

## Process for Generating Engine Fuel Consumption Map

(Ricardo Cooled EGR Boost 24-bar Standard Car Engine Tier 2 Fuel)

Version: 11-28-2016

This document summarizes the process followed to utilize the fuel consumption map of a Ricardo modeled engine and vehicle fuel consumption data to generate a full engine fuel consumption map which can be used by EPA's ALPHA vehicle simulations. The original Ricardo engine modeling, simulated as a 27-Bar downsized boosted engine with cooled EGR, was completed as part of the final rulemaking for MY2017-2025 light duty greenhouse gas standards. The map generated defines the complete operating boundaries of the engine needed for ALPHA modeling, including idle, WOT, minimum torque, and maximum speed.

### Gather Engine Physical Characteristics

Source: GE118\_Input\_Data\_Review\_v38\_-\_SI\_for\_EPA.pdf - Slide 15

*Note: This process generates a fuel consumption map for a 24-bar engine based upon the Ricardo simulated 27-Bar downsized boosted with cooled EGR.*

```
engine.name = 'Ricardo 27 Bar EGR Boost DI with Cam Switching for Std Car';  
engine.combustion_type = enum_engine_combustion_type.spark_ignition;  
engine.displacement_L = 1.04;  
engine.num_cylinders = 3;
```

*Note: The inertia is estimated from Ricardo's WOT simulation "standard\_car\_EGRB\_Nominal.WOT.csv" using output torque from the "TS\_RigidOut\_BE" variable and acceleration calculated from engine speed "OM\_PostProcess\_BE" variable.*

```
engine.inertia_kgm2 = 0.075;
```

### Load Simulation Data

Source: standard\_car\_EGRB\_Nominal.FTP.csv

Source: standard\_car\_EGRB\_Nominal.HWFET.csv

Source: standard\_car\_EGRB\_Nominal.US06.csv

*Note: Load output data from Ricardo's EASY5 simulations for FTP, HWFET and US06, and remove zero fuel points related to simplistic start stop implementation.*

```
ftp_data = readtable( '../data/raw\2020 EGRB with  
AT\standard_car\EGRB\standard_car_EGRB_Nominal.FTP.csv', 'HeaderLines', 4 );  
hwfet_data = readtable( '../data/raw\2020 EGRB with  
AT\standard_car\EGRB\standard_car_EGRB_Nominal.HWFET.csv', 'HeaderLines', 4 );  
us06_data = readtable( '../data/raw\2020 EGRB with  
AT\standard_car\EGRB\standard_car_EGRB_Nominal.US06.csv', 'HeaderLines', 4 );  
  
fuel_data.shaft_torque_Nm = [ftp_data.TA_RigidOut_BE; hwfet_data.TA_RigidOut_BE;  
us06_data.TA_RigidOut_BE];
```

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```
fuel_data.speed_rpm = [ftp_data.OM_PostProcess_BE; hwfet_data.OM_PostProcess_BE;  
us06_data.OM_PostProcess_BE];  
fuel_data.fuel_gps = [ftp_data.Fuel_rate_out_hot; hwfet_data.Fuel_rate_out_hot;  
us06_data.Fuel_rate_out_hot];  
fuel_data.accessory_power_W = [ftp_data.PowerAccessoryLoad_F010;  
hwfet_data.PowerAccessoryLoad_F010; us06_data.PowerAccessoryLoad_F010];
```

**% Compute gross engine torque (shaft and accessories)**

```
fuel_data.torque_Nm = fuel_data.shaft_torque_Nm + fuel_data.accessory_power_W ./ (  
fuel_data.speed_rpm * convert.rpm2radps) ;
```

## Load Ricardo Map Images

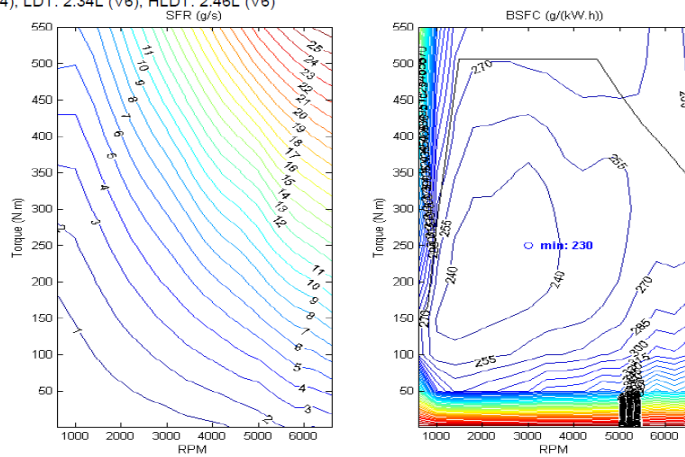
Source: GE118\_Input\_Data\_Review\_v38\_-\_SI\_for\_EPA.pdf - Slide 15

*Note: Images are for a nominal 2.4L I4 and must be scaled to matching displacement and number of cylinders using Ricardo Scaling methodology "Scaling\_Metholodogy\_review\_v07.pdf" A BSFC correction was applied as engine displacements were changed, based on a Ricardo study. This correction was predominantly a correction of thermal losses relative to combustion system surface-to-volume ratio.*

### EGR Boost DI with Cam Switching



- The following is an example of a 2.4L, 240 kW I-4 map for this technology
- This engine technology is used in all seven vehicle classes. The reference displacement and engine configurations are as follows:
  - Small Car: 0.69L (I3), Standard Car: 1.04L (I3), Small MPV: 1.16L (I3), Full Sized Car: 1.58L (I4), Large MPV: 1.51L (I4), LDT: 2.34L (V6), HLDT: 2.46L (V6)

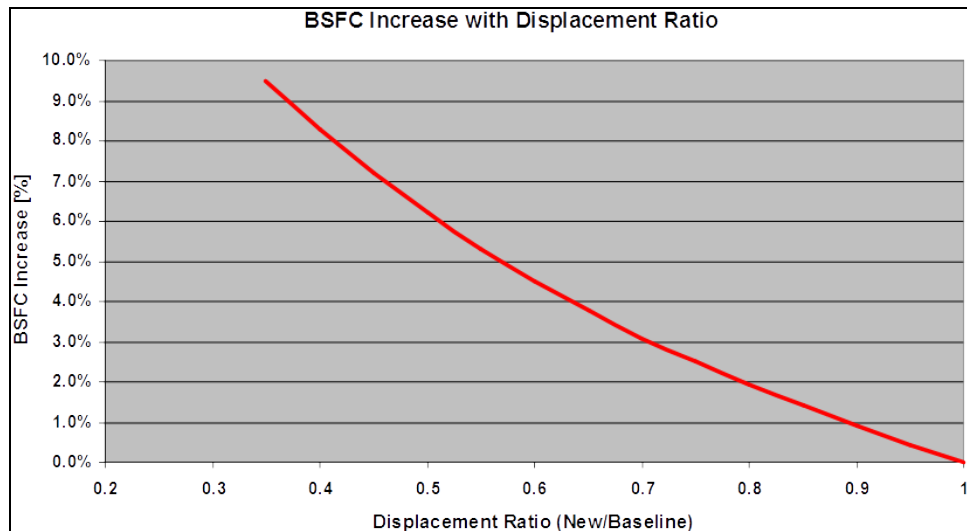


GE118 RICARDO, Inc. Proprietary Competition Sensitive Data 18 March 2010 RD\_10/181305.1 ©Ricardo plc 2010 15

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## % Ricardo Scale adjustments

```
scale_factor = engine.displacement_L / 2.4;
```

```
cylinder_scale_factor = (engine.displacement_L / engine.num_cylinders) / (2.4 / 4);
```

```
scale_bsfc = @(s) -0.1058.*s.^3 + 0.3458.*s.^2 + -.4565.*s + 1.2164;
```

```
image_data.torque_Nm = image_data.torque_Nm * scale_factor;
```

```
image_data.fuel_gps = image_data.fuel_gps * scale_factor * scale_bsfc(cylinder_scale_factor);
```

## Obtain Maximum Torque (WOT) Curve Data

Source: GE118\_Input\_Data\_Review\_v38\_-\_SI\_for\_EPA.pdf - Slide 15

```
load('.../data/map_image_points\2.4_EGRB_DI_tc_pts.mat');
```

```
WOT_data.speed_rpm = tc(:, 1);
```

```
WOT_data.torque_Nm = tc(:, 2) * scale_factor;
```

```
disp(struct2table(WOT_data))
```

<u>speed_rpm</u>	<u>torque_Nm</u>
617.4	63.466
779.87	71.903
1005.2	125.97
1482.2	219.93
4511.5	219.93
4999	199.6
6010.5	165.86
6602.7	147.06

## Process for Generating Engine Fuel Consumption Map

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### Obtain Minimum Torque (Motoring) Curve Data

Source: standard\_car\_EGRB\_Nominal.FTP.csv

Source: standard\_car\_EGRB\_Nominal.HWFET.csv

Source: standard\_car\_EGRB\_Nominal.US06.csv

*Note: These Ricardo simulations were completed as part of the final rulemaking for MY2017-2025 light duty greenhouse gas standards and provide a record of engine characteristics, including the motoring curve. The simulation included operation along the motoring curve that was analyzed to construct minimum torque curve.*

### Obtain Fuel Properties

Source: Ricardo file 2020 Camry EGRB nominal rev30.xlsm

- Heating value: 44.0 MJ/kg
- Specific Gravity: 0.739
- Specific CO<sub>2</sub>: 9087 g/gal

*Note: Fuel and associated fuel map data are normalized to a standard fuel when conducting technology assessments*

#### %Load from fuel database

```
engine.fuel = class_REVS_fuel('RICARDO_GASOLINE');  
disp(engine.fuel);
```

```
class_REVS_fuel with properties:  
    id: 'RICARDO_GASOLINE'  
    description: 'Estimated Ricardo Gasoline'  
    density_kgpL_15C: 0.73829  
    energy_density_MJpkg: 44  
    carbon_weight_fraction: 0.88651  
    anti_knock_index: []  
    research_octane_number: []  
    motor_octane_number: []  
    cetane_number: []  
    alcohol_pct_vol: 0  
    gCO2pgal: 9087  
    energy_density_BTUplbm: 18917  
    specific_gravity: 0.739
```

### Calibrate Idle Fuel Consumption and Define Idle Speed

Source: standard\_car\_EGRB\_Nominal.FTP.csv

Simulation included idle operation that was analyzed to determine idle speed and fuel consumption.

```
engine.idle_speed_radps = 789 * convert.rpm2radps ;
```

### Build Fuel Consumption Map

*Notes: Generate fuel map and WOT curves using REVS\_build\_engine with default settings. This map defines the complete operating boundaries of the engine needed for ALPHA modeling, including idle, WOT, minimum torque, and maximum speed.*

```
out_speed = [0: 200: 3000, 3500: 500: 7000] * convert.rpm2radps;
out_torque = -50: 10: 230;

engine = REVS_build_engine(engine, fuel_data, WOT_data, [],
'out_speed', out_speed, 'out_torque', out_torque, 'no_point_labels');
```

### Set Model Calibration Options

*Note: These parameters influence particular behaviors within the ALPHA model. They often do not have a corresponding value with test data, but are calibrated to match observed behavior.*

Accelerator pedal maps to engine power - standard for passenger cars

```
engine.pedal_map_type = enum_engine_pedal_map_type.max_engine_power;

% Default Fueling Adjustments – Same as Chevy Malibu
engine.refuel_profile_mult = [1 2 1];
engine.refuel_profile_time_secs = [0 0.1 4];
engine.refuel_limit_gps = 3;
engine.refuel_min_defuel_duration_secs = 0.5;

engine.acceleration_penalty_gpradps2 = 0.01;
engine.acceleration_penalty_squelch_gps = 0.1;

% Transient Response
engine.throttle_duration_secs = 0.2;
engine.boost_time_constant_secs = 0.7;
```

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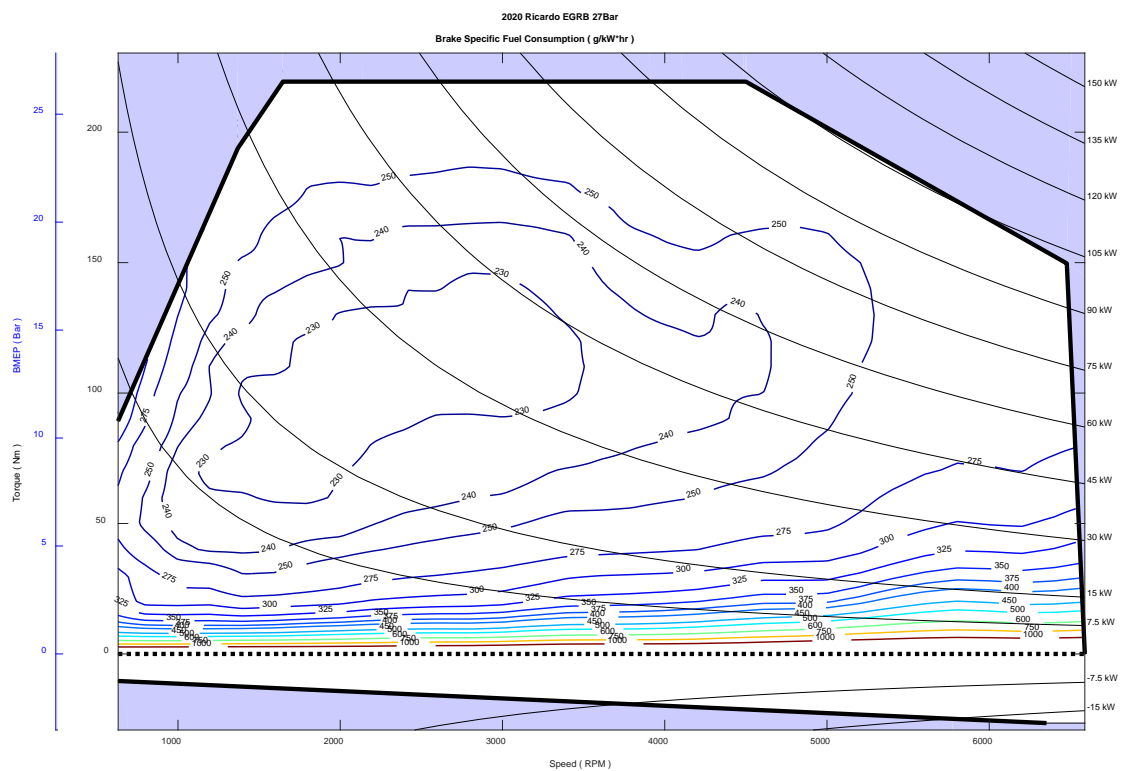
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Note: Simulation data exhibited substantial reductions in fueling rate during upshifting

```
engine.fast_torque_fuel_adjust_norm = 1.0;
```

## Generate File for 27-Bar Engine

```
write_REVS_engine('engine_std_car_EGRB27.m', engine);  
REVS_plot_engine_bsfrc(engine, 'show_bmep', 'no_min_bsfrc', 'show_ctp_curve')
```



## Convert 27-Bar Engine to 24-Bar Engine

Determine torque reduction for reducing boost level from 27 Bar to 24 Bar BMEP. Apply reduction then scale engine back up to match 27 Bar torque level. Include BSFC adjustment factor for scaling.

```
engine.full_throttle_torque_Nm = min(engine.full_throttle_torque_Nm, max(  
engine.full_throttle_torque_Nm * 24/27));
```

```
% Scale engine back to max torque  
scale_factor = 27/24;
```

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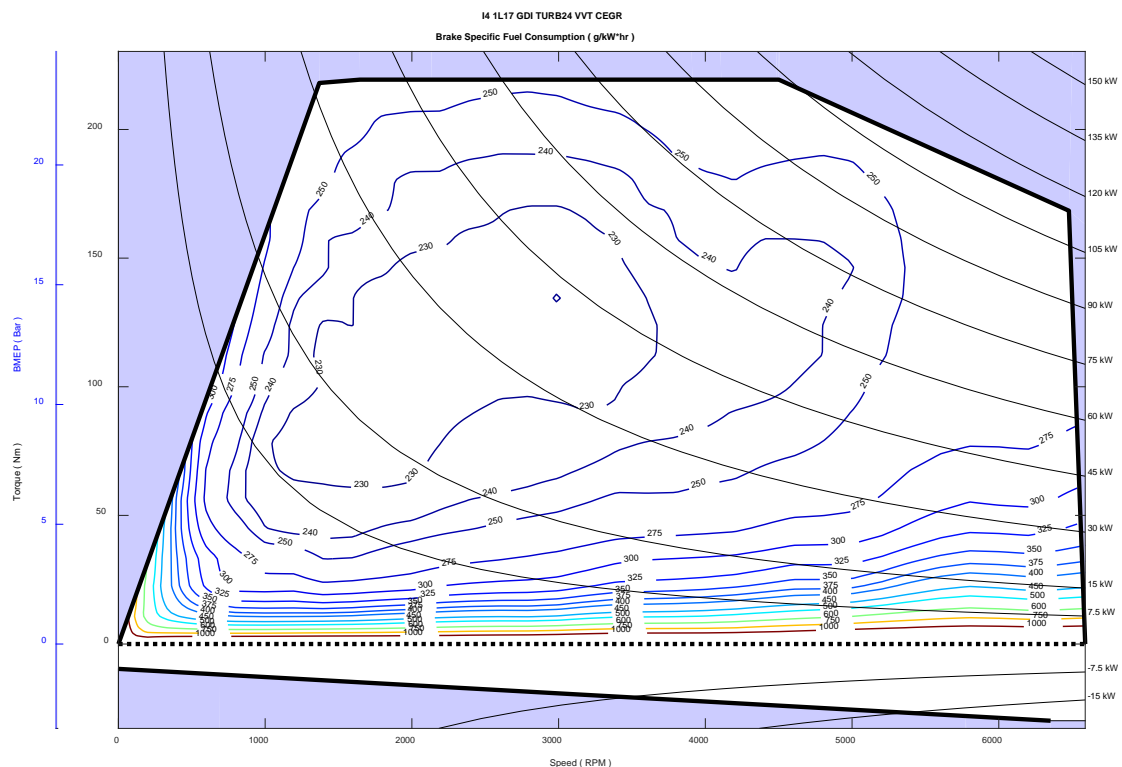
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```
cylinder_scale_factor = scale_factor;  
scale_bsfrc = @(s) -0.1058.*s.^3 + 0.3458.*s.^2 + -.4565.*s + 1.2164;  
  
engine.displacement_L = engine.displacement_L * scale_factor;  
engine.full_throttle_torque_Nm = engine.full_throttle_torque_Nm * scale_factor;  
engine.fuel_map_torque_Nm = engine.fuel_map_torque_Nm * scale_factor;  
engine.fuel_map_gps = engine.fuel_map_gps * scale_factor * scale_bsfrc(cylinder_scale_factor);  
  
engine.name = 'Ricardo 24 Bar EGR Boost DI with Cam Switching for Std Car';
```

## Build Fuel Consumption Map

*Note: Generate fuel map and WOT curve using REVS\_build\_engine. This map defines the complete operating boundaries of the engine needed for ALPHA vehicle simulations, including idle, WOT, minimum torque, and maximum speed.*

```
REVS_plot_engine_bsfrc( engine, 'show_bmp', 'no_min_bsfrc', 'show_ctp_curve' )
```



## Save Engine Consumption Map for 24-bar Engine

```
write_REVS_engine( 'engine_std_car_EGRB24.m', engine);
```

## Display Summary of Engine Fuel Consumption Map Information (24-bar engine)

*Note: The listing below shows only the engine's fuel consumption map related information contained in the ALPHA Engine Definition .m file for this engine. This information is a subset of the full engine definition .m file that adds vehicle level information related to dynamic fuel use, accessories, etc.*

```
% ALPHA ENGINE DEFINITION
% Generated 10-Nov-2016 14: 16: 31
% Ricardo 24 Bar EGR Boost DI with Cam Switching for Std Car

% Constructor
engine = class_REVS_engine_legacy();
engine.name = mfilename;
engine.matrix_vintage = enum_matrix_vintage.future;

% Physical Description
engine.combustion_type = enum_engine_combustion_type.spark_ignition;
engine.displacement_L = 1.1700000;
engine.num_cylinders = 3.0000000;
engine.inertia_kgm2 = 0.0844;

% Fuel Properties
engine.fuel = class_REVS_fuel('RICARDO_GASOLINE');

% Idle Speed
engine.idle_speed_radps.axis_1.signal = 'veh_spd_mps';
engine.idle_speed_radps.axis_1.breakpoints = [0, 1];
engine.idle_speed_radps.table = [82.6239, 82.6239];

% Pedal Calibration
engine.pedal_map_type = enum_engine_pedal_map_type.max_engine_power;

% Maximum Torque Curve
engine.full_throttle_speed_radps = [ 0, 143.371, 172.454, 223.674,
409.609, 430.247, 469.989, 471.327, 678.367, 690 ];
engine.full_throttle_torque_Nm = [ 0, 218.078, 219.375, 219.375,
219.375, 219.375, 219.375, 219.375, 168.419, 0, ];

% Minimum Torque Curve
engine.closed_throttle_speed_radps = [ 0, 72.5, 604.812, 665.293, ];
engine.closed_throttle_torque_Nm = [ -9.66416, -11.8605, -27.9868, -29.8191,
];

% Fuel Map
engine.fuel_map_speed_radps = [ 0, 20.944, 41.8879, 62.8319, 83.7758, 104.72,
```



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```
125. 664, 146. 608, 167. 552, 188. 496, 209. 44, 230. 383,
251. 327, 272. 271, 293. 215, 314. 159, 335. 103, 356. 047,
376. 991, 397. 935, 418. 879, 439. 823, 460. 767, 481. 711,
502. 655, 523. 599, 544. 543, 565. 487, 586. 431, 607. 375,
628. 319, 649. 262, 670. 206, 691. 15, ];
engine.fuel_map_torque_Nm = [ -56. 25, -45, -33. 75, -22. 5, -11. 25, 0, 11. 25, 22. 5,
33. 75, 45, 56. 25, 67. 5, 78. 75, 90, 101. 25, 112. 5, 123. 75, 135, 146. 25, 157. 5,
168. 75, 180, 191. 25, 202. 5, 213. 75, 225, 236. 25, 247. 5, 258. 75, 270, ];
engine.fuel_map_gps = [
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, ;
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, ;
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000,
0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, 0. 00000000, ;
0. 00000000, 0. 0080524087, 0. 023449247, 0. 038429945, 0. 052872803, 0. 067376869, 0. 082968835,
0. 099838899, 0. 11553744, 0. 13067875, 0. 15046621, 0. 17226647, 0. 19395691, 0. 21400797,
0. 23457490, 0. 26100669, 0. 29581814, 0. 33069413, 0. 35683721, 0. 37753039, 0. 39713235,
0. 42911815, 0. 48354129, 0. 54389630, 0. 60862905, 0. 67872812, 0. 75235461, 0. 82248625,
0. 87997061, 0. 92496182, 0. 95584220, 0. 98447104, 1. 0265382, 1. 0799594, ;
0. 014243122, 0. 036555576, 0. 058375455, 0. 079884570, 0. 10246101, 0. 12691754, 0. 15252833,
0. 17859235, 0. 20674573, 0. 23922908, 0. 27183082, 0. 30628826, 0. 34004713, 0. 37052731,
0. 39700814, 0. 43405481, 0. 48374368, 0. 53012724, 0. 56349755, 0. 59904827, 0. 64018822,
0. 69197450, 0. 75618127, 0. 81922049, 0. 88087127, 0. 94988015, 1. 0424612, 1. 1453128,
1. 2431310, 1. 3272637, 1. 3488119, 1. 3497906, 1. 4061556, 1. 4952119, ;
0. 044464277, 0. 072498198, 0. 099990350, 0. 12610483, 0. 15195451, 0. 18926691, 0. 22836065,
0. 25733602, 0. 29715741, 0. 33864058, 0. 38100566, 0. 43257866, 0. 47912550, 0. 52462906,
0. 56791894, 0. 61603007, 0. 67769587, 0. 74080643, 0. 78876682, 0. 83881353, 0. 89292932,
0. 95314782, 1. 0237031, 1. 0991118, 1. 1476064, 1. 2049795, 1. 3188053, 1. 4608193,
1. 5954395, 1. 7028751, 1. 7349923, 1. 7518952, 1. 8205346, 1. 9189736, ;
0. 088019272, 0. 11637227, 0. 14733423, 0. 18353035, 0. 22329998, 0. 25807013, 0. 30721560,
0. 34153124, 0. 39178566, 0. 45105052, 0. 51246754, 0. 57513864, 0. 63631710, 0. 69615819,
```

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0. 75914925,	0. 82638830,	0. 90208062,	0. 98190241,	1. 0513232,	1. 1148743,	1. 1800892,
1. 2494624,	1. 3345511,	1. 4254187,	1. 4864496,	1. 5488526,	1. 6638562,	1. 8052066,
1. 9408791,	2. 0569059,	2. 1187289,	2. 1686526,	2. 2656668,	2. 3837717, ;	
0. 15196448,	0. 16984636,	0. 19165231,	0. 22322698,	0. 27105314,	0. 31460073,	0. 37114608,
0. 43316510,	0. 49629003,	0. 56698773,	0. 63669650,	0. 71025413,	0. 78324058,	0. 85860777,
0. 93803380,	1. 0138097,	1. 0989915,	1. 1854367,	1. 2612119,	1. 3381207,	1. 4159941,
1. 4959269,	1. 5977658,	1. 7049422,	1. 7888544,	1. 8724911,	1. 9952648,	2. 1495490,
2. 3041304,	2. 4314099,	2. 5072162,	2. 5747245,	2. 7050531,	2. 8655181, ;	
0. 23292048,	0. 23452391,	0. 24133324,	0. 26411792,	0. 31887867,	0. 38327161,	0. 45713184,
0. 53164648,	0. 60927535,	0. 68630157,	0. 76251274,	0. 85406395,	0. 94234731,	1. 0260729,
1. 1112767,	1. 2027311,	1. 3024434,	1. 4053666,	1. 4840883,	1. 5655630,	1. 6628952,
1. 7673302,	1. 8811522,	1. 9872832,	2. 0800652,	2. 1958762,	2. 3526172,	2. 5220286,
2. 6807022,	2. 8316426,	2. 9066580,	2. 9924814,	3. 1508662,	3. 3484537, ;	
0. 30611697,	0. 30611697,	0. 30611697,	0. 32151650,	0. 38572162,	0. 45439503,	0. 53908651,
0. 62798311,	0. 71242861,	0. 80008673,	0. 89701099,	1. 0041650,	1. 1069833,	1. 2051800,
1. 3049531,	1. 4045920,	1. 5135779,	1. 6215617,	1. 7246793,	1. 8292238,	1. 9343124,
2. 0406061,	2. 1722044,	2. 3031201,	2. 4275237,	2. 5617117,	2. 7306106,	2. 9179491,
3. 0848188,	3. 2287980,	3. 3383997,	3. 4629650,	3. 6116494,	3. 7867622, ;	
0. 34873861,	0. 35091940,	0. 35920376,	0. 38891225,	0. 46354543,	0. 53025578,	0. 62053295,
0. 72158381,	0. 82569817,	0. 93622473,	1. 0405920,	1. 1586586,	1. 2812186,	1. 3885562,
1. 4942136,	1. 6011529,	1. 7315888,	1. 8603329,	1. 9796524,	2. 0941170,	2. 2160686,
2. 3398778,	2. 4601598,	2. 5878725,	2. 7487384,	2. 9182477,	3. 0822431,	3. 2928273,
3. 4811728,	3. 6344899,	3. 7568965,	3. 8634932,	4. 0485495,	4. 2501305, ;	
0. 37142109,	0. 39836061,	0. 42987396,	0. 47416916,	0. 54319511,	0. 62254785,	0. 71911526,
0. 83079569,	0. 93758055,	1. 0569607,	1. 1757538,	1. 3130532,	1. 4435327,	1. 5770993,
1. 6986226,	1. 8157873,	1. 9261485,	2. 0519439,	2. 2153623,	2. 3590968,	2. 4950442,
2. 6428930,	2. 7833906,	2. 9192835,	3. 0754870,	3. 2766116,	3. 4919306,	3. 7004629,
3. 9197925,	4. 0972486,	4. 2210165,	4. 3521617,	4. 5268063,	4. 7064251, ;	
0. 40954798,	0. 46198520,	0. 51755827,	0. 58006615,	0. 64984921,	0. 71729070,	0. 83037617,
0. 94570643,	1. 0548164,	1. 1833704,	1. 3184523,	1. 4613314,	1. 6012623,	1. 7484830,
1. 8867902,	2. 0150853,	2. 1533367,	2. 2988791,	2. 4519245,	2. 6184850,	2. 7723964,
2. 9164027,	3. 0797513,	3. 2517743,	3. 4314929,	3. 6144139,	3. 8825481,	4. 1181745,
4. 3026085,	4. 4858736,	4. 6488337,	4. 7905951,	4. 9711653,	5. 1787145, ;	
0. 47451293,	0. 54259212,	0. 61062722,	0. 67785954,	0. 74374322,	0. 81258274,	0. 93535530,
1. 0366202,	1. 1577445,	1. 3065125,	1. 4631172,	1. 6147017,	1. 7724143,	1. 9155405,
2. 0497840,	2. 2012100,	2. 3608324,	2. 5243168,	2. 7026645,	2. 8753841,	3. 0704003,
3. 2581898,	3. 4179782,	3. 5755265,	3. 7703616,	3. 9704238,	4. 2339105,	4. 5165257,
4. 7364789,	4. 9246709,	5. 0993529,	5. 2592108,	5. 4247443,	5. 6188207, ;	
0. 56516621,	0. 63832775,	0. 71128590,	0. 78350667,	0. 85438403,	0. 92584158,	1. 0232820,
1. 1535646,	1. 3259803,	1. 4568759,	1. 6001875,	1. 7883202,	1. 9326423,	2. 0787035,
2. 2535559,	2. 3907149,	2. 5786531,	2. 7727688,	2. 9640569,	3. 1760074,	3. 3484969,
3. 5720495,	3. 7450670,	3. 9188898,	4. 1474286,	4. 3726671,	4. 6318246,	4. 9437654,
5. 1901116,	5. 4155231,	5. 5844650,	5. 7597442,	5. 9364487,	6. 0858915, ;	
0. 68053442,	0. 75019690,	0. 82088794,	0. 89356367,	0. 96689387,	1. 0384657,	1. 1387878,
1. 2885516,	1. 4455955,	1. 5979477,	1. 7766101,	1. 9337612,	2. 1015626,	2. 3023610,
2. 4364224,	2. 5866998,	2. 8129560,	3. 0164435,	3. 2537034,	3. 4782452,	3. 6842973,
3. 9099824,	4. 0996507,	4. 2826485,	4. 5043890,	4. 7305664,	4. 9968958,	5. 3416067,
5. 6214629,	5. 8697707,	6. 0555546,	6. 2214353,	6. 4110254,	6. 5893656, ;	
0. 82045782,	0. 88052671,	0. 94107519,	1. 0041056,	1. 0739688,	1. 1585702,	1. 2732953,
1. 4393682,	1. 5807189,	1. 7725001,	1. 9324948,	2. 1134705,	2. 3243945,	2. 4648929,
2. 6666493,	2. 8453527,	3. 0733233,	3. 3083924,	3. 5585815,	3. 8261424,	4. 0729511,

# Process for Generating Engine Fuel Consumption Map

(Ricardo Cooled EGR Boost 24-bar Standard Car Engine Tier 2 Fuel)

Version: 11-28-2016

4. 2979966,	4. 4045054,	4. 6560652,	4. 8667565,	5. 1000887,	5. 4029048,	5. 7747034,
6. 0774945,	6. 3147645,	6. 5322242,	6. 7188249,	6. 9069235,	7. 1146411, ;	
0. 98066243,	1. 0319339,	1. 0826349,	1. 1346281,	1. 1960490,	1. 2824456,	1. 4014448,
1. 5416585,	1. 7483145,	1. 9317719,	2. 1305958,	2. 3354507,	2. 5036906,	2. 7179297,
2. 8900475,	3. 1018697,	3. 3464579,	3. 5858062,	3. 9034633,	4. 1775032,	4. 4401330,
4. 6693341,	4. 8374118,	5. 0564162,	5. 2815410,	5. 5264577,	5. 8330029,	6. 2457128,
6. 5723767,	6. 8169316,	7. 0061967,	7. 1555145,	7. 3704503,	7. 5867175, ;	
1. 1549559,	1. 2009446,	1. 2469599,	1. 2904081,	1. 3236544,	1. 3755017,	1. 5020081,
1. 6883537,	1. 9256369,	2. 1250540,	2. 3386889,	2. 5182081,	2. 7559425,	2. 9415273,
3. 1505425,	3. 3778673,	3. 6288941,	3. 9099375,	4. 2269133,	4. 4869851,	4. 7971392,
5. 0581847,	5. 2882096,	5. 5145552,	5. 7367857,	5. 9694937,	6. 3131616,	6. 7358047,
7. 0310618,	7. 2704364,	7. 4704615,	7. 8588257,	8. 0999125,	8. 0999125, ;	
1. 3394279,	1. 3743512,	1. 4103524,	1. 4470737,	1. 4789890,	1. 5338275,	1. 6581221,
1. 8548977,	2. 0379497,	2. 2815260,	2. 4859261,	2. 7463997,	2. 9495567,	3. 2080722,
3. 4408551,	3. 6724253,	3. 9356232,	4. 2170727,	4. 5676780,	4. 8879522,	5. 1993089,
5. 4972488,	5. 6962083,	5. 9196419,	6. 1691759,	6. 4609136,	6. 8542729,	7. 2217195,
7. 4925696,	7. 8068779,	8. 2494833,	8. 4518442,	8. 5891982,	8. 5891982, ;	
1. 5300623,	1. 5494268,	1. 5692798,	1. 5934973,	1. 6337546,	1. 7110567,	1. 8326097,
1. 9778259,	2. 2135987,	2. 4523646,	2. 7282416,	2. 9737906,	3. 2265993,	3. 4756183,
3. 7445804,	4. 0162709,	4. 3091650,	4. 6157707,	4. 9056467,	5. 3035180,	5. 6388942,
5. 9243156,	6. 1799182,	6. 4332334,	6. 6910249,	6. 9943428,	7. 3614931,	7. 7014601,
8. 2024336,	8. 5130493,	8. 7399211,	8. 7399211,	8. 8815793,	9. 0748629, ;	
1. 7185310,	1. 7291875,	1. 7408818,	1. 7545731,	1. 7690595,	1. 8119375,	1. 9373301,
2. 1246937,	2. 4081656,	2. 6266292,	2. 9077674,	3. 2105155,	3. 4731234,	3. 7550494,
4. 0129833,	4. 2958549,	4. 6286753,	4. 9447777,	5. 3340400,	5. 7083198,	6. 0367429,
6. 3711085,	6. 6539201,	6. 9110480,	7. 2047260,	7. 5580303,	7. 9235996,	8. 3637292,
8. 7822939,	9. 0086808,	9. 0524908,	9. 1926907,	9. 4137552,	9. 5997743, ;	
1. 8945518,	1. 9031001,	1. 9111014,	1. 9178763,	1. 9212059,	1. 9564303,	2. 0953271,
2. 2950440,	2. 5600504,	2. 8649365,	3. 1658116,	3. 4611973,	3. 7477768,	4. 0428719,
4. 3439212,	4. 6708103,	5. 0339523,	5. 3956924,	5. 7488098,	6. 1130389,	6. 4654672,
6. 7920220,	7. 0875099,	7. 4128622,	7. 7804863,	7. 9532680,	8. 1798265,	8. 8212533,
9. 0266647,	9. 2658471,	9. 5011483,	9. 7228616,	9. 9205153,	10. 100442, ;	
2. 0436906,	2. 0609468,	2. 0745239,	2. 0830481,	2. 0982419,	2. 1564747,	2. 2904668,
2. 4765147,	2. 7251953,	3. 0490673,	3. 3708979,	3. 7063142,	4. 0252032,	4. 3450903,
4. 6813479,	5. 0447446,	5. 3971031,	5. 7455121,	6. 1098906,	6. 4800246,	6. 8351420,
7. 2102328,	7. 5675077,	7. 9042725,	8. 1273248,	8. 2171550,	8. 7554146,	9. 1995154,
9. 5341190,	9. 8032168,	10. 018516,	10. 228394,	10. 421230,	10. 593560, ;	
2. 1537014,	2. 1930405,	2. 2318916,	2. 2633426,	2. 2633426,	2. 2801572,	2. 4217053,
2. 6497942,	2. 9130832,	3. 2295354,	3. 5914737,	3. 9431857,	4. 2888403,	4. 6307716,
4. 9903102,	5. 3496200,	5. 7116350,	6. 0868188,	6. 4834083,	6. 9147619,	7. 3142531,
7. 7110076,	8. 0639035,	8. 3452473,	8. 6357863,	9. 1706164,	9. 5137057,	9. 7381932,
9. 9897920,	10. 322733,	10. 534422,	10. 728441,	10. 906048,	11. 077345, ;	
2. 2270538,	2. 2804739,	2. 3315608,	2. 3734661,	2. 3942399,	2. 4343557,	2. 5814556,
2. 8168926,	3. 1358824,	3. 4704852,	3. 8064392,	4. 1852931,	4. 5426034,	4. 9145982,
5. 3258712,	5. 7305987,	6. 1330596,	6. 5448095,	6. 9471072,	7. 3520514,	7. 7419496,
8. 1355002,	8. 4461299,	8. 8520198,	9. 3060556,	9. 6734250,	9. 9826448,	10. 274280,
10. 471645,	10. 817619,	11. 038921,	11. 227712,	11. 400709,	11. 558128, ;	
2. 2681698,	2. 3299968,	2. 3906420,	2. 4518508,	2. 5239806,	2. 6299058,	2. 7926000,
3. 0199181,	3. 3231491,	3. 6543805,	4. 0454958,	4. 4457070,	4. 8251763,	5. 2171813,
5. 6189921,	6. 0640262,	6. 4783344,	6. 8947438,	7. 3067497,	7. 7442651,	8. 1741774,
8. 6062256,	9. 0014211,	9. 3981346,	9. 7796708,	10. 155806,	10. 480113,	10. 776478,

## Process for Generating Engine Fuel Consumption Map

(Ricardo Cooled EGR Boost 24-bar Standard Car Engine Tier 2 Fuel)

Version: 11-28-2016

```
10. 966302,    11. 306632,    11. 545469,    11. 733795,    11. 900593,    12. 039519, ;  
    2. 2908040,    2. 3664186,    2. 4466536,    2. 5394049,    2. 6533353,    2. 7948160,    2. 9703138,  
3. 2016637,    3. 5101138,    3. 8817200,    4. 2827268,    4. 7050544,    5. 0977488,    5. 5219874,  
5. 9852156,    6. 4281682,    6. 8509672,    7. 2913966,    7. 7301450,    8. 1818065,    8. 6283430,  
9. 0569408,    9. 4644085,    9. 8755238,    10. 272894,    10. 645833,    10. 980951,    11. 272776,  
11. 479148,    11. 785955,    12. 055258,    12. 261249,    12. 415787,    12. 543808, ];
```

```
engine.refuel_profile_mult = [ 1 2 1];  
engine.refuel_profile_time_secs = [ 0 0.1 4];  
engine.refuel_limit_gps = 3;  
engine.refuel_min_defuel_duration_secs = 0.5;
```

```
engine.acceleration_penalty_gpradps2 = 0.01;  
engine.acceleration_penalty_squelch_gps = 0.1;
```

```
engine.throttle_duration_secs = 0.2;  
engine.boost_time_constant_secs = 0.7;
```

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### Revision History

Version 06-20-2016: Initial release

Version 11-28-2016: (a) Added transient fuel adjustments characteristics to the calibrations options; (b) modified maximum and minimum speed and torque characteristics; (c) regenerated fuel map grid points and recalculated fuel consumption; and (d) corrected BSFC images.