CRC E108 Octane Program Update for the ASTM Octane Task Group

Bill Studzinski
GM Powertrain Fuels Group

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CRC Emissions Project E108: 10 Car Fleet Evaluation – 85 and 87 AKI Performance Effects

Program Objective

- Evaluate vehicle performance and emissions effects of 85 AKI gasoline relative to 87 AKI gasoline at two elevations.

Test Locations

- Variable Altitude Chassis Dyno Emissions Chambers (GM, Ford, Chrysler)
- Two test elevations: Low = 1,000 ft and High 5,000 ft

Metrics

- Fuel economy
- Tailpipe Emissions (CO_2, CO, NO_x, THC, NMOG)
- Exhaust Temperatures: Pre-cat inlet and mid-cat
- Throttle Position
- Manifold Absolute Pressure
- Mass Air Flow
- Spark Advance
- Stoichiometry
- Percent Load

Test Order

- Start: 2 x Tier 2 US FTP (start)
- Octane A – 1000 ft: 2 x [USFTP, LA92, US06] and 5,000 ft: 2 x [USFTP, LA92, US06]
- Octane B – 1000 ft: 2 x [USFTP, LA92, US06] and 5,000 ft: 2 x [USFTP, LA92, US06]
- Start: 2 x Tier 2 US FTP (End)

Status

Program Timing

- Vehicle Emissions and Performance Data Capture: Completed May 2014
- 307 Variable Altitude Chamber Emissions Test Cycles and Preps conducted

Vehicle	Model Year	Odometer	Fuel System	Induction System	Eng. Disp. (L)	Curb Wt. (kg)	M/D (kg/L)	Federal Emissions
Honda Fit	2012	19,378	PFI	Nat. Asp.	1.5	1134	756	T2 B5
Ford Focus	2008	12,563	PFI	Nat. Asp.	2.0	1361	681	T2 B4
Toyota Corrola	2008	13,248	PFI	Nat. Asp.	1.8	1304	724	T2 B5
Ford Transit Connect	2010	11,860	PFI	Nat. Asp.	2.0	1562	781	T2 B4
Ford F-150 Ecoboost	2011	5,200	DI	Turbo	3.5	2326	665	T2 B4
Dodge Dart	2013	14,403	PFI	Turbo	1.4	1445	1032	T2 B5
Ford F-150	2008	15,487	PFI	Nat. Asp.	5.4	2381	441	T2 B8
Honda Odyssey	2008	13,248	PFI	Nat. Asp.	3.5	2154	615	T2 B5
Chevy Equinox	2010	37,396	DI	Nat. Asp.	3.0	1706	568	T2 B4

Data Capture Team – 3 OEMs (Ford, Fiat Chrysler, GM)

- Sent 9 vehicle "composite emissions and performance data summary" to Jim Rutherford and Kyra Singh (Chevron Statisticians)
- Individual tests rated "valid" or "invalid", if identified test procedure / equipment problem

Data Analysis Panel

- Members: Vaughn Burns, Dominic DiCicco, King Eng, Jeff Farenback-Brateman, Rich George, Jerry Horn, David Lax, Scott Mason, Jenny Sigelko, Jim Simnick, Bill Studzinski, Marie Valentine. (Asim Iqbal, Eric Blash, Johanna Dolch, Mark Winston-Galant – Data Capture Team)
- Reviewing statistical analyses. Will draw conclusions and publish a report.

Report Timing: Difficult to predict – early Fall, 2014 ?

Test Plan for 1 Vehicle Pair

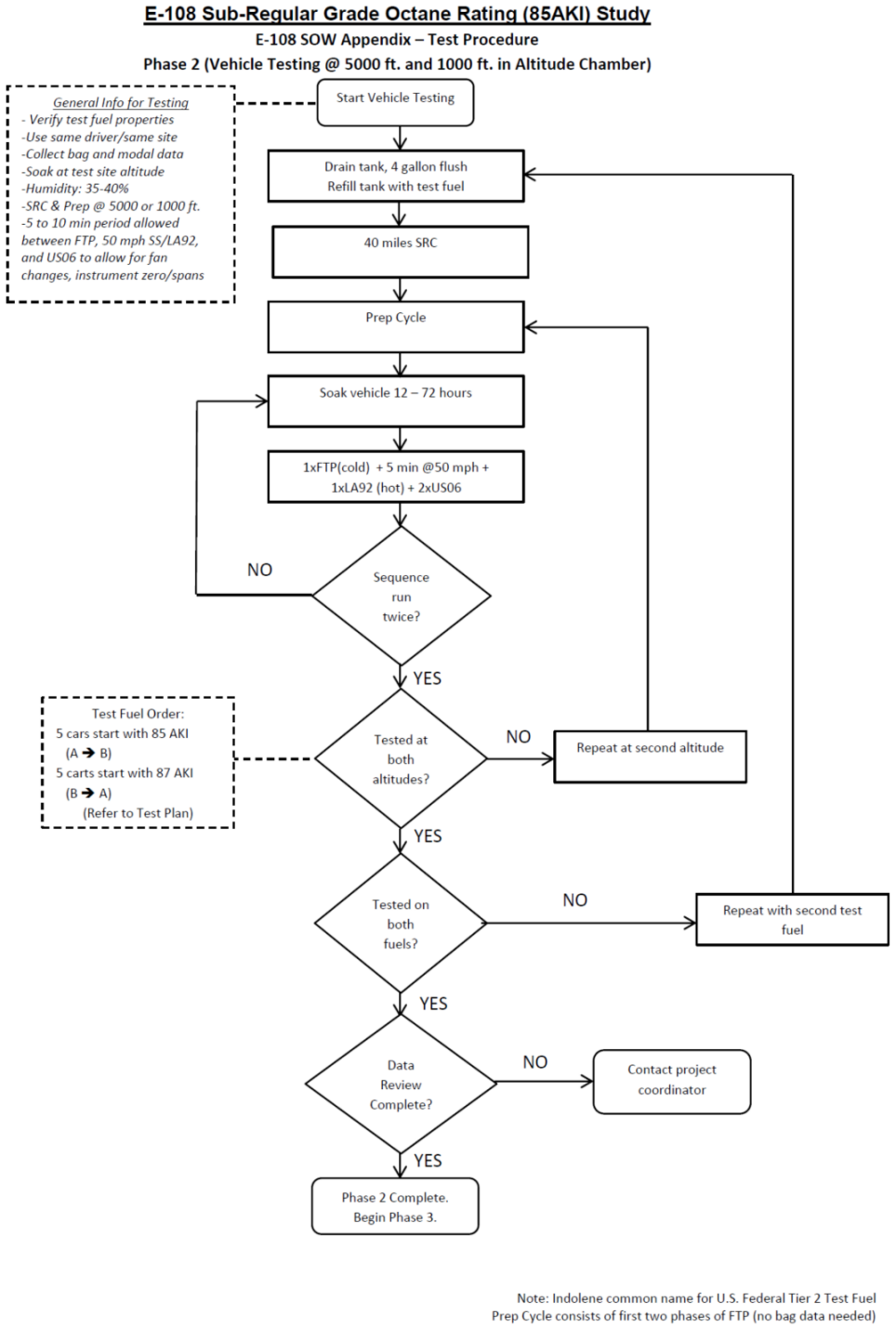
- **16 Test Days / Veh.**
- **4 Data Loggers to be shared by 3 OEMs**
- **½ the fleet started on 85 AKI and ½ on 87 AKI**
- **ECM Preps conducted at Elevation**

Day	Step	Fuel	Vehicles	Cycle(s)	Elevation
1	Fuel Prep	Tier 2	Dodge Dart	40 miles on SRC + 8 mile Prep cycle	Site Elevation
		Tier 2	Honda Odyssey	40 miles on SRC + 8 mile Prep cycle	
2	Emissions Tests	Tier 2	Dodge Dart	US FTP	Site Elevation
		Tier 2	Honda Odyssey	US FTP	
3	Emissions Tests	Tier 2	Dodge Dart	US FTP	Site Elevation
		Tier 2	Honda Odyssey	US FTP	
4	Fuel Prep	85 AKI	Dodge Dart	40 miles New Fuel Conditioning	Site Elevation
		87 AKI	Honda Odyssey	40 miles New Fuel Conditioning	Site Elevation
	Fuel Prep	85 AKI	Dodge Dart	8 mile Prep cycle	5000 ft.
		87 AKI	Honda Odyssey	8 mile Prep cycle	5000 ft.
5	Emissions Tests	85 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
		87 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
6	Emissions Tests	85 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
		87 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
	Fuel Prep	85 AKI	Dodge Dart	8 mile Prep cycle	1000 ft.
		87 AKI	Honda Odyssey	8 mile Prep cycle	1000 ft.
7	Emissions Tests	85 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
		87 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
8	Emissions Tests	85 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
		87 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
9	Fuel Prep	85 AKI	Dodge Dart	40 miles New Fuel Conditioning	Site Elevation
		87 AKI	Honda Odyssey	40 miles New Fuel Conditioning	Site Elevation
	Fuel Prep	85 AKI	Dodge Dart	8 mile Prep cycle	5000 ft.
		87 AKI	Honda Odyssey	8 mile Prep cycle	5000 ft.
10	Emissions Tests	87 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
		85 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
11	Emissions Tests	87 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
		85 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	5000 ft.
	Fuel Prep	87 AKI	Dodge Dart	8 mile Prep cycle	1000 ft.
		85 AKI	Honda Odyssey	8 mile Prep cycle	1000 ft.
12	Emissions Tests	87 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
		85 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
13	Emissions Tests	87 AKI	Dodge Dart	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
		85 AKI	Honda Odyssey	US FTP, LA92 (hot start), US06 (hot start)	1000 ft.
14	Fuel Prep	Tier 2	Dodge Dart	40 miles on SRC + 8 mile Prep cycle	Site Elevation
		Tier 2	Honda Odyssey	40 miles on SRC + 8 mile Prep cycle	
15	Emissions Tests	Tier 2	Dodge Dart	US FTP	Site Elevation
		Tier 2	Honda Odyssey	US FTP	
16	Emissions Tests	Tier 2	Dodge Dart	US FTP	Site Elevation
		Tier 2	Honda Odyssey	US FTP	

Flow Charts

Each of 3 Test Phases had Flowcharts

- **SOT FTP**
- **Octane Tests**
- **EOT FTP**



Example Raw Data – Emissions Data and Performance Data (Focus on Test Precision)

Vehicle Name																
Vehicle	**A**	**A**	Avg (2 tests)	% COV	**A**	**A**	Average	COV	**A**	**A**	Average	COV	**A**	**A**	Average	COV
Altitude	Site Elevation	Site Elevation			5,000	5,000			1,000	1,000			5,000	5,000		
Octane	Tier 2	Tier 2			87 E10	87 E10			87 E10	87 E10			85 E10	85 E10		
	w / Prep	w / Prep			All g/mi								All g/mi			
Test Cycle 1	US FTP	US FTP			US FTP	US FTP			US FTP	US FTP			US FTP	US FTP		
Test ID	MS34008520	MS35004296			MS34008535	MS34008541			MS34008565	MS34008574			MS34008583	MS34008590		
Test Date	8/28/2013	9/5/2013			9/11/2013	9/12/2013			9/18/2013	9/19/2013			9/23/2013	9/24/2013		
Test Time	23:57	14:44			1:47	3:15			4:50	3:07			2:46	3:14		
Veh Mileage	19408	19427			19504	19550			19604	19653			19767	19821		
Baro (kPa)	97.48	97.74			84.0	84.4			97.90	97.85			84.4	84.5		
Temp (F)	76.0	74.7			75.1	75.00			74.9	74.8			75.1	75.0		
RH	35.7	37.6			31.7	31.8			36.3	37.4			31.4	31.8		
Driver's Initials	333	333			333	333			333	333			333.0	333.0		
J2951 RMSE	0.42	0.48			0.45	0.45			0.42	0.50			0.54	0.52		
THC	0.02883	0.03015	0.0295	3.17%	0.02303	0.02600	0.02452		0.02182	0.02138	0.02160		0.02404	0.02630	0.02517	
CH4	0.00508	0.00449	0.0048	8.72%	0.00281	0.00309	0.00295		0.00314	0.00301	0.00308		0.00253	0.00337	0.00295	
Non-Methane					0.02042	0.23120	0.12581		0.01890	0.01858	0.01874		0.02168	0.02316	0.02242	
CO	0.24743	0.30124	0.2743	13.87%	0.10898	0.15519	0.13209	24.7%	0.13852	0.12325	0.13089	8.2%	0.13863	0.15205	0.14534	6.5%
Nox	0.01213	0.01125	0.0117	5.32%	0.00472	0.00524	0.00498		0.00505	0.00555	0.00530		0.00650	0.00556	0.00603	
CO2	237.53	237.464	237.4970	0.02%	219.834	223.074	221.45400	1.0%	230.106	229.939	230.02250	0.1%	223.359	223.856	223.60750	0.2%
FE (mpg)	37.3996	37.4235	37.4116	0.024	37.7864	37.2246	37.50550	-0.562	36.0947	36.1249	36.10980	0.030	37.1511	37.064	37.10755	0.044
NMOG	0.02503	0.02699	0.0260	5.33%	0.02123	0.02835	0.02479		0.01965	0.01932	0.01949		0.02255	0.02408	0.02332	
Miles Driven	11.070	11.120	11.0950		11.07600	11.09100	11.08350		11.07900	11.11900	11.09900		11.13800	11.10500	11.12150	

Vehicle A		**Vehicle A**				**Octane Tests**	**Mean Values**		
Octane		**87**	**87**	**Average**	**COV**	**87**	**87**	**Average**	**COV**
Altitude		**5,000**	**5,000**			**1,000**	**1,000**		
Test		**FTP-1 (Bags 1 & 2)**	**FTP-2 (Bags 1 & 2)**			**FTP-3 (Bags 1 & 2)**	**FTP-4 (Bags 1 & 2)**		
Comment									
Date		**9/11/2013**	**9/12/2013**			**9/18/2013**	**9/19/2013**		
Vehicle Speed (mph)		**No Data Logger**	**19.43**	**19.43**	#DIV/0!	**19.49**	**19.59**	**19.54**	0.36%
Engine Speed (rpm)		**No Data Logger**	**1337.56**	**1337.56**	#DIV/0!	**1322.70**	**1325.4**	**1324.05**	0.14%
Throttle Position (%)		**No Data Logger**	**17.21**	**17.21**	#DIV/0!	**16.47**	**16.49**	**16.48**	0.09%
MAP (kPa)		**No Data Logger**	**38.77**	**38.77**	#DIV/0!	**42.03**	**42.37**	**42.20**	0.57%
MAF (g/sec)		**No Data Logger**	**5.78**	**5.78**	#DIV/0!	**5.82**	**5.88**	**5.85**	0.73%
Load (%)		**No Data Logger**	**25.98**	**25.98**	#DIV/0!	**26.57**	**26.85**	**26.71**	0.74%
Ignition Timing (deg. BTDC)		**No Data Logger**	**20.20**	**20.20**	#DIV/0!	**19.94**	**19.99**	**19.97**	0.18%
Lambda		**No Data Logger**	**1.0033**	**1.0033**	#DIV/0!	**0.9993**	**0.9986**	**1.00**	0.05%
Pre-Cat Temp (deg.F)		**No Data Logger**	**825.7**	**825.72**	#DIV/0!	**845.3**	**848.8**	**847.05**	0.29%
Mid-Cat Temp (deg.F)		**No Data Logger**	**1036.3**	**1036.31**	#DIV/0!	**1045.1**	**1045.0**	**1045.05**	0.01%
Pre-Cat Max. (deg.F)		**No Data Logger**	**1282.3**	**1282.33**	#DIV/0!	**1275.6**	**1259.2**	**1267.40**	0.91%
Mid-Cat Max. (deg.F)		**No Data Logger**	**1385.6**	**1385.60**	#DIV/0!	**1389.9**	**1378.0**	**1383.95**	0.61%

		Vehicle A			
Octane		**85**	**85**	**Average**	**COV**
Altitude		**5,000**	**5,000**		
Test		**FTP-1 (Bags 1 & 2)**	**FTP-2 (Bags 1 & 2)**		
Comment					
Date		**9/23/2013**	**9/24/2013**		
Vehicle Speed (mph)		**19.56**	**19.57**	**19.57**	0.03%
Engine Speed (rpm)		**1342.33**	**1343.00**	**1342.66**	0.04%
Throttle Position (%)		**17.18**	**17.16**	**17.17**	0.07%
MAP (kPa)		**38.64**	**38.73**	**38.68**	0.15%
MAF (g/sec)		**5.78**	**5.79**	**5.79**	0.16%
Load (%)		**25.83**	**25.92**	**25.87**	0.23%
Ignition Timing (deg. BTDC)		**19.70**	**20.26**	**19.98**	1.99%
Lambda		**1.00026**	**0.9972**	**0.9987**	0.22%
Pre-Cat Temp (deg.F)		**834.9**	**839.1**	**837.00**	0.36%
Mid-Cat Temp (deg.F)		**1041.2**	**1048.8**	**1045.00**	0.52%
Pre-Cat Max. (deg.F)		**1276.9**	**1287.3**	**1282.11**	0.57%
Mid-Cat Max. (deg.F)		**1393.2**	**1408.8**	**1401.01**	0.79%

Test Data Package

Data Sets

- Individual Test Emissions, FE, and Performance – "Composite Bags"
  - Averaged / Bag Data for each Emissions Test Cycle
  - Percent changes between Octane Levels and Elevation
    - Linearity of 87 vs 85 Octane Response
    - Statistically Analyses for Significant Effects
      - Outlier Analyses
      - US FTP SOT and EOT to check for vehicle response drift
      - Main Effects for Octane, Altitude, Vehicles
      - Interactive Effects

- Individual Test Emissions and FE – Modal

- Emissions and Performance – 1 Sec Realtime Data
  - Acceleration Only Events (when Octane is needed) Cumulative Emissions

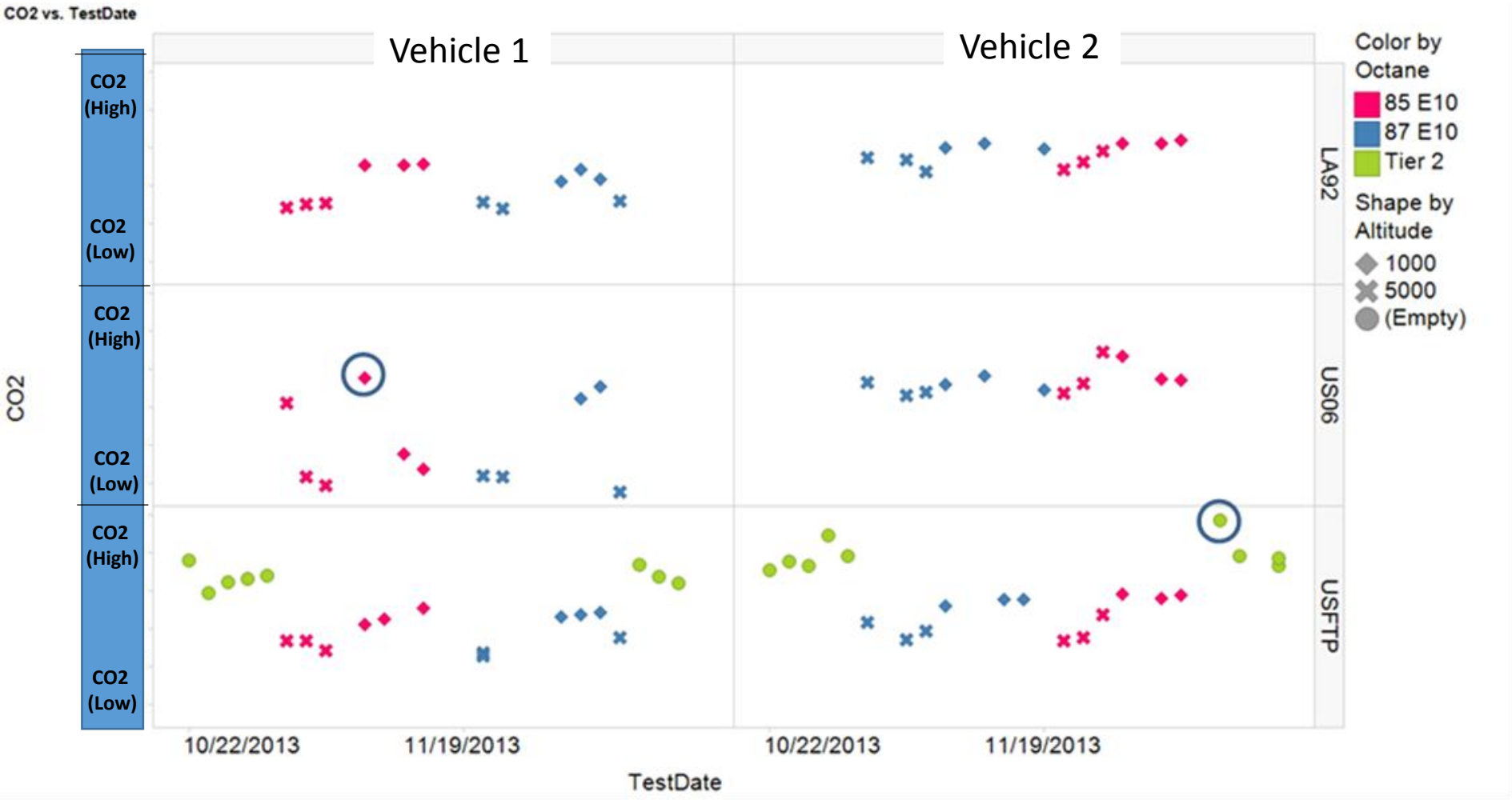
- Correlated Data
  - Vehicle Parameters correlated with Vehicle Outputs (Emissions and Performance)

Note: Data Analyses considered to date. Data Analysis Panel will likely want others.

Determination of Statistical Difference and Confidence Level

Example Raw Data – Focus on Data Analysis Methodology

1. Summarize "Checked" Data
2. Outlier Analysis – 2 test points flagged in example below
3. Determine if transformations are necessary
4. Generate Models for each parameter of interest, e.g. CO2, CO, Engine Load, etc…



Example SAS Model Development

CO2, US06, 2 Vehicles Only

Linear Models

The GLM Procedure

TestCycle=US06

Class Level Information		
Class	Levels	Values
Vname	2	
Altitude	2	1,000 5,000
Octane	2	85 E10 87 E10

Number of Observations Read	23
Number of Observations Used	23

Full Models = 36 Observations (9x2x2)

Generated by the SAS System ('Local', X64_7PRO) on February 14, 2014 at 4:18:48 PM

Linear Models

The GLM Procedure

Dependent Variable: CO2

95% Confidence Limit = P < 0.05

TestCycle=US06

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2419.545349	345.649336	7.01	0.0008
Error	15	739.201481	49.280099		
Corrected Total	22	3158.746830			

R-Square	Coeff Var	Root MSE	CO2 Mean
0.765983	2.610962	7.019979	268.8656

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Vname*Altitud*Octane	7	2419.545349	345.649336	7.01	0.0008

Industry Meetings

CRC Data Analysis Panel Meetings

- 1st – May 12th — Introduced "checked and summarized" data sets. No SAS analyses.
- 2nd – June 12th — Review 1st statistical analyses – outliers, composite analyses, statistical difference
- 3rd - July 18th — Review 2nd statistical analyses.

NCWM Meeting

- Fuels and Lubricants Subcommittee - July 13th – 17th (Detroit, MI)

ASTM Octane Task Group Mtgs.

- Fall, 2014 after CRC E108 Report

New Octane Rating Related Literature: SAE Congress Papers (April, 2014)

Octane Rating and Vehicle / Engine Performance and Efficiency Papers

SAE Item Number	Title	Author(s)	Description
2014-01-1397	Octane Response in a Downsized, Highly Boosted Direct Injection Spark Ignition Engine	Remmert, S.; Cracknell, R.; Head, R.; Schuetze, A.; Lewis, A.; Akehurst, S.; Turner, J.; Popplewell, A.	Influence of RON (95 - 112) on fuel consumption and vehicle peformance with a highly boosted, downsized 4 cylinder engine.
2014-01-1228	Effects of Fuel Octane Rating and Ethanol Content on Knock, Fuel Economy, and CO2 for a Turbocharged DI Engine	Leone, T.; Olin, E.; Anderson, J.; Jung, H.; Shelby, M.; Stein, R.	Engine dyno testing of a turbo-charged, direct injected engine operating on high octane ethanol blends (E10 -E30).
2014-01-1961	Benefits of a Higher Octane Standard Gasoline for the U.S. Light-Duty Vehicle Fleet	Chow, E.; Heywood, J.; Speth, R.	Paper calculates the fuel consumption and GHG benefits of moving the entire vehicle fleet to Premium Octane grade gasoline.
2014-01-1206	Performance Maps of Turbocharged SI Engines with Gasoline-Ethanol Blends: Torque, Efficiency, Compression Ratio, Knock Limits, and Octane	Jo, Y.; Lewis, R.; Bromberg, L.; Heywood, J.	Paper explores the operating limits of a turbocharged engine with gasoline ethanol blends (E0 - E85)

Item Number	Title	Author(s)
2014-01-1216	The Effects of Octane, Sensitivity and on the Performance and Fuel Economy of a Direct Injection Spark Ignition Vehicle	Orlebar, C.; Joedicke, A.; Studzinski, W.