stationary engine idle tests.

Vehicle	Idle Speed (rpm)	Temperatures (ºC)						
		Catalytic 1	Catalytic 2	Catalytic 3	Manifold 1	Manifold 2	Exhaust at Tank	Exhaust Before Muffler
Ford Focus	800	93	115	143	91	88	92	71
	1600	164	204	237	174	148	123	115
	2400	183	211	270	182	185	151	159
	3200	215	266	351	197	249	200	208
Dodge Caravan	750	203	138	198	243	140	97	65
	1500	260	221	275	276	203	140	111
	2250	295	301	339	298	231	209	167
	3000	316	315	343	306	248	267	228
Dodge Neon	750	177	95	143	216	232	43	47
	1500	270	164	250	313	355	91	84
	2250	340	250	346	404	459	133	146
	3000	343	274	387	417	487	162	184
Chevrolet Silverado	500	163	131	124	144	142	54	31
	1000	287	257	247	219	272	176	78
	1500	335	297	285	250	316	210	90
	2000	397	348	325	271	376	248	97

Note: Cells that exceed the lowest auto ignition temperature of under hood fluids other than gasoline are shaded.

Table 6: Summary of measured temperatures from the hottest vehicle components during the level road driving tests.

Vehicle	Vehicle Speed (km/h)	Vehicle Speed (mph)	Temperatures (ºC) Catalytic 1	Catalytic 2	Catalytic 3	Manifold 1	Manifold 2	Exhaust at Tank	Exhaust Before Muffler
Ford Focus	48	30	155	171	214	149	122	118	107
	64	40	170	195	240	162	145	134	118
	80	50	185	187	265	182	162	151	128
	96	60	193	201	285	209	152	141	131
	112	70	230	240	339	239	176	158	156
Dodge Caravan	48	30	196	161	202	251	154	107	75
	64	40	216	189	232	295	180	120	88
	80	50	213	177	228	266	170	112	82
	96	60	235	208	245	296	187	136	113
	112	70	269	243	282	328	209	162	143
Dodge Neon	48	30	222	176	220	340	374	106	115
	64	40	202	176	198	337	369	98	113
	80	50	194	156	203	337	369	85	100
	96	60	217	197	231	376	421	115	144
	112	70	230	185	213	391	440	109	132
Chevrolet Silverado	48	30	234	172	200	159	219	63	111
	64	40	236	199	209	151	231	55	124
	80	50	240	208	213	156	233	58	133
	96	60	262	223	227	161	254	53	155
	112	70	286	244	235	169	283	55	174

Note: Cells that exceed the lowest auto ignition temperature of under hood fluids are shaded.

Table 7: Summary of measured temperatures from the hottest vehicle components during the uphill driving tests.

Vehicle	Vehicle Speed		Temperatures (ºC)						
	(km/h)	(mph)	Catalytic 1	Catalytic 2	Catalytic 3	Manifold 1	Manifold 2	Exhaust at Tank	Exhaust Before Muffler
Ford Focus	64	40	220	256	306	223	207	168	172
	80	50	237	282	348	269	224	177	187
	96	60	246	288	363	278	231	185	200
	112	70	258	306	387	295	264	208	230
Dodge Caravan	64	40	310	283	317	374	219	199	170
	80	50	313	291	318	340	221	210	190
	96	60	330	289	310	354	234	210	204
	112	70	328	293	319	367	241	215	214
Dodge Neon	64	40	308	259	312	409	496	143	195
	80	50	308	254	300	429	511	165	201
	96	60	328	268	319	454	540	186	226
	112	70	332	279	323	465	550	197	240
Chevrolet Silverado	64	40	334	270	278	183	306	63	206
	80	50	354	296	291	194	330	63	229
	96	60	373	311	298	203	351	61	256
	112	70	390	315	302	210	366	66	273

Note: Cells that exceed the lowest auto ignition temperature of under hood fluids are shaded.

Referring to Table 4, none of the vehicles, when idling, exhibited temperatures that exceeded the threshold levels reported by Santrock and Kononen. Only at elevated idle speeds did the component temperatures begin to exceed the temperatures necessary to ignite some of the fluids.

Depending on their speed during the level road tests (see Table 5), each vehicle exceeded the minimum temperatures required for the auto ignition of engine compartment fluids. The temperatures at a given measurement location typically increased with an increase in speed. However, the effects of convective cooling moderated the increases in temperatures and in some cases caused a drop in temperature.

The additional load imposed by driving uphill significantly raised the measured temperatures as is evident by the larger incident of critical temperatures being reached (see shaded cells in Table 6). Under these conditions the Dodge Neon exhibited the highest under hood temperatures, the maximum of which reached the temperature range required for the auto ignition of antifreeze and engine coolant. The highest temperatures reached during the driving tests for each of the vehicles was achieved during the uphill tests at 112 km/h and are listed in Table 8.

Table 8: Maximum temperature recorded on each of the vehicles during the uphill driving tests.

Vehicle	**Maximum Recorded Temperature (°C)**
Ford Focus	387
Dodge Caravan	367
Dodge Neon	550
Chevrolet Silverado	390

Based on the limited samples of vehicles there does not appear to be any correlation between the power to weight ratio and the vehicles temperatures.

It is worth repeating here that the peak temperatures during the level road and uphill tests were measured after the vehicles had stopped moving and their engines turned off. With the vehicle stopped, the rate at which the heat generated by the engine could be removed, without the benefits of forced convection, drastically decreased thereby resulting in increases in surface temperatures. The maximum temperatures measured occurred roughly between 1 and 2 minutes after the engine was stopped and was followed by gradual cooling. Between 3 and 12 additional minutes were required for the hottest temperature to decrease below the lowest auto ignition temperature of 260 ºC indicated in Table 4. This suggests that even after a crash with the vehicle's engine turned off the conditions necessary for auto ignition of engine compartment fluids may persist for sometime.

6. Summary and Recommendations

When exposed to sufficiently elevated temperatures vehicle engine compartment fluids such as engine oil, transmission oil, brake fluid, coolant, power steering and gasoline are susceptible to auto ignition. The temperature at 11 under hood locations was measured at several driving speeds for level road and uphill driving conditions and compared to fluid auto ignition temperatures. Four vehicles representing various vehicles classes were tested, each of which was ballasted to its rated capacity to maximize the loading on the engine.

Upon reaching a stabilized temperature under the specific driving condition, the temperature measurements were continued with the vehicles pulled off to the side of the road and the engine turned off. This simulated a collision in which the vehicle may come to a sudden halt. For both the level road and the hill tests the measured temperatures initially increased with the maximum temperatures being reached approximately 1 to 2 min after the vehicle was completely stopped and the engine turned off.

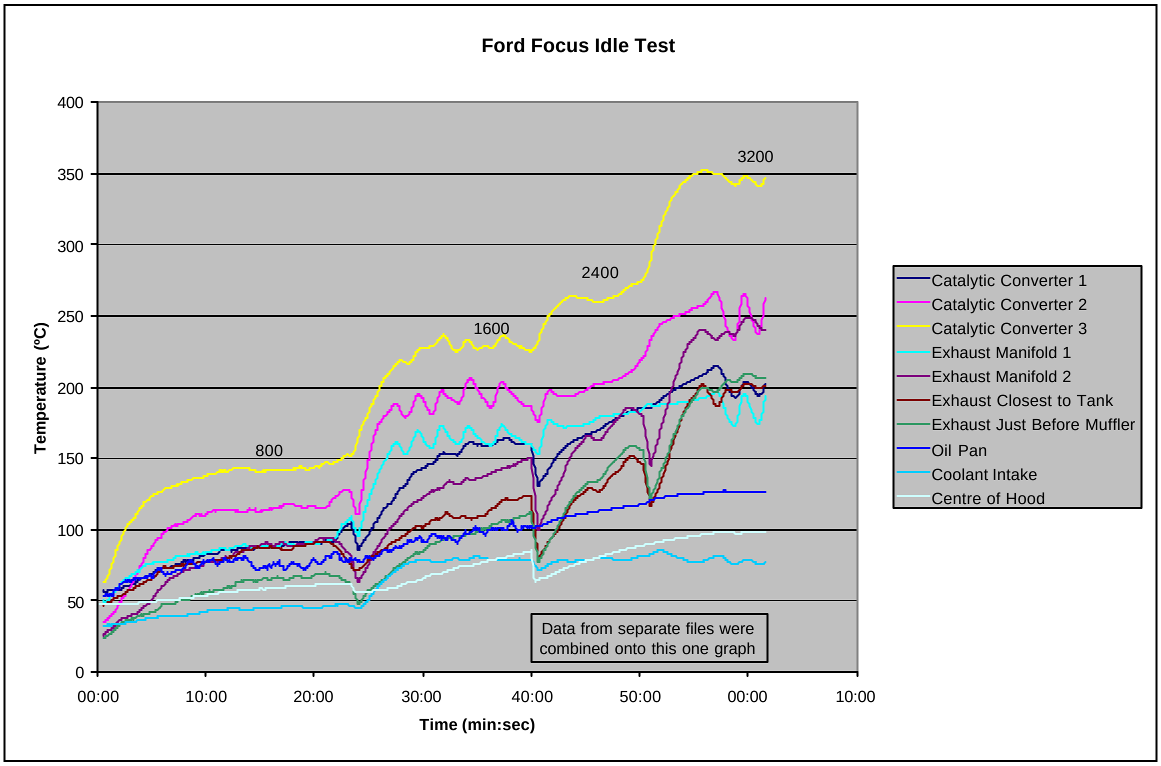
While moving the convective cooling moderated the temperature especially with respect to the catalytic converter and the exhaust manifold which were the hottest components on each of the vehicles.

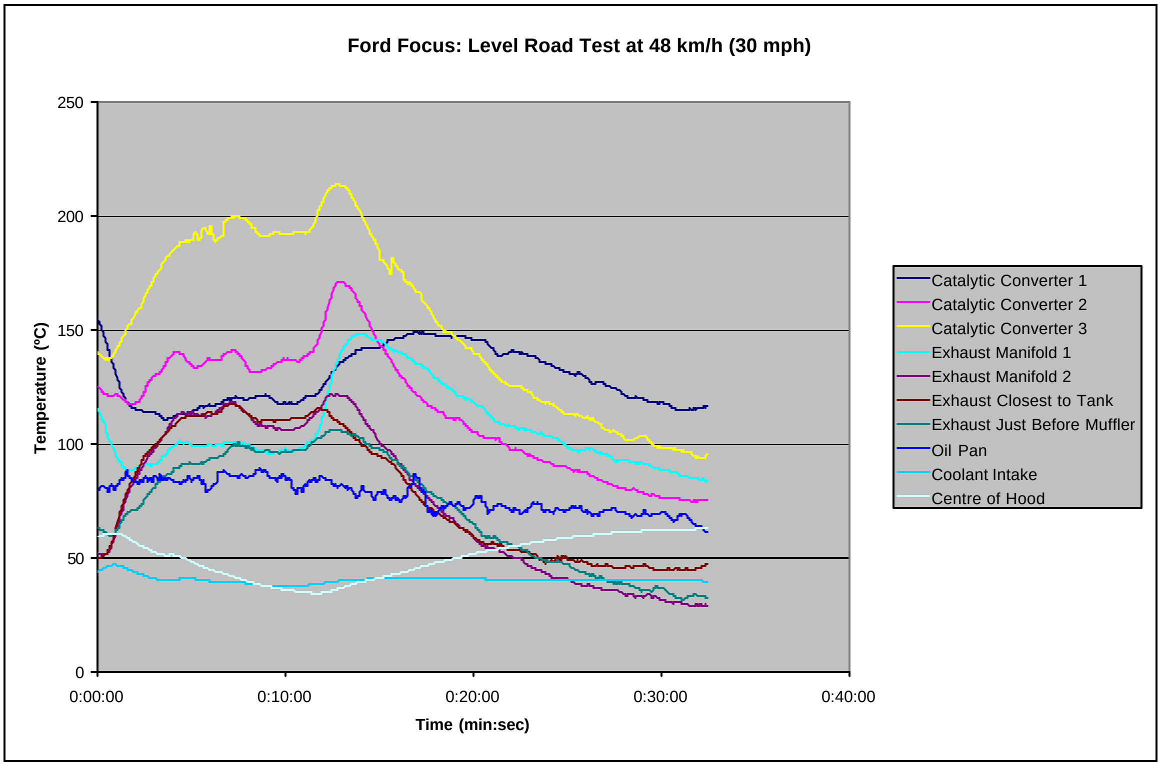
Under both driving conditions, elevated temperatures were recorded sufficient to cause auto ignition of most of the engine compartment fluids. The hottest temperature was recorded on the Dodge Neon with the engine turned off immediately following an uphill climb. This temperature was sufficient for auto ignition of all under hood fluids including the coolant or anti freeze which exhibits the highest auto ignition temperature. In all cases, an additional 3 to 12 minutes following the peak temperature was required for the hottest temperature to decrease below the lowest auto ignition temperature. Therefore, following a crash and even though the vehicles may no longer be running, the conditions necessary for auto ignition of engine compartment fluids may persist for sometime.

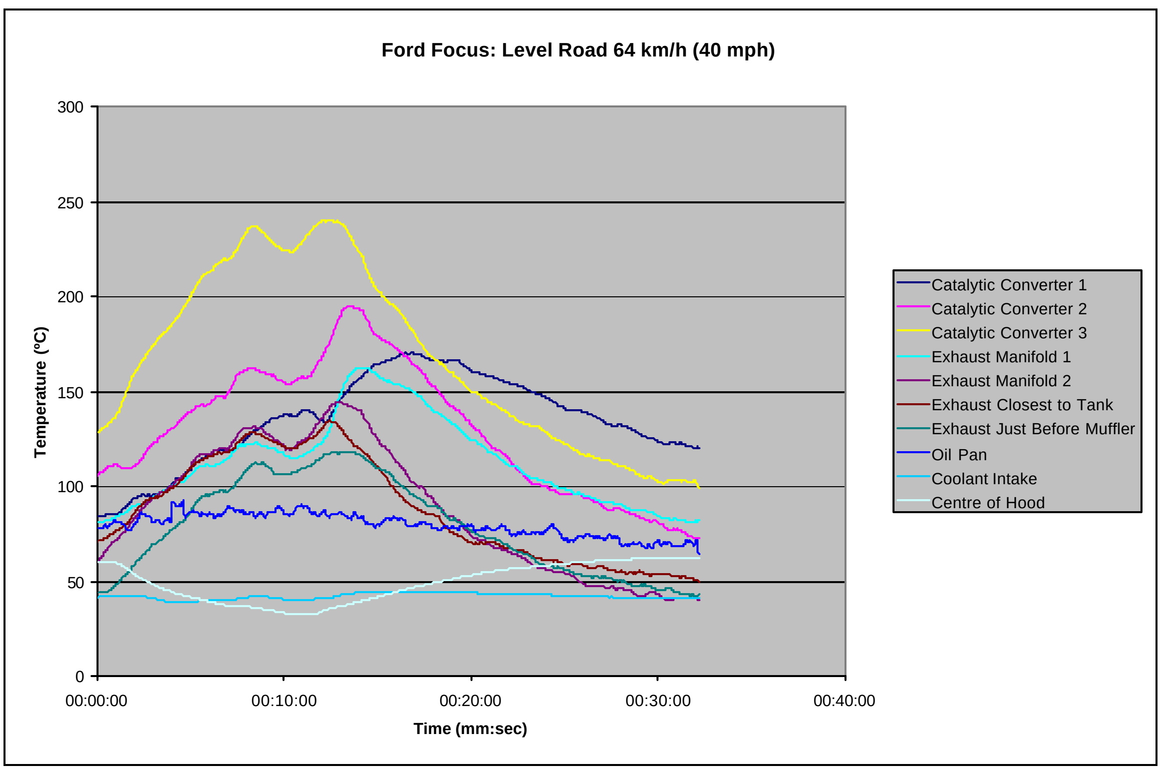
7. References

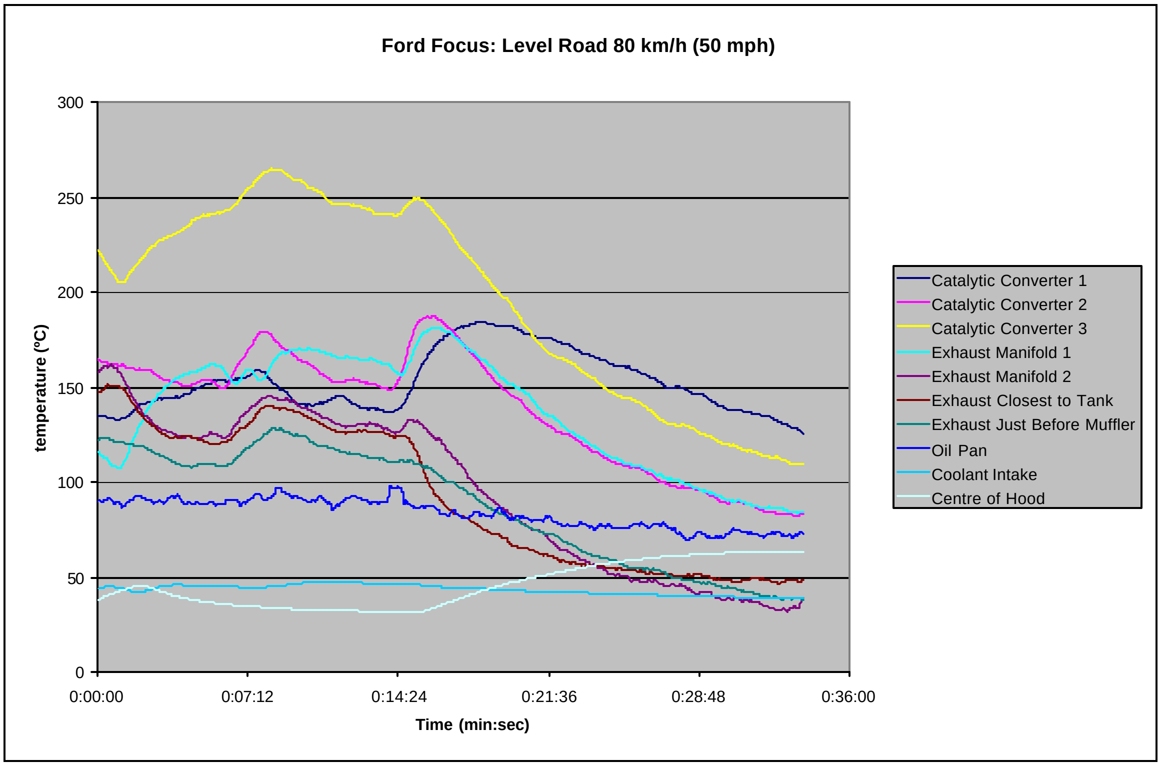
Ref. 1 Santrock, J., Kononen, D. W.,"Project B.10 – Study of Flammability of Materials: Flammability Properties of Engine Compartment Fluids Other than Gasoline; Auto Ignition Characteristics of Non-Gasoline Motor Vehicle Fluids on Heated Surfaces", National Highway Traffic Safety Administration Docket No. NHTSA-98-3588-193.

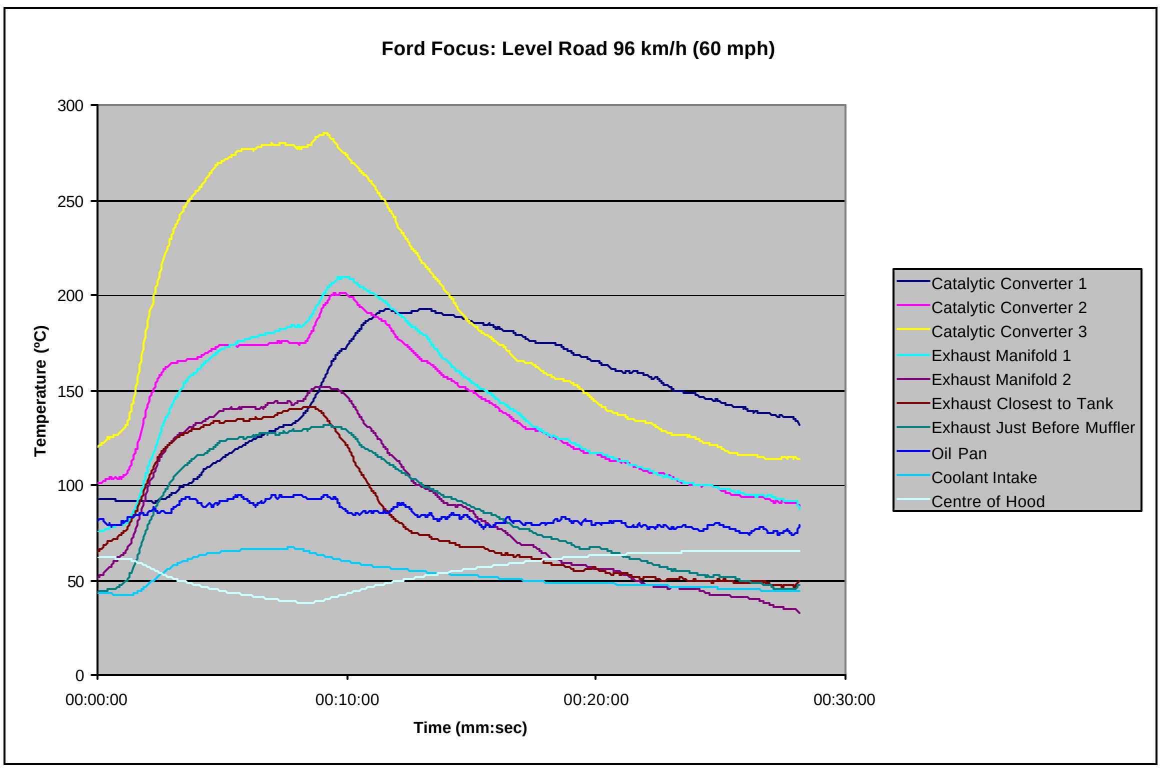
Appendix A : Data Traces – Ford Focus

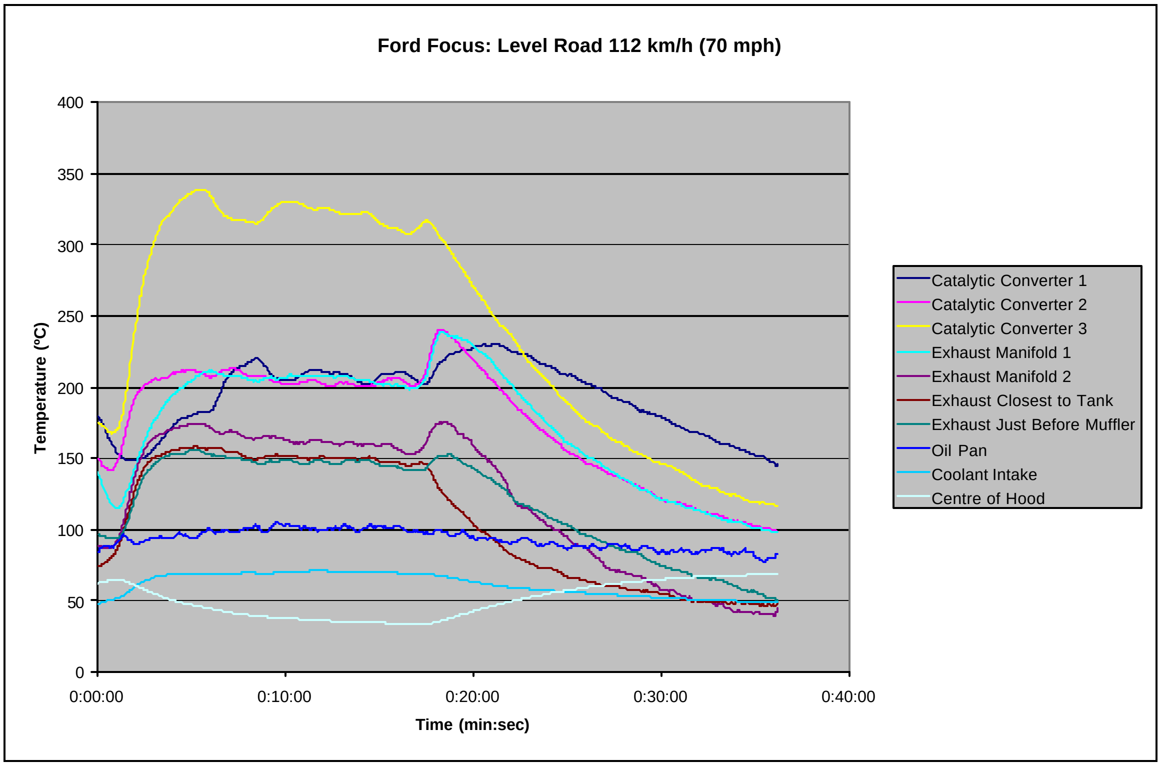


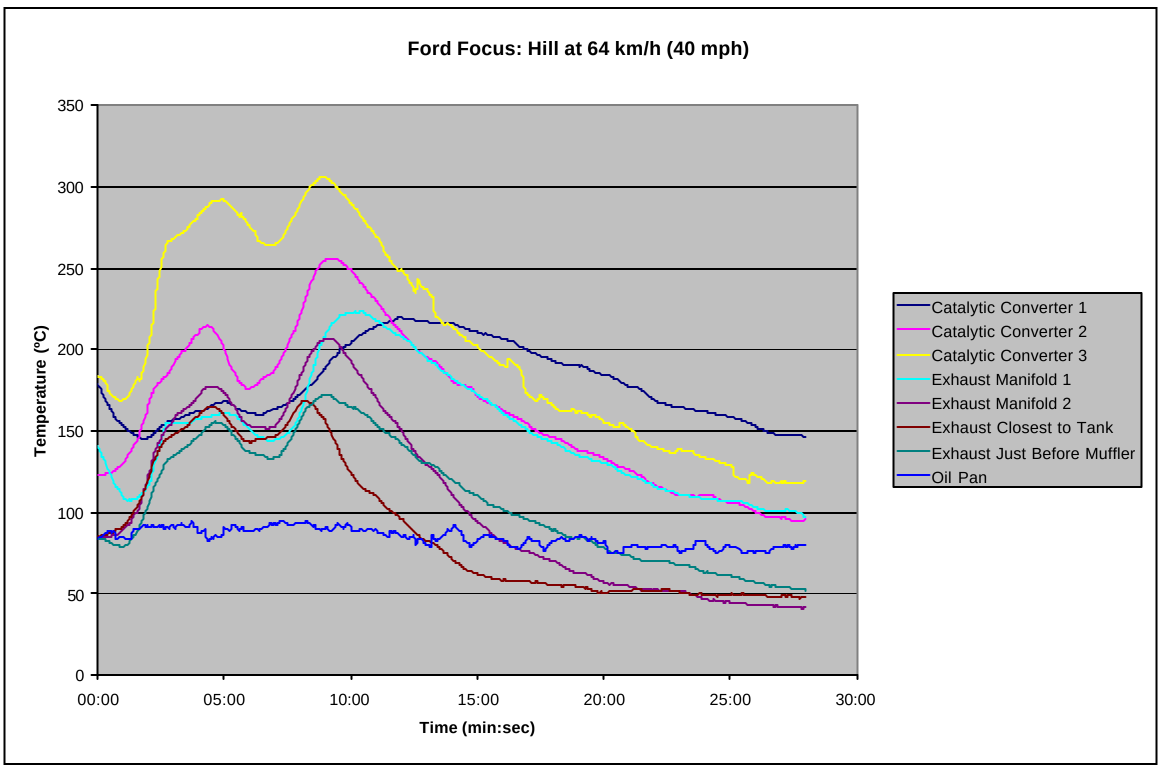

Ford Focus: Level Road Test at 48 km/h (30 mph)
Temperature (ºC)
250
200
150
100
50
0
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood

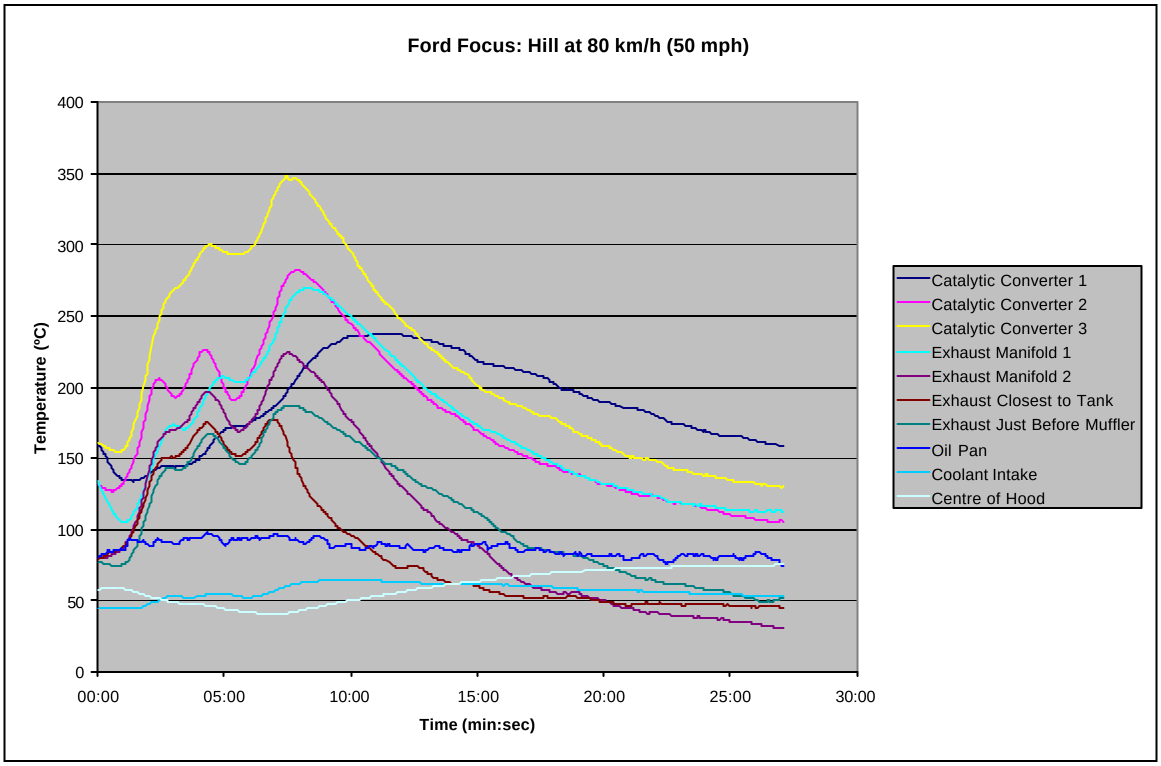

Ford Focus: Level Road 64 km/h (40 mph)
Temperature (ºC)
300
250
200
150
100
50
0
00:00:00
00:10:00
00:20:00
00:30:00
00:40:00
Time (mm:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood


Ford Focus: Level Road 80 km/h (50 mph)
300
250
200
150
100
50
0
temperature (ºC)
0:00:00
0:07:12
0:14:24
0:21:36
0:28:48
0:36:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood


Ford Focus: Level Road 96 km/h (60 mph)
300
250
200
150
100
50
0
Temperature (ºC)
00:00:00
00:10:00
00:20:00
00:30:00
Time (mm:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood


Ford Focus: Level Road 112 km/h (70 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood


Ford Focus: Hill at 64 km/h (40 mph)
Temperature (ºC)
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan


Ford Focus: Hill at 80 km/h (50 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
400
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
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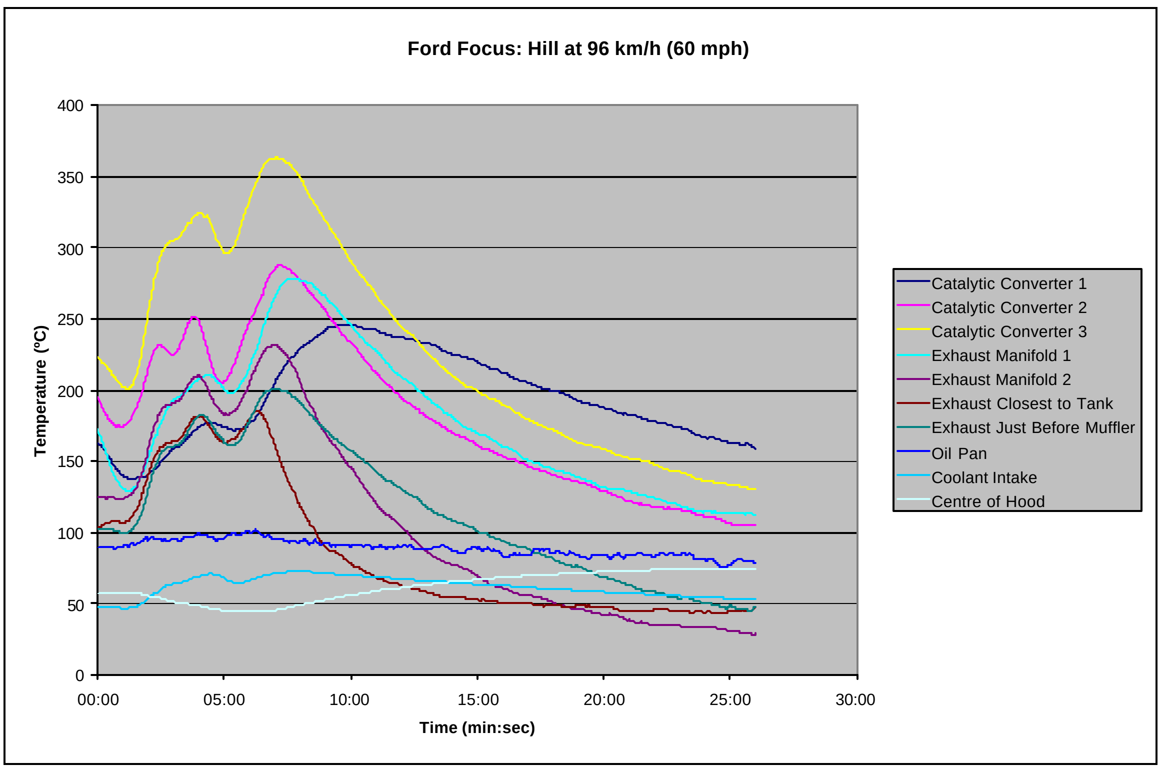
Ford Focus: Hill at 96 km/h (60 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
400
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
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Exhaust Closest to Tank
Exhaust Just Before Muffler
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Coolant Intake
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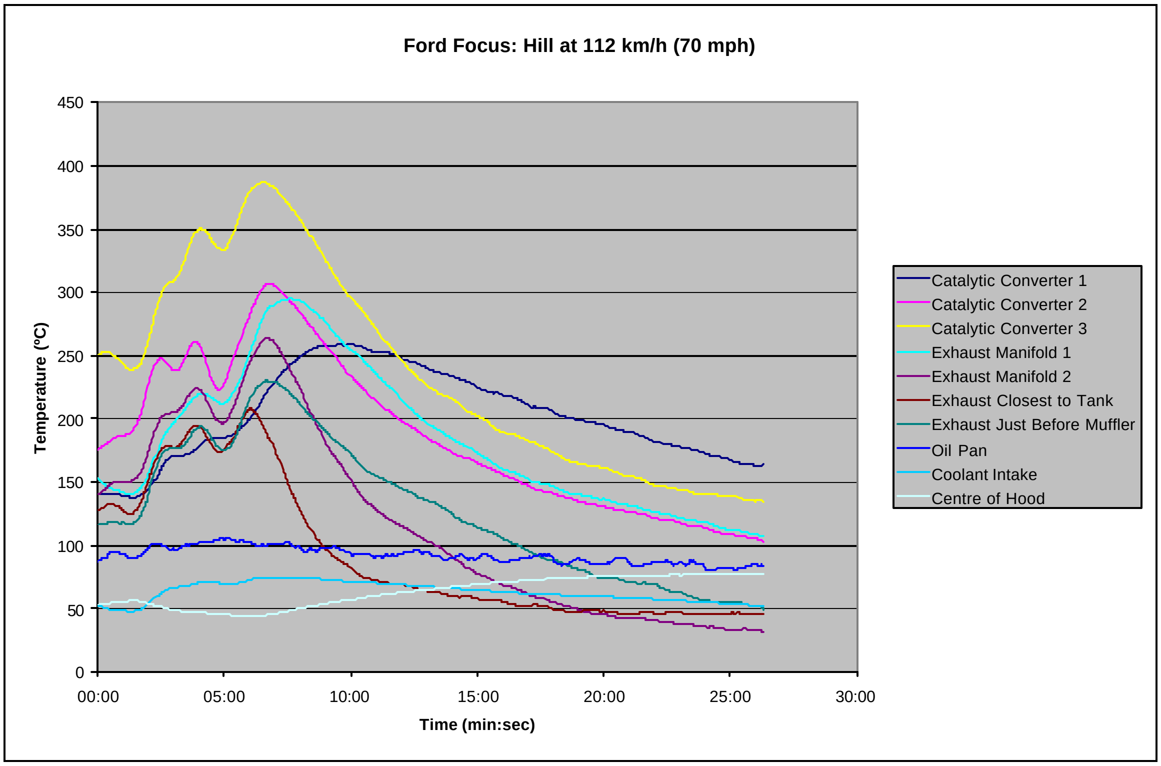
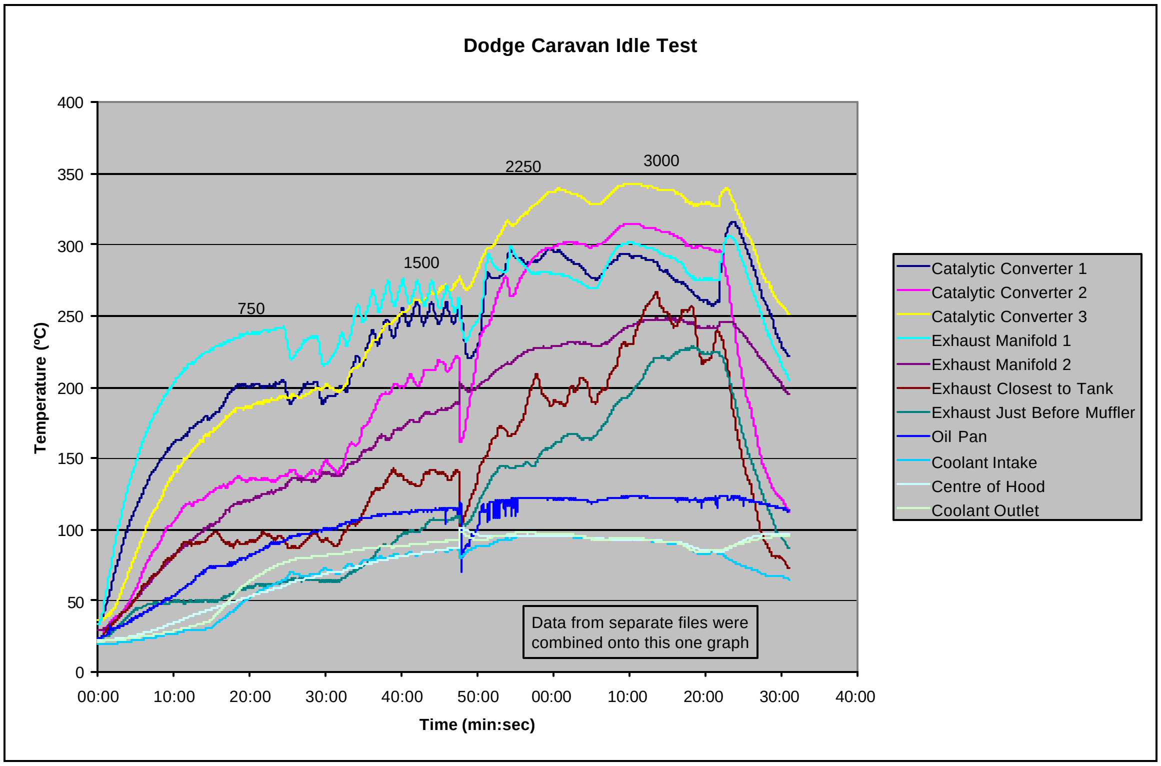
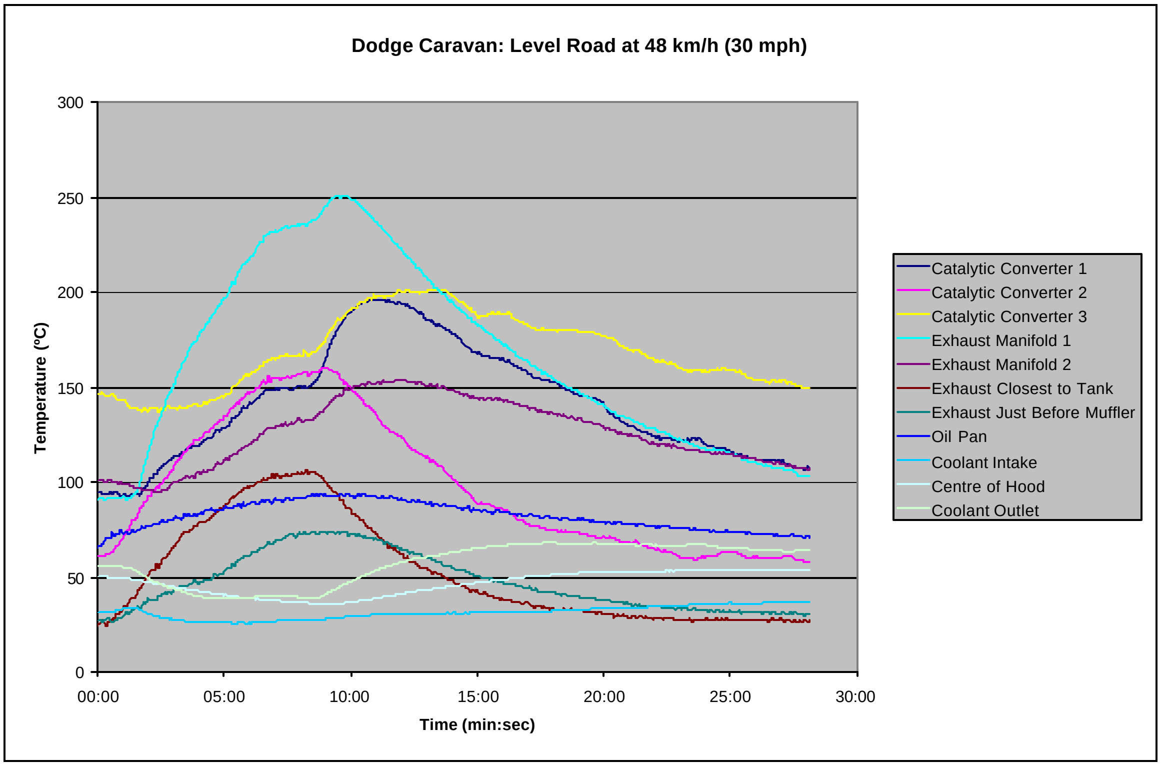
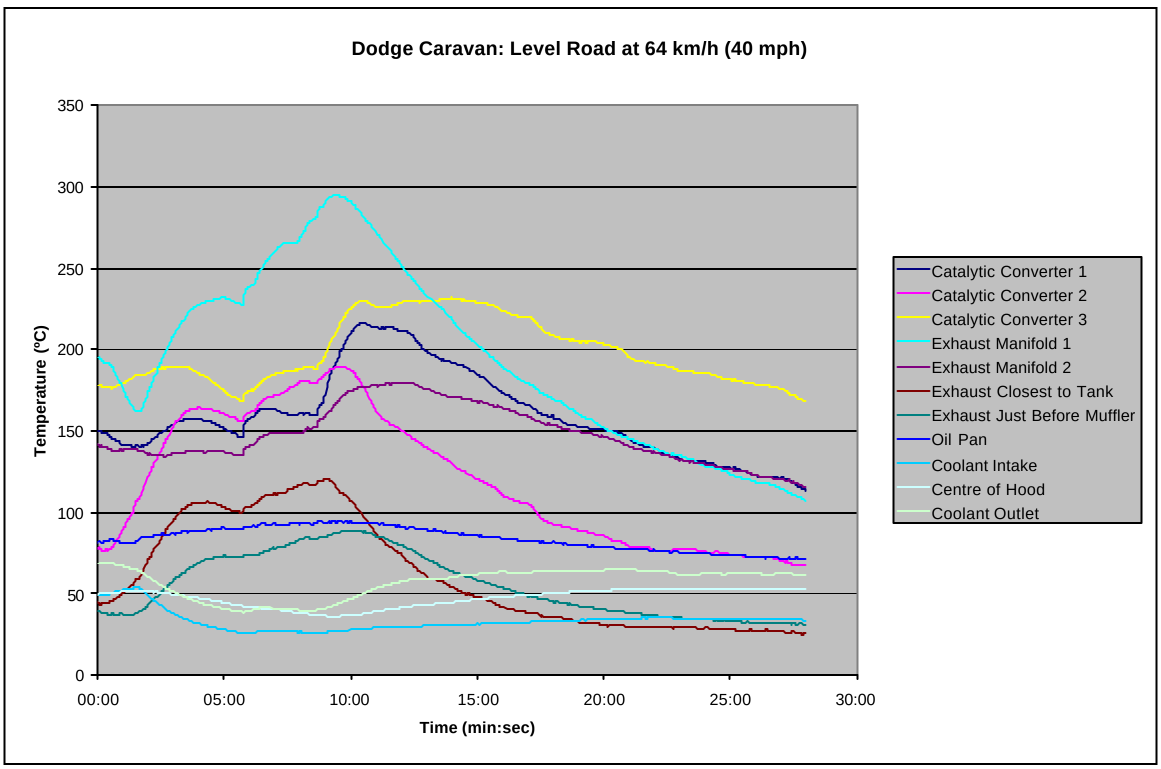


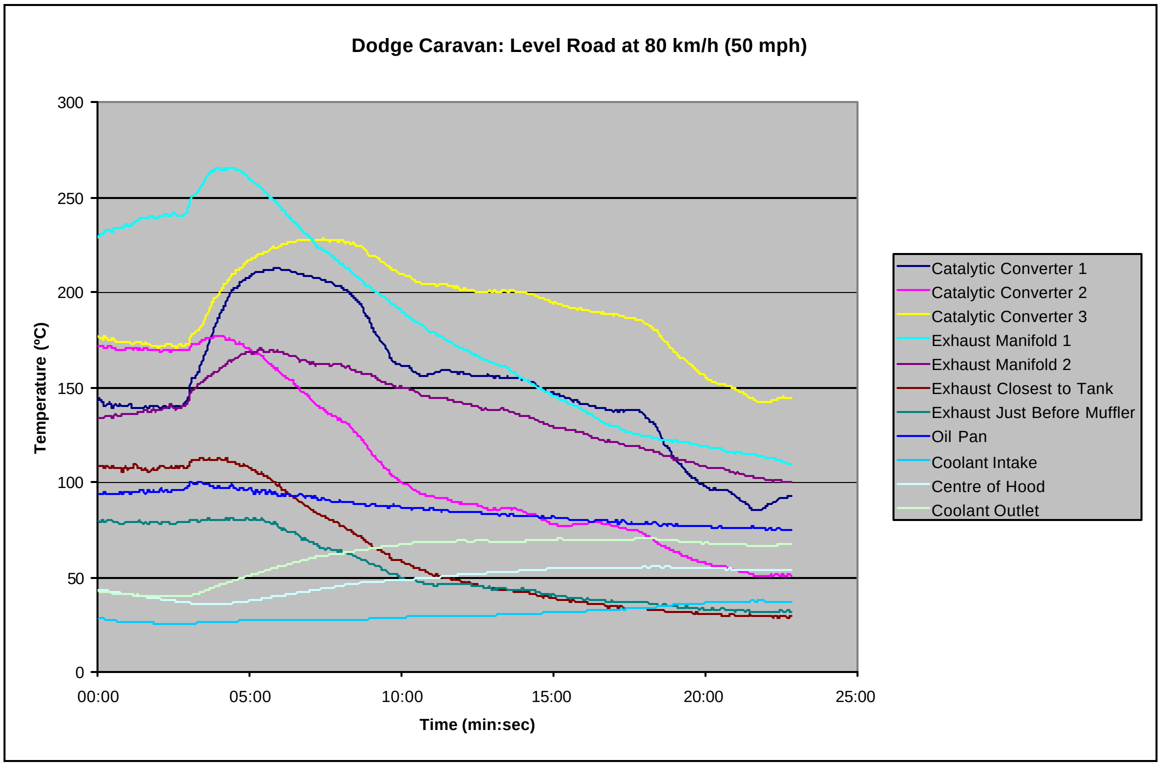
Ford Focus: Hill at 112 km/h (70 mph)
Temperature (ºC)
450
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood

Appendix B : Data Traces – Dodge Caravan

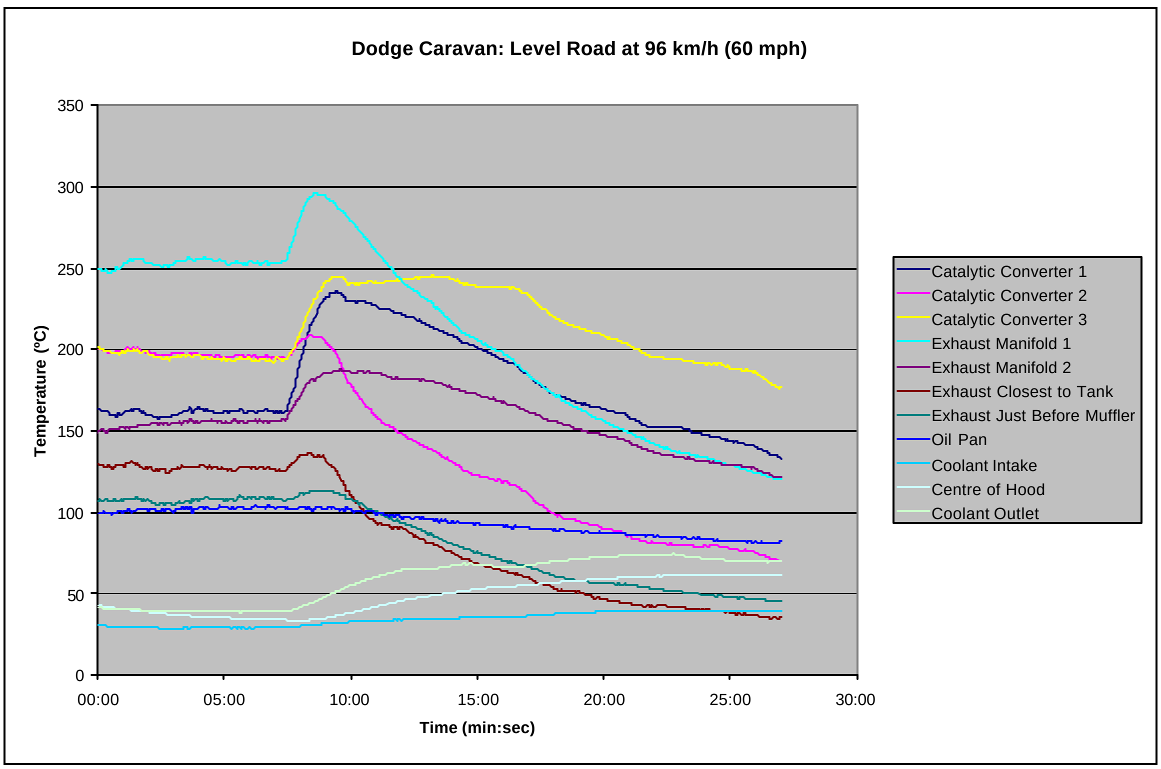



Dodge Caravan: Level Road at 48 km/h (30 mph)
Temperature (ºC)
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

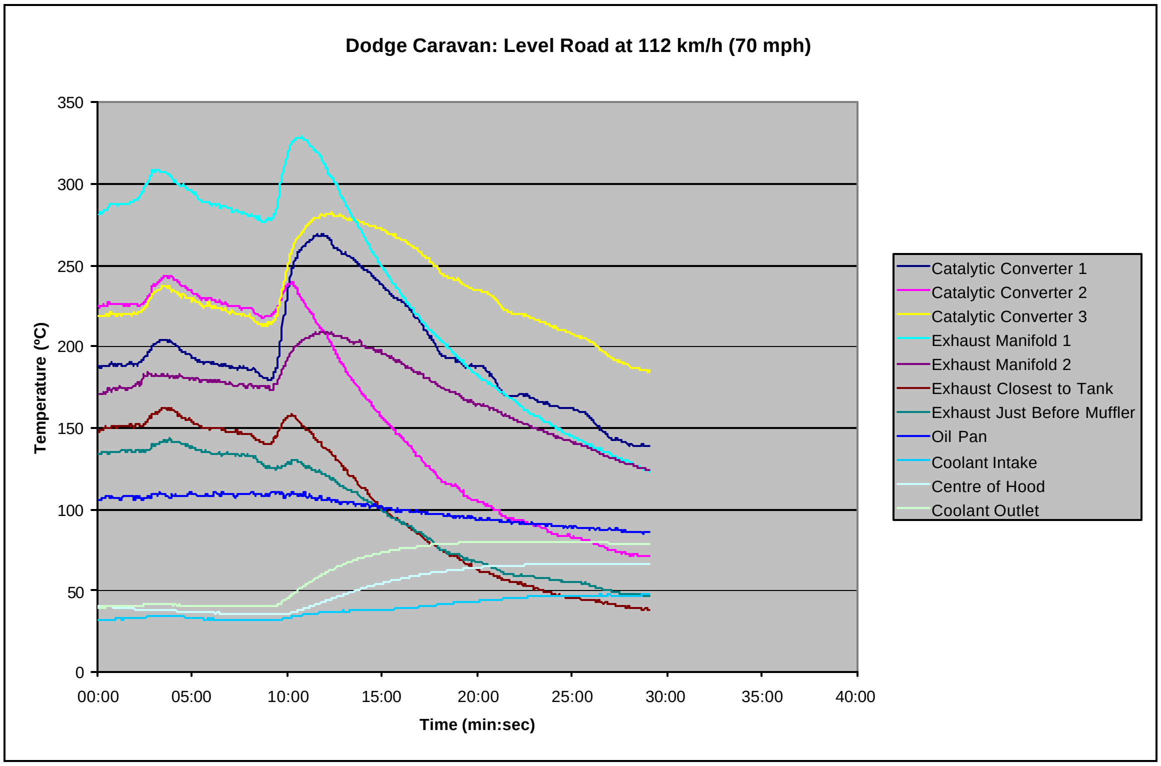

Dodge Caravan: Level Road at 64 km/h (40 mph)
Temperature (ºC)
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

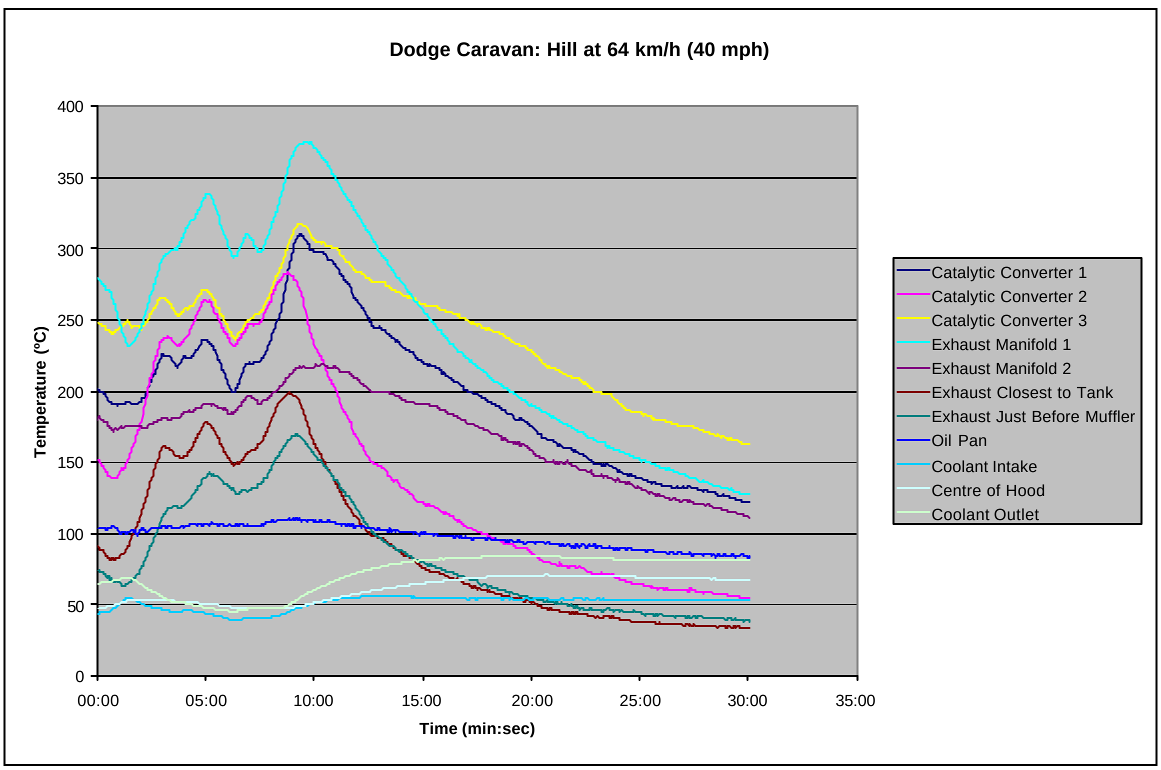


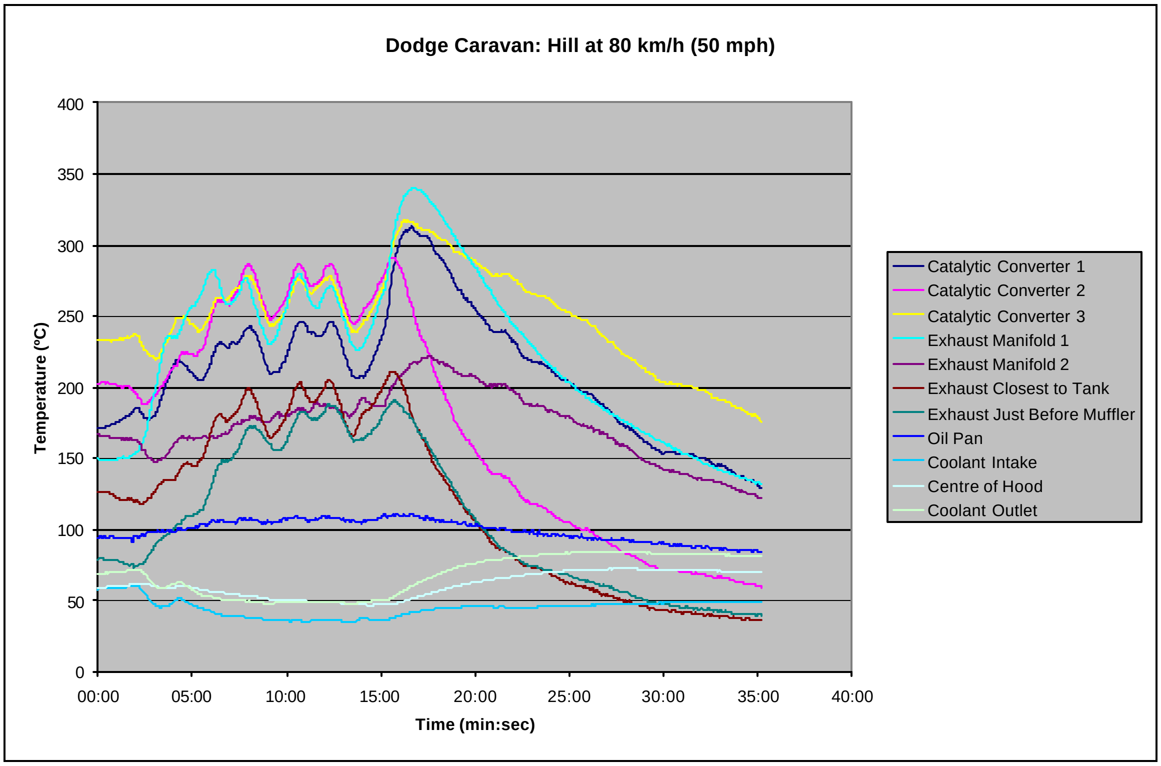
Dodge Caravan: Level Road at 80 km/h (50 mph)
Temperature (ºC)
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet



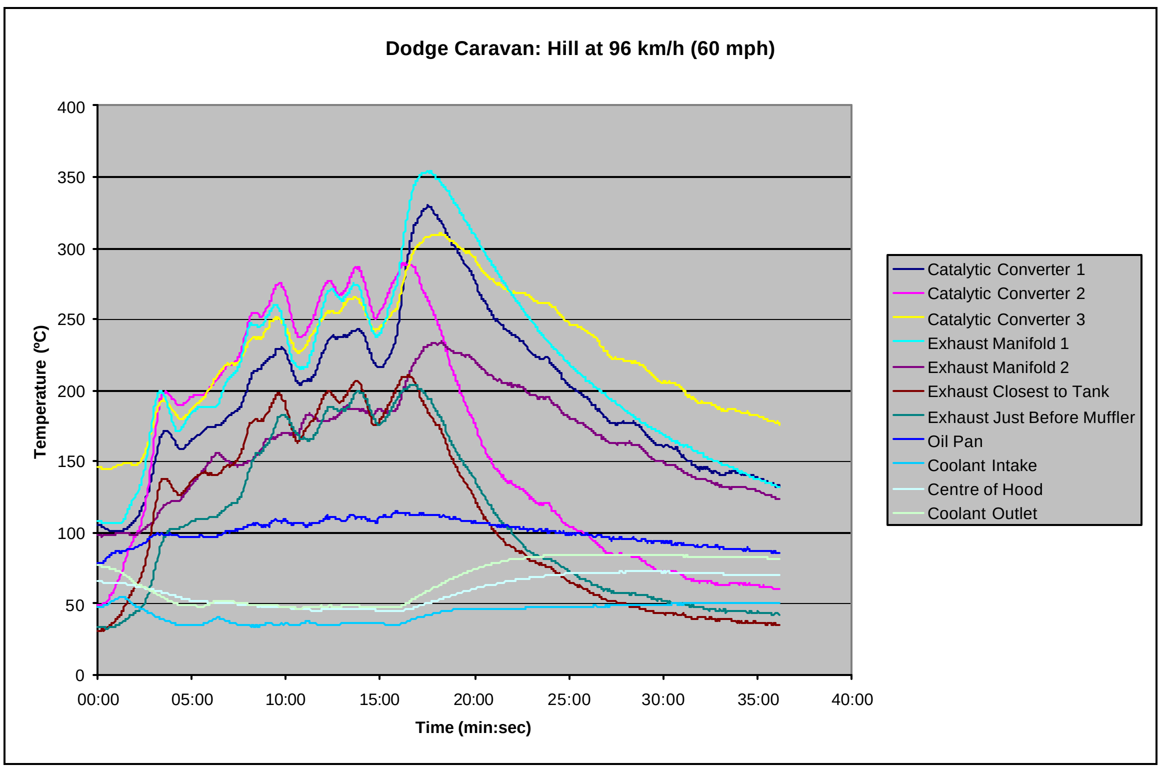
Dodge Caravan: Level Road at 96 km/h (60 mph)
Temperature (ºC)
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Dodge Caravan: Level Road at 112 km/h (70 mph)
Temperature (°C)
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

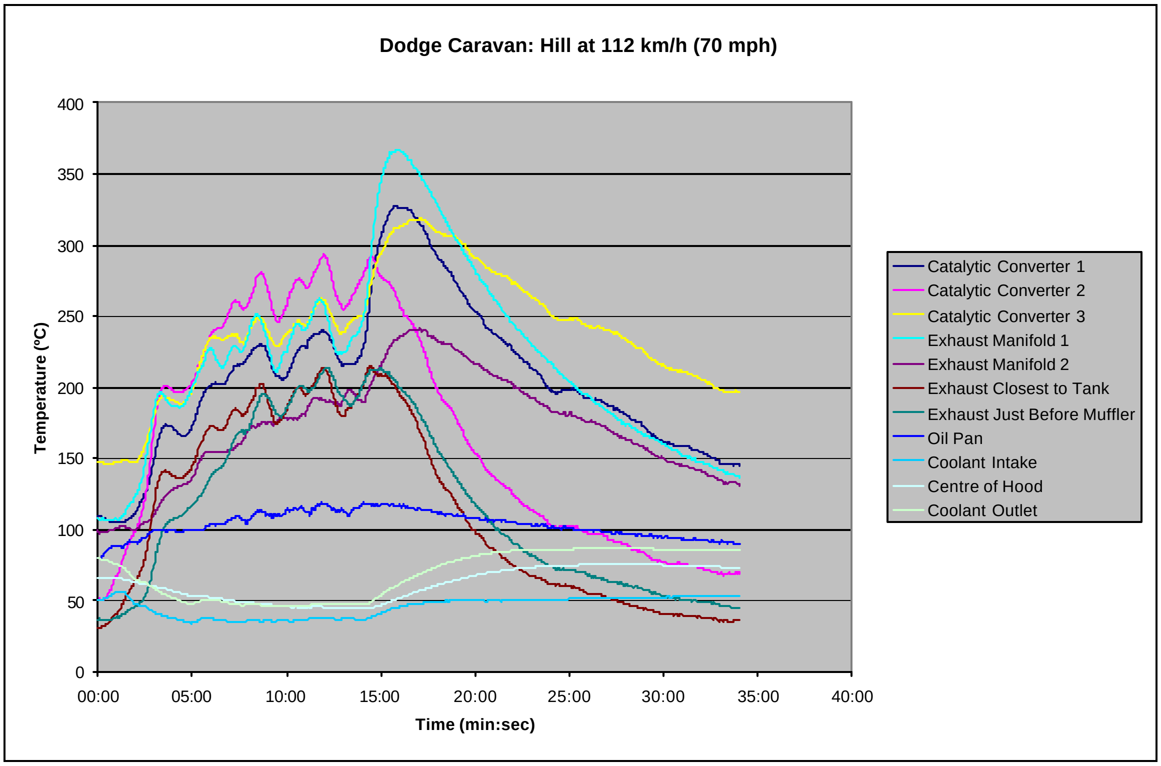

Dodge Caravan: Hill at 64 km/h (40 mph)
Temperature (°C)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet



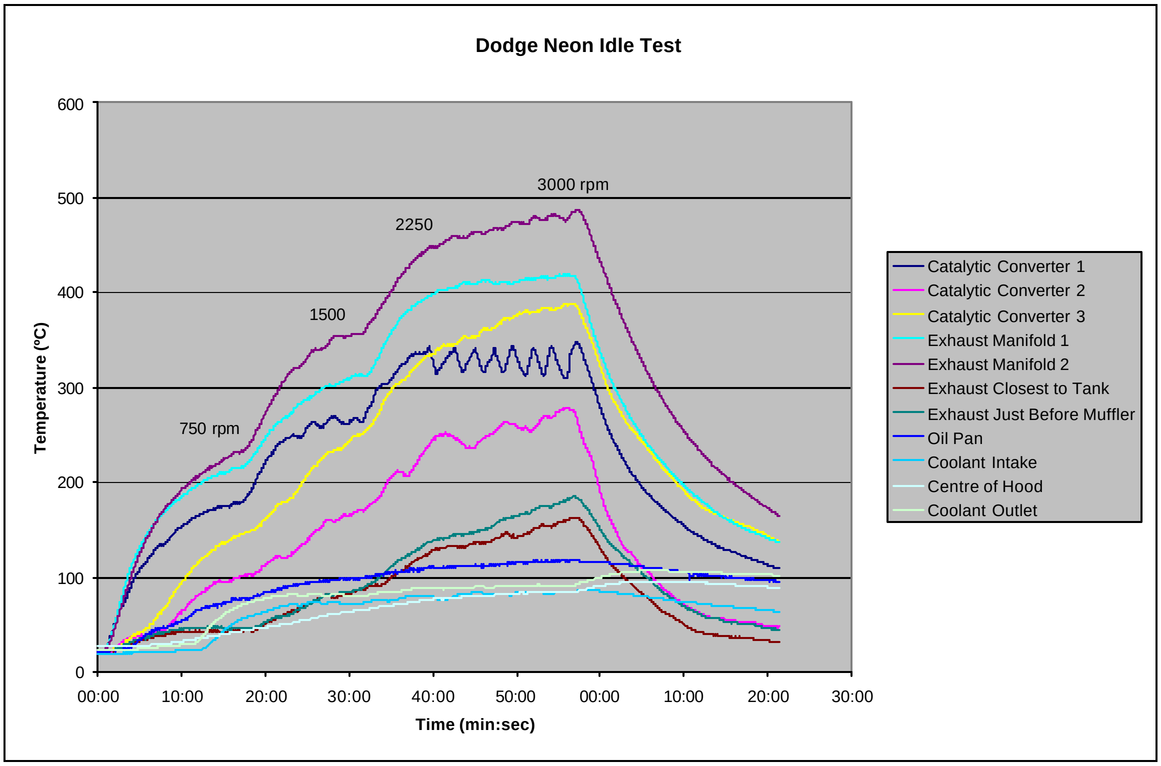
Dodge Caravan: Hill at 80 km/h (50 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

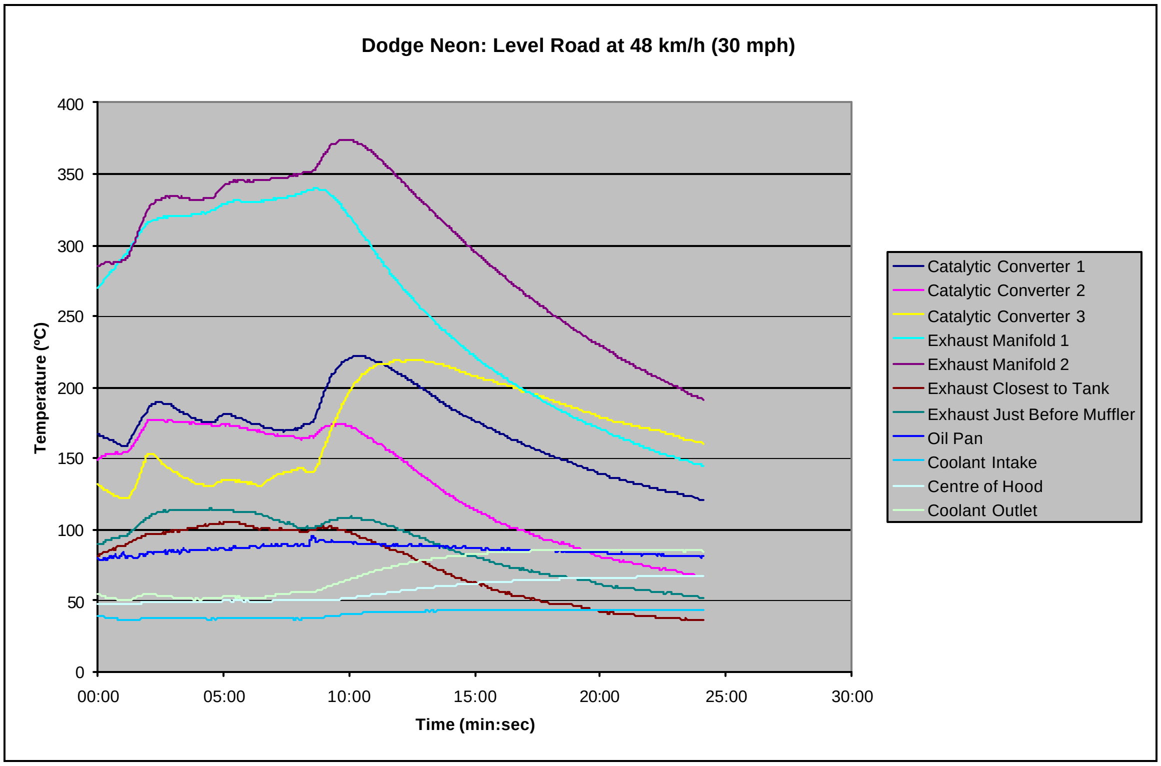


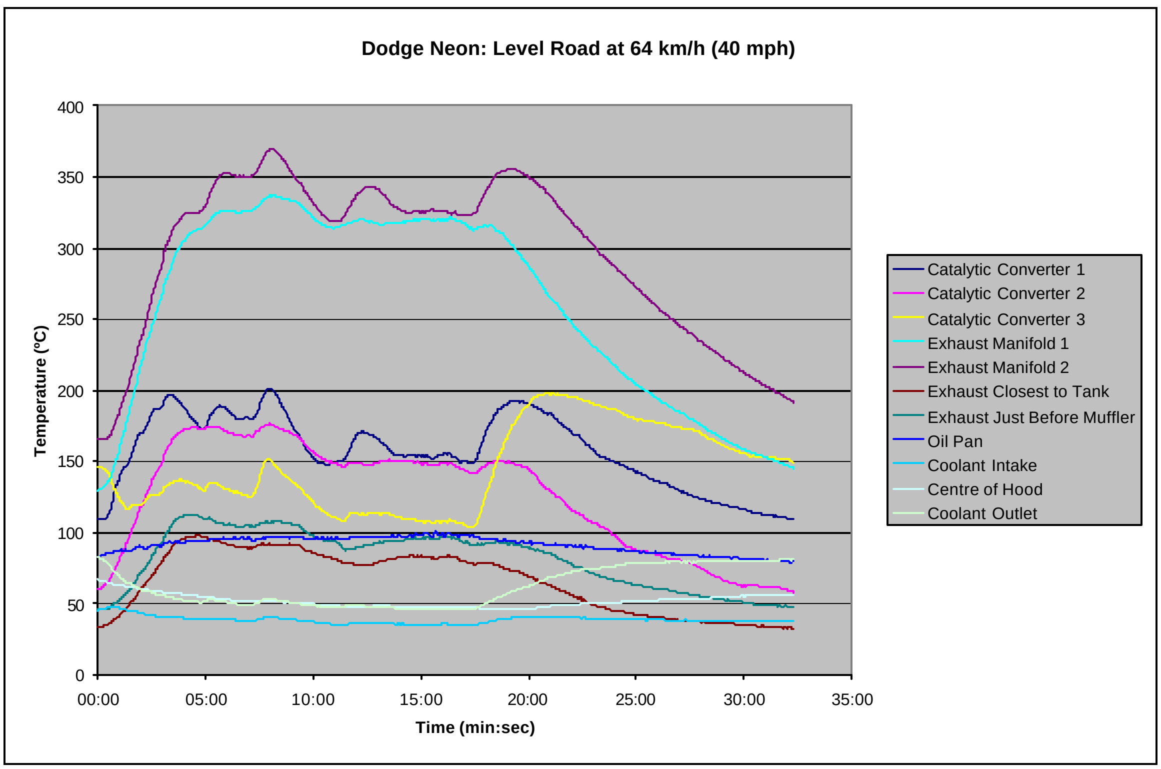
Dodge Caravan: Hill at 96 km/h (60 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

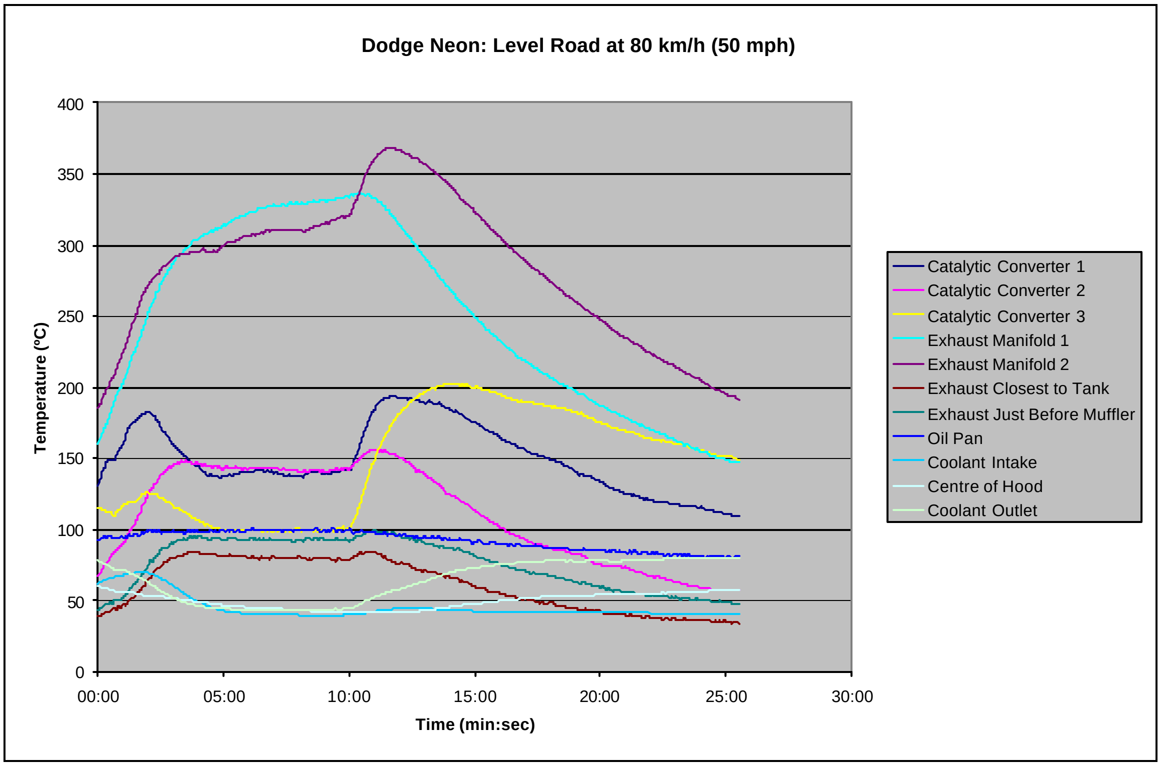

Dodge Caravan: Hill at 112 km/h (70 mph)
Temperature (°C)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

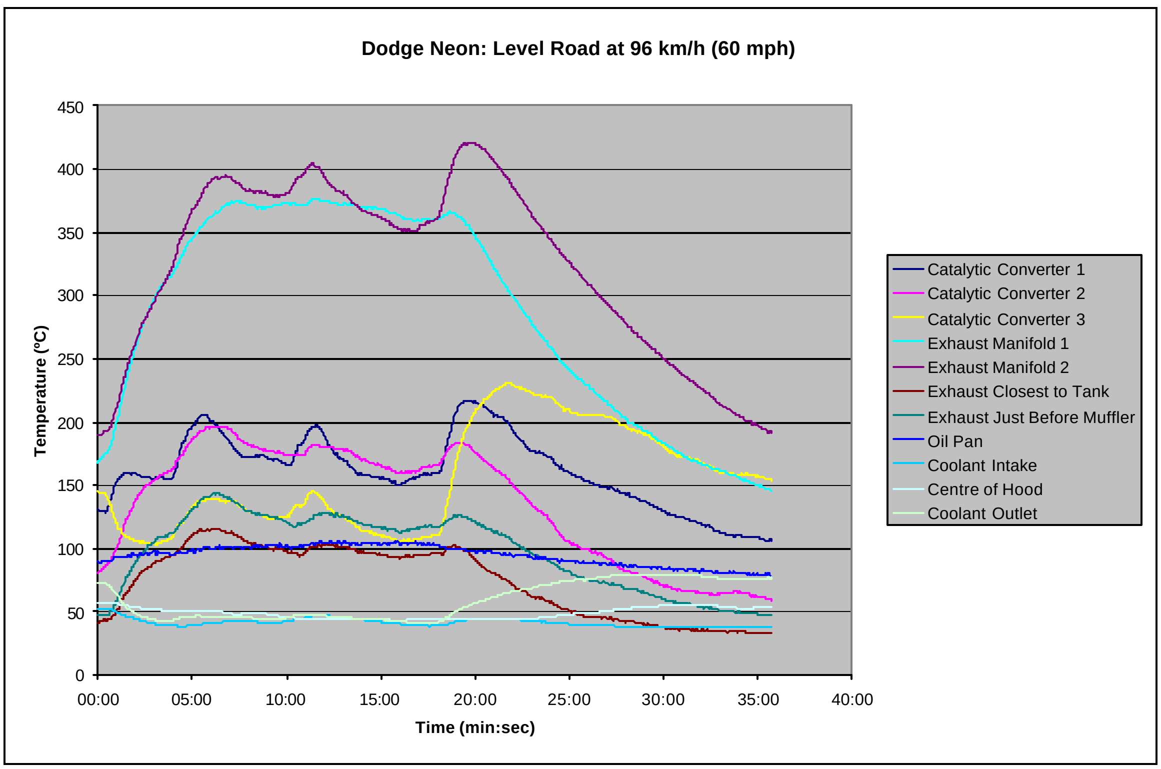
Appendix C : Data Traces – Dodge Neon

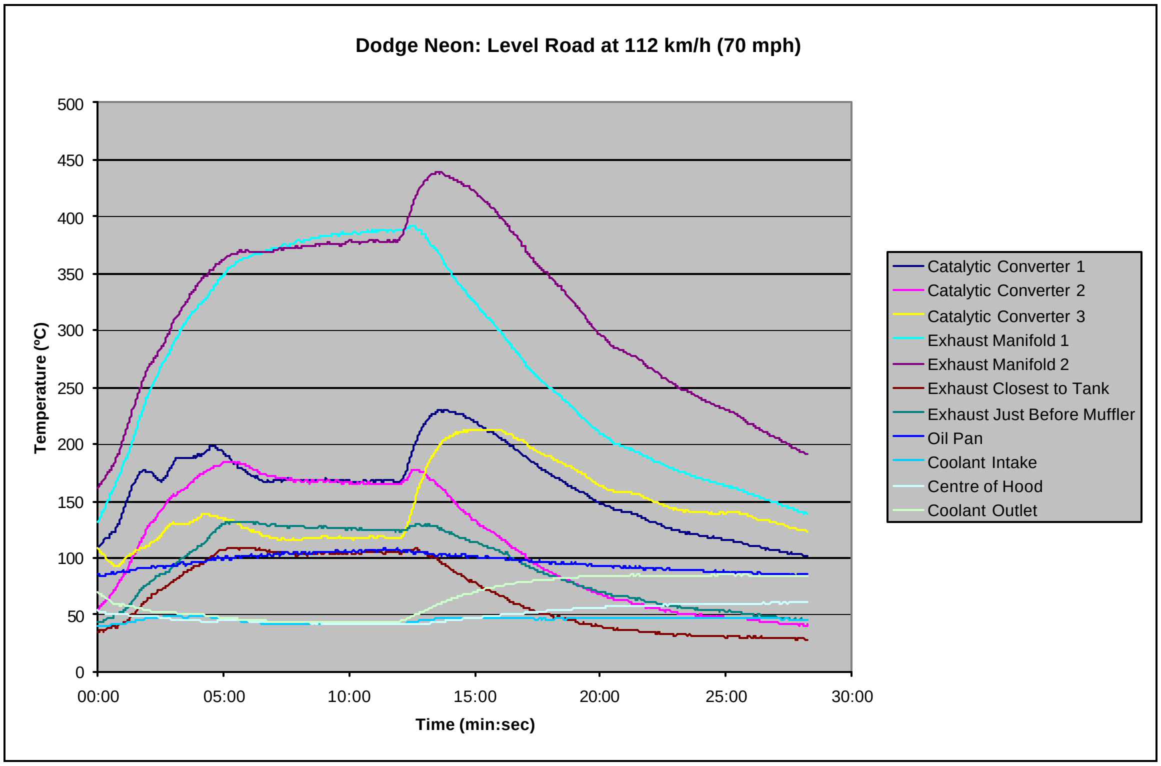


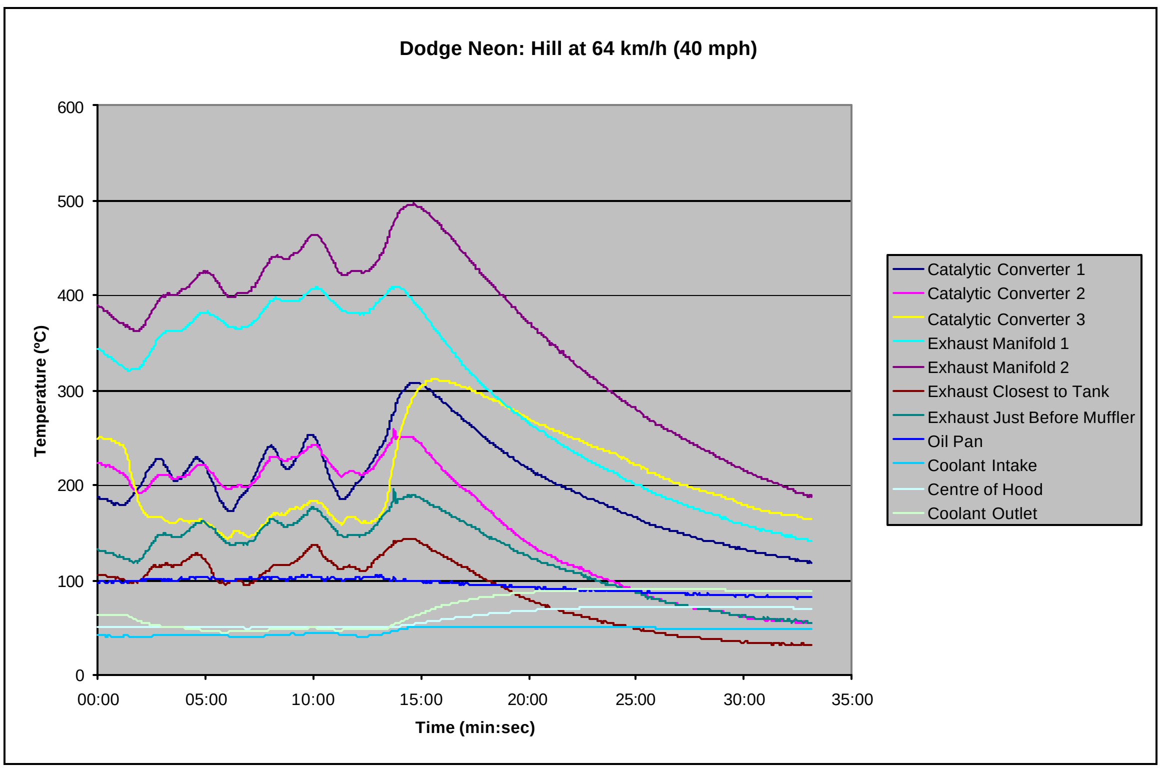

Dodge Neon: Level Road at 48 km/h (30 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

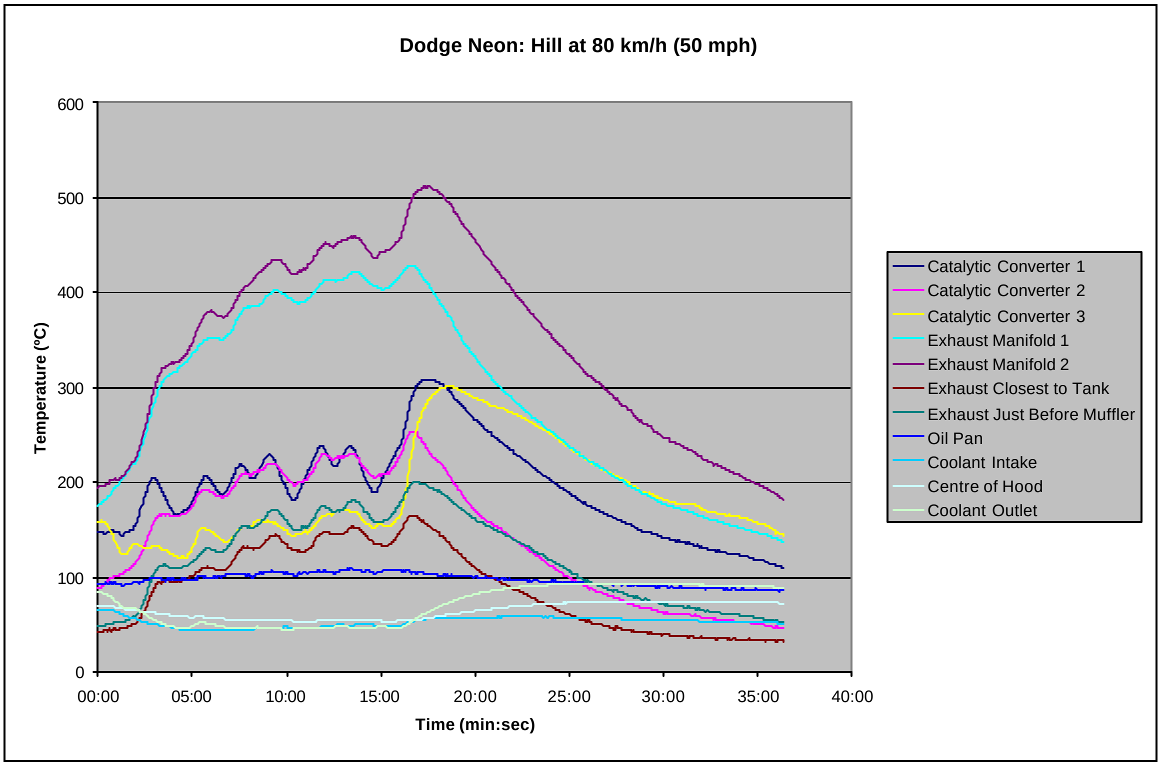

Dodge Neon: Level Road at 64 km/h (40 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

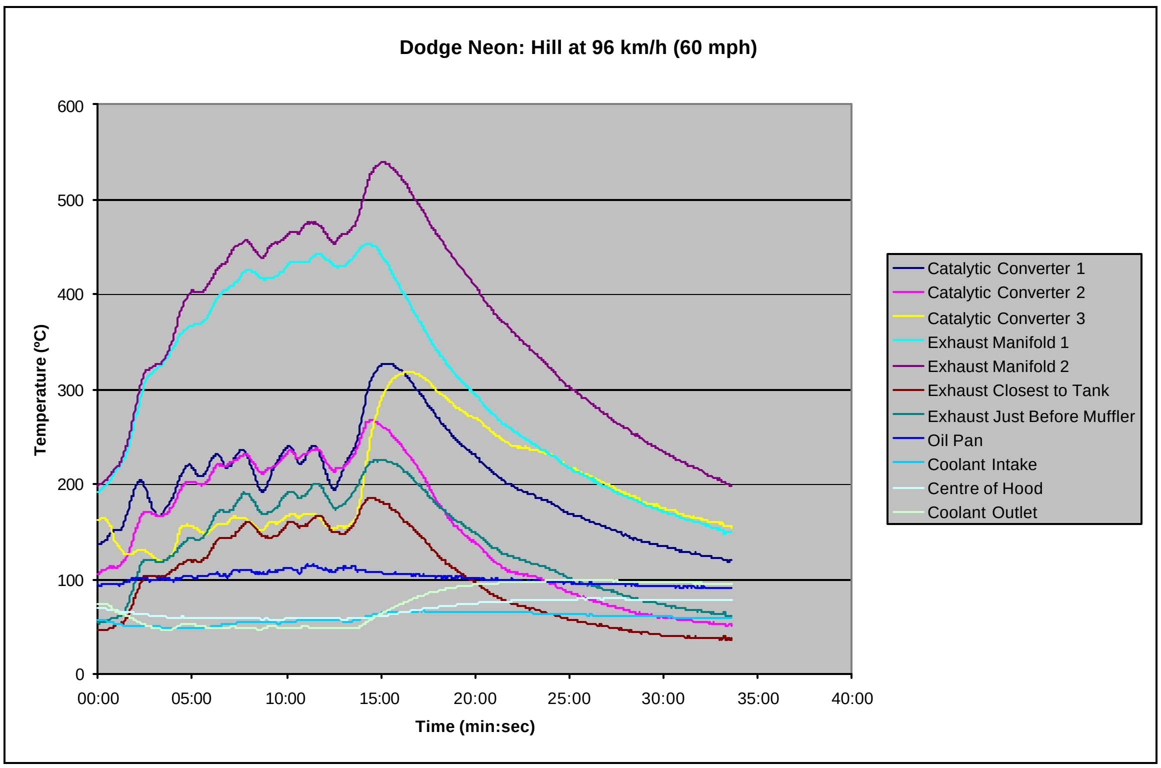

Dodge Neon: Level Road at 80 km/h (50 mph)
Temperature (ºC)
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

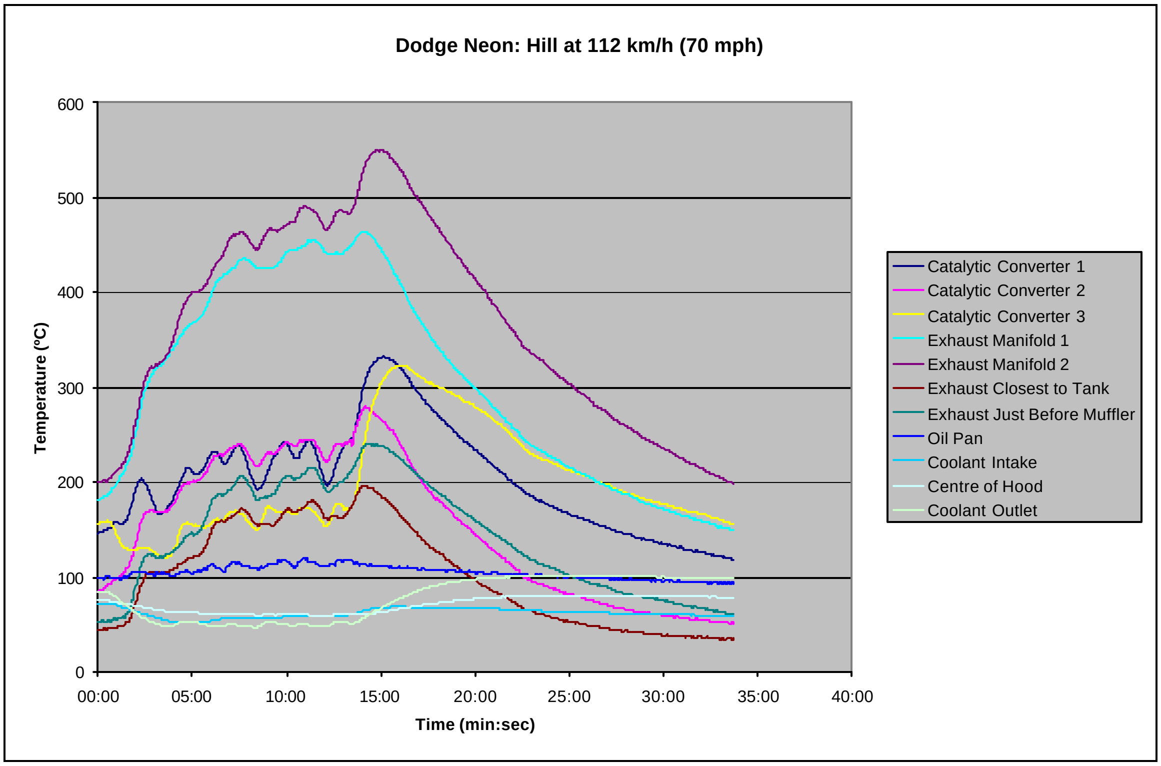

Dodge Neon: Level Road at 96 km/h (60 mph)
Temperature (ºC)
450
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Dodge Neon: Level Road at 112 km/h (70 mph)
Temperature (°C)
500
450
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

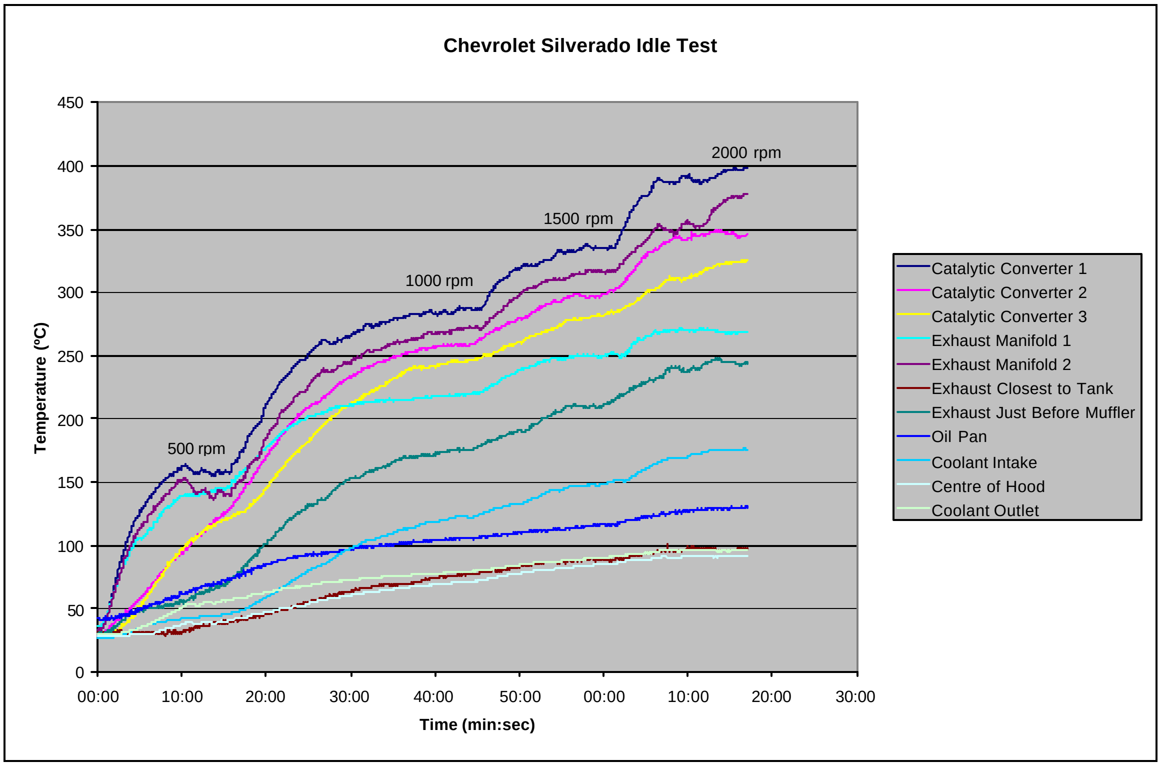

Dodge Neon: Hill at 64 km/h (40 mph)
Temperature (°C)
600
500
400
300
200
100
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

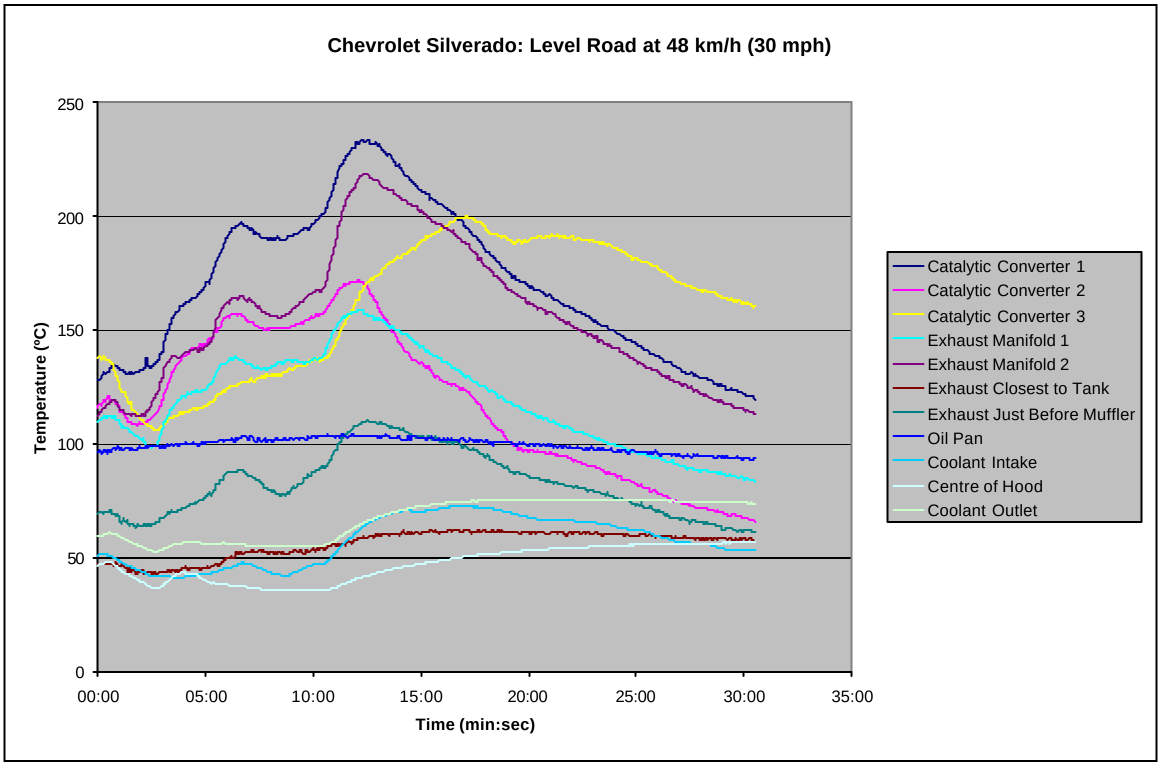

Dodge Neon: Hill at 80 km/h (50 mph)
Temperature (ºC)
600
500
400
300
200
100
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

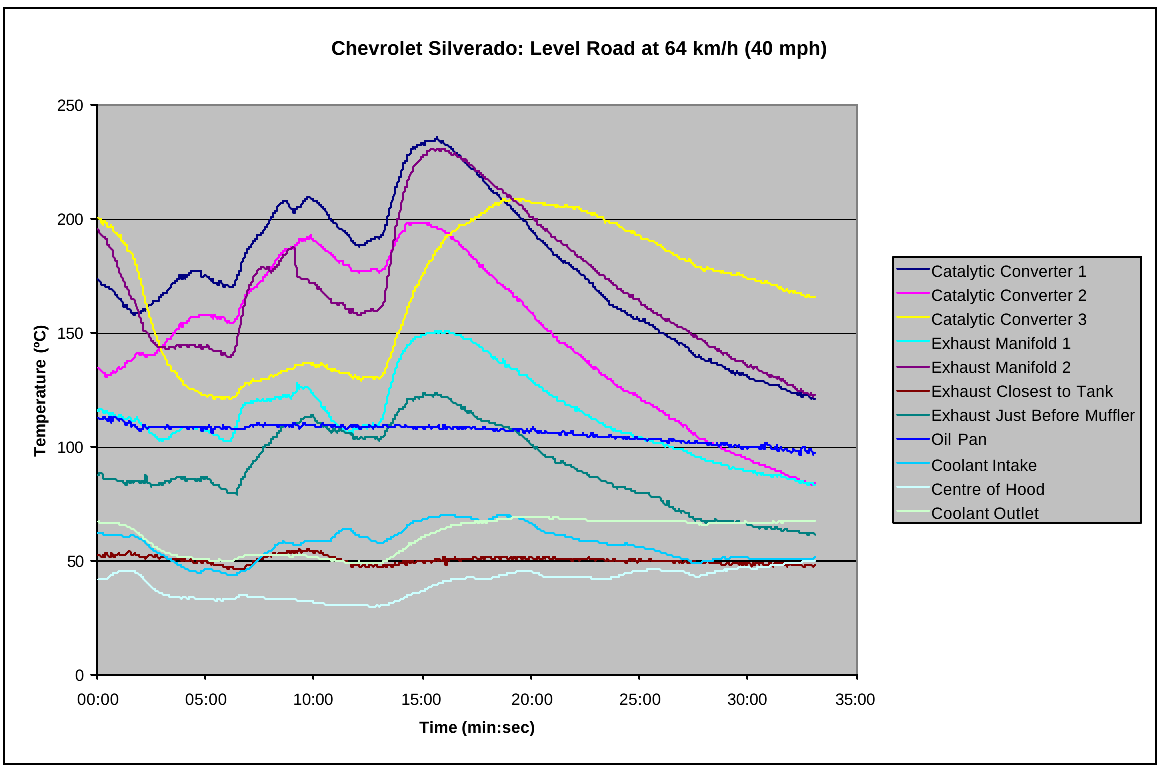

Dodge Neon: Hill at 96 km/h (60 mph)
Temperature (ºC)
600
500
400
300
200
100
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

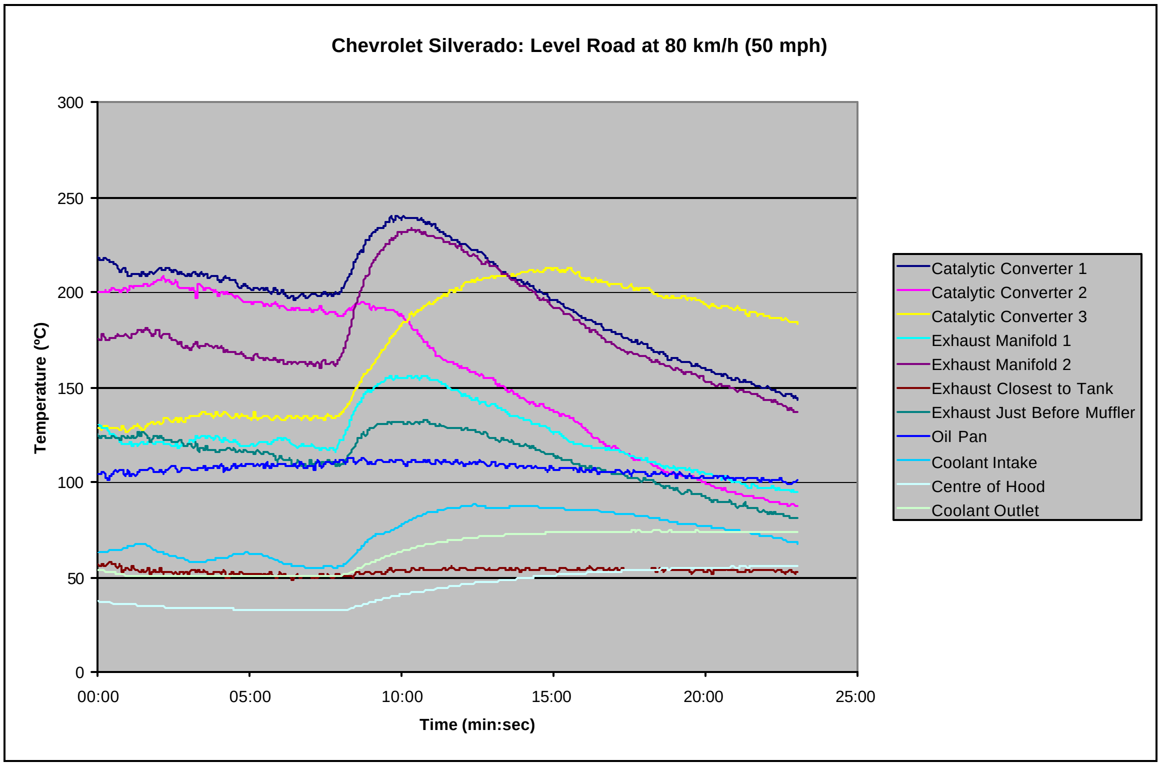

Dodge Neon: Hill at 112 km/h (70 mph)
Temperature (ºC)
600
500
400
300
200
100
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

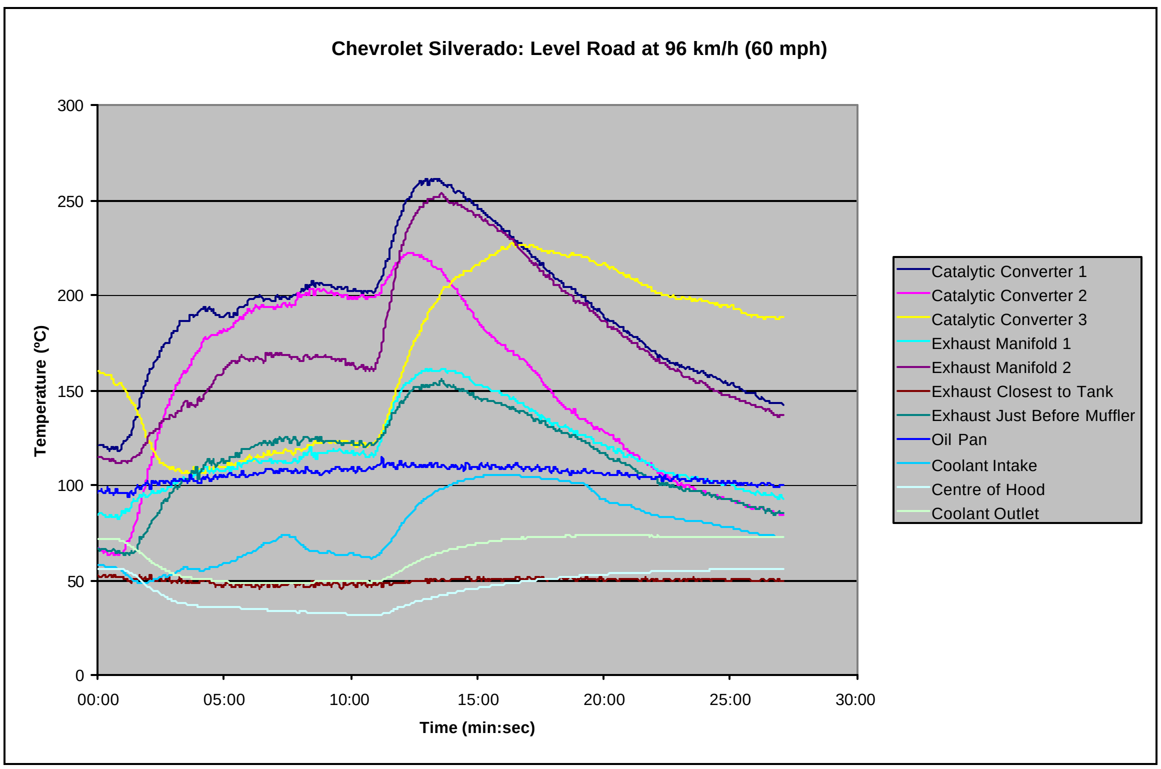
Appendix D : Data Traces – Chevrolet Silverado

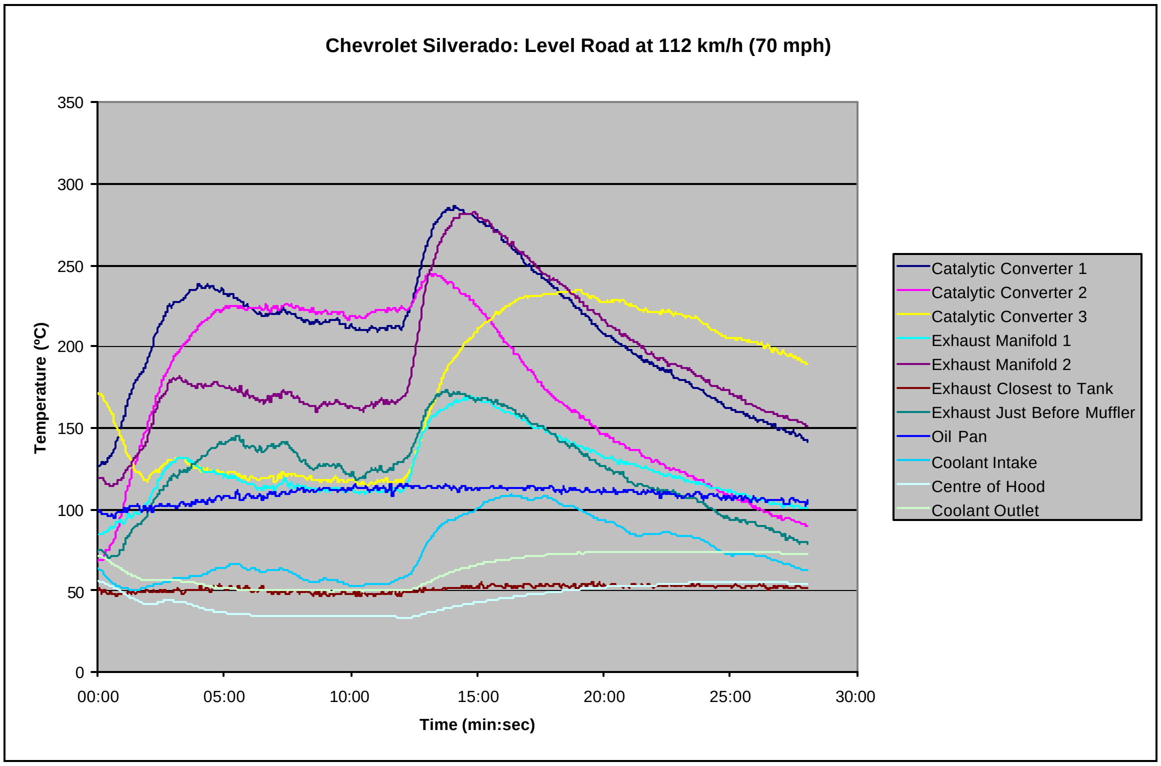


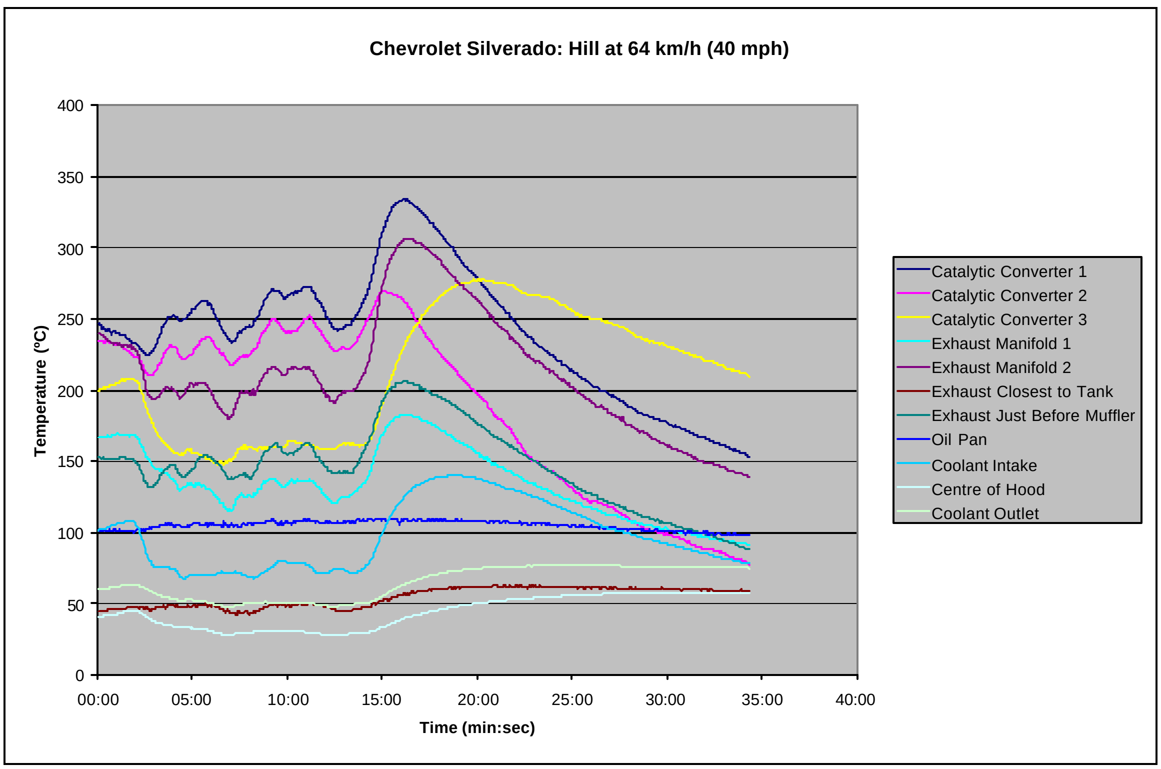

Chevrolet Silverado: Level Road at 48 km/h (30 mph)
Temperature (ºC)
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

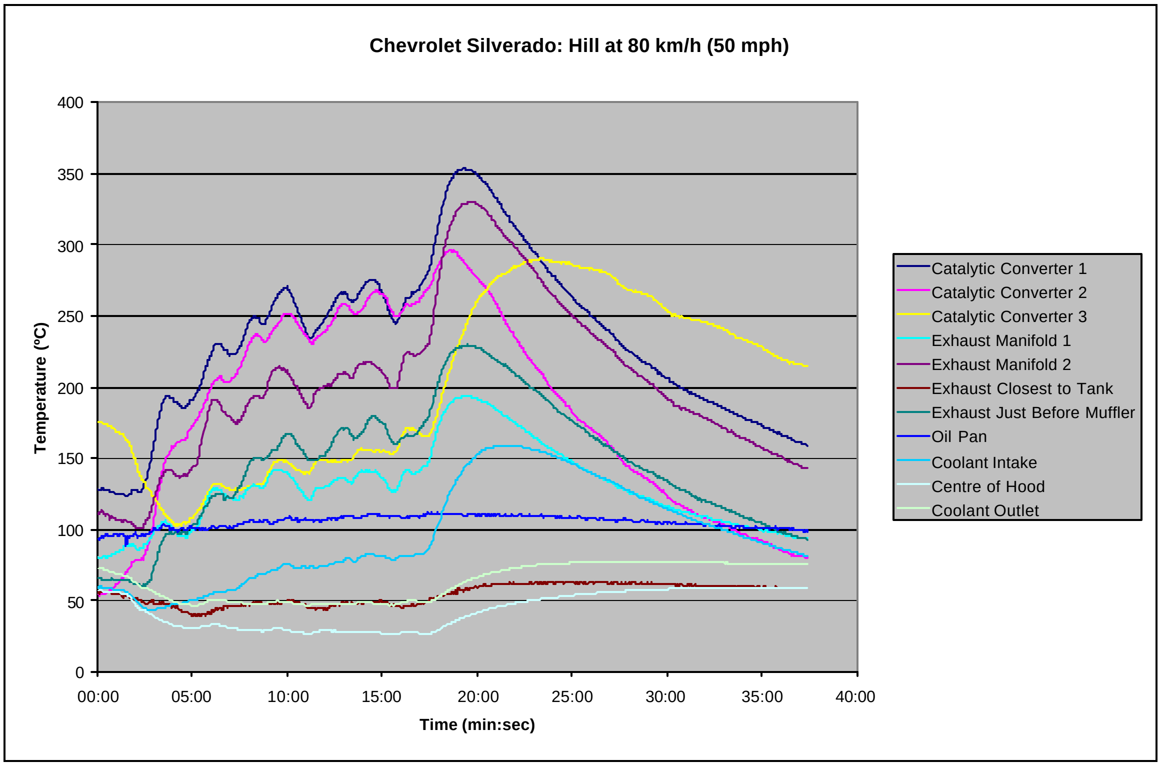

Chevrolet Silverado: Level Road at 64 km/h (40 mph)
Temperature (ºC)
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

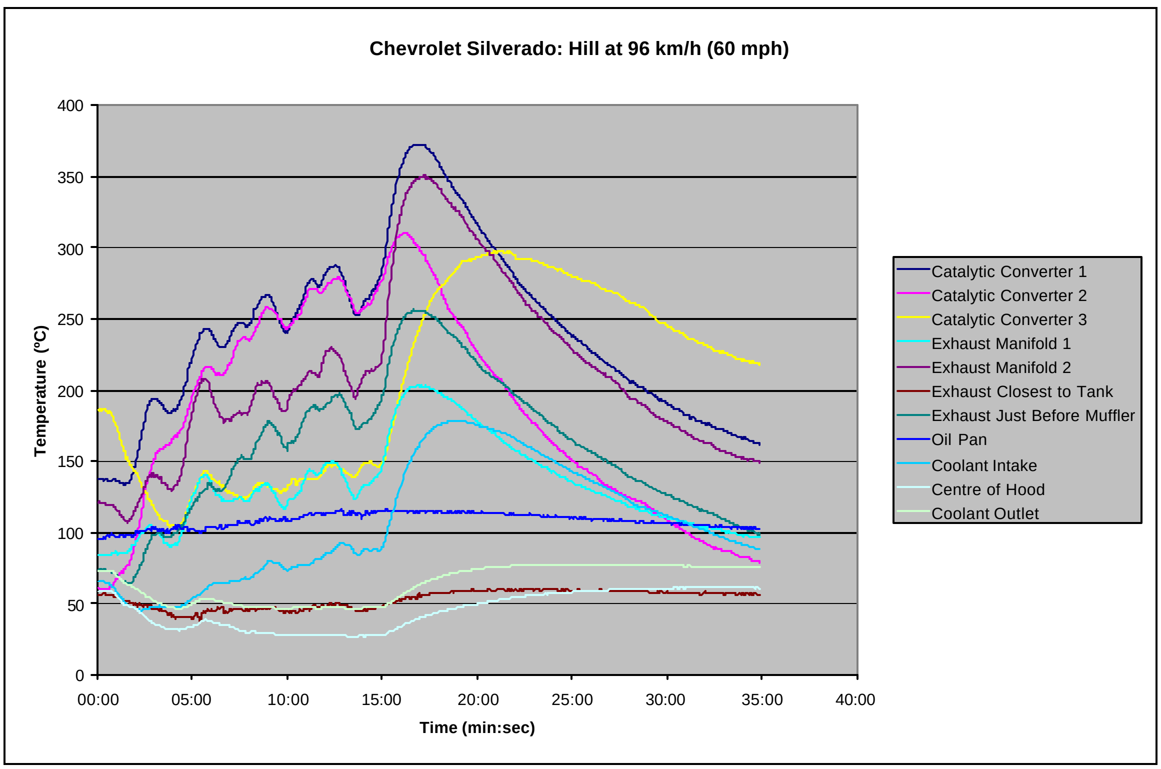

Chevrolet Silverado: Level Road at 80 km/h (50 mph)
Temperature (ºC)
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet

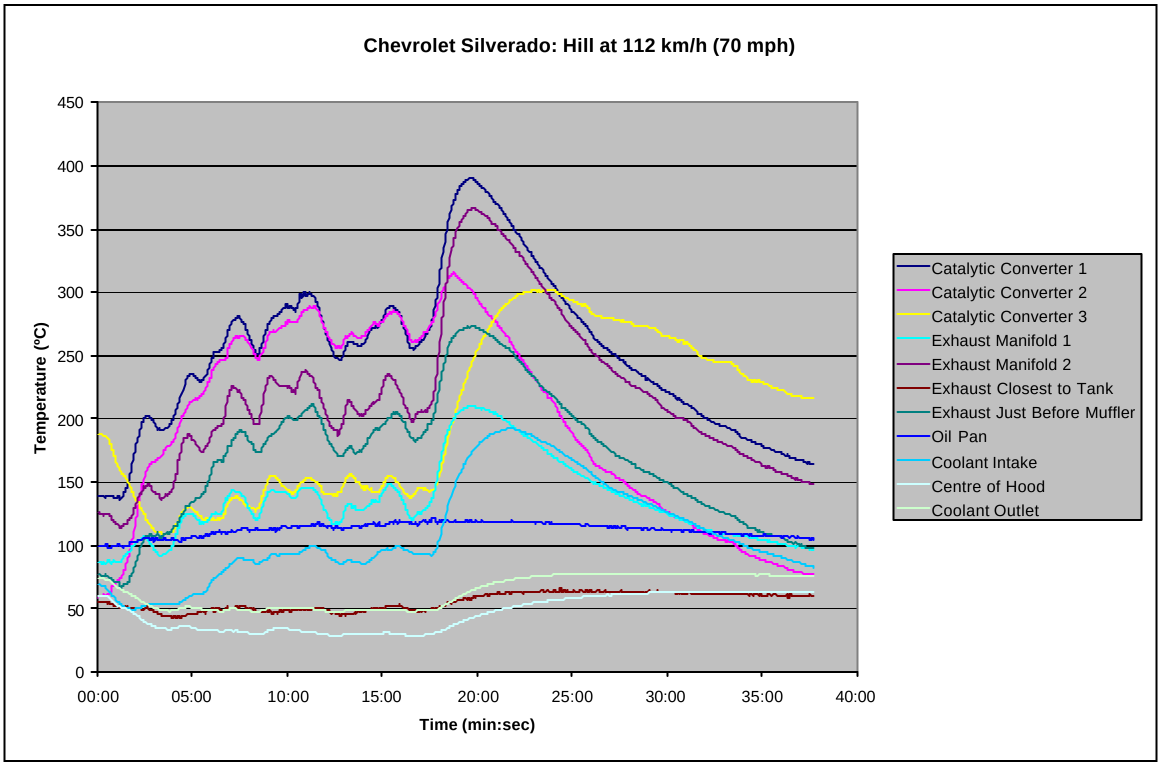

Chevrolet Silverado: Level Road at 96 km/h (60 mph)
Temperature (ºC)
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Chevrolet Silverado: Level Road at 112 km/h (70 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
00:00
05:00
10:00
15:00
20:00
25:00
30:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Chevrolet Silverado: Hill at 64 km/h (40 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
400
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Chevrolet Silverado: Hill at 80 km/h (50 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
400
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Chevrolet Silverado: Hill at 96 km/h (60 mph)
Temperature (°C)
0
50
100
150
200
250
300
350
400
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet


Chevrolet Silverado: Hill at 112 km/h (70 mph)
Temperature (°C)
450
400
350
300
250
200
150
100
50
0
00:00
05:00
10:00
15:00
20:00
25:00
30:00
35:00
40:00
Time (min:sec)
Catalytic Converter 1
Catalytic Converter 2
Catalytic Converter 3
Exhaust Manifold 1
Exhaust Manifold 2
Exhaust Closest to Tank
Exhaust Just Before Muffler
Oil Pan
Coolant Intake
Centre of Hood
Coolant Outlet