

Process for Generating Engine Fuel Consumption Map

(Mazda SKYACTIV 2.0L engine using Tier 2 fuel)

Version: 11-28-2016

This document summarizes the process followed to utilize laboratory engine dyno test data and generate a full engine fuel consumption map which can be used by EPA's ALPHA vehicle simulations. 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: http://en.wikipedia.org/wiki/SkyActiv#2.0_L

```
engine.name = '2014 Mazda Skyactiv 2.0L US Tier 2';  
engine.combustion_type = enum_engine_combustion_type.spark_ignition;  
engine.displacement_L = 2.0;  
engine.num_cylinders = 4;
```

Source: Estimated from engine displacement

```
engine.inertia_kgm2 = 0.1;
```

Load Fuel Map Test Data from Core Test Dataset

Source: EPA test data (2014 Mazda 2.0L Skyactiv 13-1 Tier 2 Fuel - Core Test Data.xlsx file)

```
datagrabber('..\data_engine\US Engine 93 AKI\2014 Mazda 2.0L Skyactiv 13-1 Tier 2 Fuel - Core  
Test Data.xlsx', 'structure', 'core_data', 'data_line', 5, 'header_line', 3, 'quiet');  
  
fuel_data.speed_rpm = core_data.Speed;  
fuel_data.torque_Nm = core_data.Torque;  
fuel_data.fuel_gps = core_data.Fuel_Flow;
```

Obtain Maximum Torque (WOT) Curve Data

Source: EPA test data (WOT Curve.csv file)

Source: Published peak power point from http://en.wikipedia.org/wiki/SkyActiv#2.0_L

Note: Test data points below 900 RPM represent the lead-in to the WOT test sweep. An additional maximum power data point was added at 6000 RPM and 116 kW.

```
datagrabber('..\data_engine\US Engine 93 AKI\Torque Curve\WOT  
Curve.csv', 'structure', 'WOT_test_data', 'data_line', 9, 'header_line', 6, 'unit_line', 'none', 'quiet');  
  
lead_in = WOT_test_data.CAN_dyno_spd < 900;  
WOT_data.speed_rpm = WOT_test_data.CAN_dyno_spd( ~lead_in);  
WOT_data.torque_Nm = WOT_test_data.CAN_dyno_trq( ~lead_in);
```

```
WOT_data.speed_rpm(end+1) = 6000;  
WOT_data.torque_Nm(end+1) = 184;
```

Obtain Minimum Torque (Motoring) Curve Data

Source: EPA test data (0% Throttle Curve.csv file)

Note: Test data points below 1350 rpm used fuel, and thus, are not included in the minimum torque curve. We only use data points above 1350 rpm.

```
datagrabber('..\data_engine\US Engine 93 AKI\Torque Curve\0% Throttle  
Curve.csv', 'structure', 'CT_test_data', 'data_line', 9, 'header_line', 6, 'unit_line', 'none', 'quiet');  
  
lead_in = CT_test_data.CAN_dyno_spd < 1350;  
CT_data.speed_rpm = CT_test_data.CAN_dyno_spd( ~lead_in);  
CT_data.torque_Nm = CT_test_data.CAN_dyno_trq( ~lead_in);
```

Obtain Properties of the Fuel Used When Mapping the Engine

Source: FTAG 23945 Referenced in 2014 Mazda 2.0L Skyactiv 13-1 Tier 2 Fuel - Core Test Data.xlsx

Note: When using ALPHA to conduct specific technology assessments, the fuel properties and associated fuel consumption map for this engine definition are adjusted to suit the standard fuel being used during the specific assessment. For example, fuel rate is adjusted for LD GHG assessments to represent a suitable fuel rate with Tier 2 Certification fuel.

```
%Load from fuel database  
engine.fuel = class_REVS_fuel('FTAG 23945');  
disp(engine.fuel);
```

```
class_REVS_fuel with properties:  
    id: 'FTAG 23945'  
    description: 'Tier 2 Cert'  
    density_kgpL_15C: 0.743  
    energy_density_MJpkg: 42.887  
    carbon_weight_fraction: 0.86678  
    anti_knock_index: []  
    research_octane_number: 97.1  
    motor_octane_number: 88.2  
    cetane_number: []  
    alcohol_pct_vol: 0  
    gCO2pgal: 8932.8  
    energy_density_BTUplbm: 18438  
  
    specific_gravity: 0.74371
```

Calibrate Idle Fuel Consumption and Define Idle Speed

Fuel consumption in the idle region of the map is calibrated using vehicle benchmarking data collected on a vehicle chassis dyno. Actual idle fuel consumption during an ALPHA vehicle simulation would depend on the transmission drag and accessory loads.

Source: CANLog_2016.02.09_13.12.31.txt & Others

Note: Chassis testing data shows that engine “idle speed” varies with vehicle speed, which is approximated by the idle speed definition below.

```
% Idle speed dynamic with vehicle speed > 1 m/s => 800 RPM, stopped => 550 RPM
engine.idle_speed_radps.axis_1.signal = 'veh_spd_mps';
engine.idle_speed_radps.axis_1.breakpoints = [ 0, 1 ];
engine.idle_speed_radps.table = [ 550, 800 ] *
convert.rpm2radps;
```

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.

```
engine.pedal_map_type = enum_engine_pedal_map_type.max_engine_power;

%Post DFCO fuel adjustment – calibrated from time series test data
engine.refuel_profile_mult = [1.0, 1.3, 1.0];
engine.refuel_profile_time_secs = [0.0, 1.8];
engine.refuel_limit_gps = 0.2;
engine.refuel_min_defuel_duration_secs = 1.5;

%Acceleration based fuel adjustment – calibrated from time series test data
engine.acceleration_penalty_gpradps2 = 0.007;
engine.acceleration_penalty_squelch_gps = 0.1;

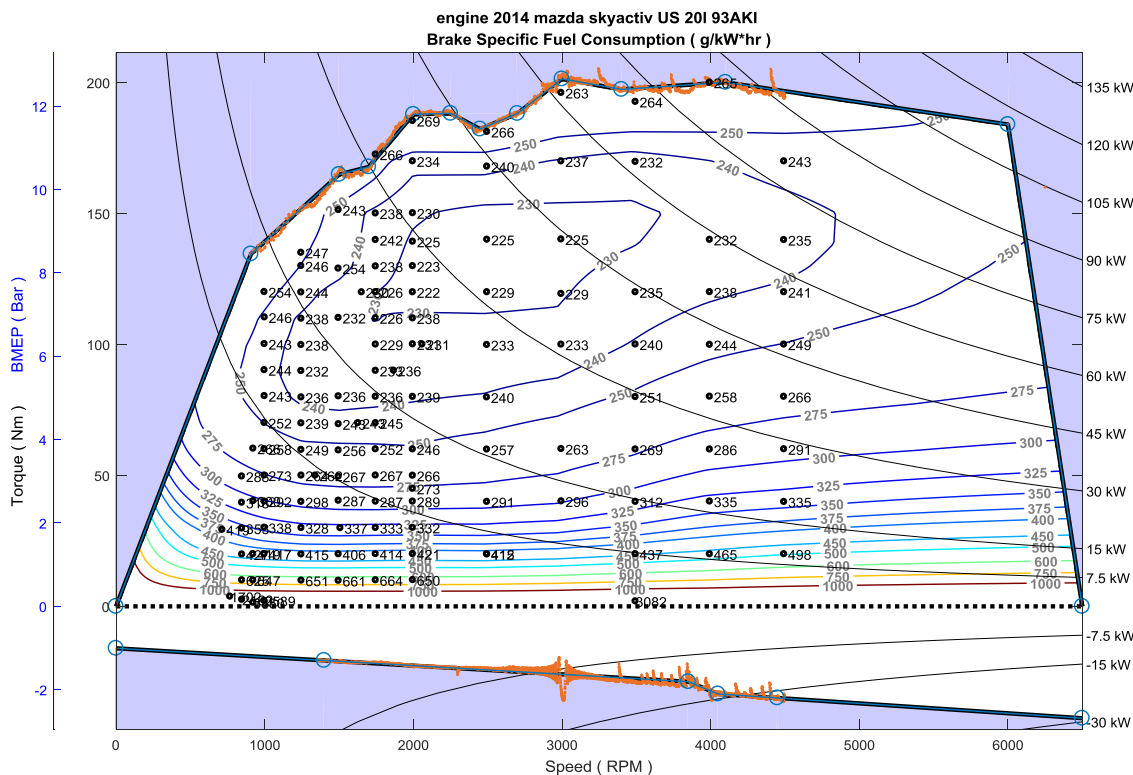
%Transient Response Time Constants
engine.throttle_duration_secs = 0.2;
engine.boost_time_constant_secs = 0.2;
```

Build Fuel Consumption Map

Note: 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.

```
engine = REVS_build_engine(engine, fuel_data, WOT_data, CT_data);
```

NOTE: Individual data points from steady state mapping (shown numerically on map), data points from the WOT sweep (shown as red line on top of map) and data points from the minimum torque sweep (shown as red line on bottom of map) are shown as reference for comparison to the generated contours on the below BSFC map.



Save Engine Fuel Consumption Map

```
wri te_REVS_engi ne( ' engi ne_2014_mazda_skyacti v_US_2LO_ti er2. m' , engi ne);
```

Display Summary of Engine Fuel Consumption Map Information

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 9-Nov-2016 16: 33: 19
% 2014 Mazda Skyactiv 2.0L US Tier 2

% Constructor
engi ne = cl ass_REVS_engi ne_l egacy();
engi ne. name = mfi l ename;
engi ne. matri x_vi ntage = enum_matri x_vi ntage. present;
```

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% Physical Description

```
engine.combustion_type = enum_engine_combustion_type.spark_ignition;  
engine.displacement_L = 2.0;  
engine.num_cylinders = 4;  
engine.inertia_kgm2 = 0.1;
```

% Fuel Properties

```
engine.fuel = class_REVS_fuel('FTAG 23945');
```

% Pedal Calibration

```
engine.pedal_map_type = enum_engine_pedal_map_type.max_engine_power;
```

% Idle Speed

```
engine.idle_speed_radps_axis_1.breakpoints = [ 0.0000000, 1.0000000, ];  
engine.idle_speed_radps_axis_1.signal = 'veh_spd_mps';  
engine.idle_speed_radps.table = [ 57.595865, 83.775804, ];
```

% Maximum Torque Curve

```
engine.full_throttle_speed_radps = [ 0.0000000, ; 95.039723, ; 157.17760,  
; 177.96973, ; 209.47442, ; 235.68091, ; 256.39794,  
; 282.73763, ; 314.14238, ; 356.10551, ; 429.36596,  
; 628.31853, ; 680.67841, ];  
engine.full_throttle_torque_Nm = [ 0.0000000, ; 134.56250, ; 164.92581,  
; 167.81143, ; 187.87381, ; 188.25000, ; 182.26000,  
; 188.21273, ; 201.40161, ; 197.39857, ; 200.09762,  
; 184.00000, ; 0.0000000, ];
```

% Minimum Torque Curve

```
engine.closed_throttle_speed_radps = [ 0.0000000, ; 146.55530, ;  
403.16650, ; 424.02144, ; 465.83686, ; 680.67841, ];  
engine.closed_throttle_torque_Nm = [ -16.013253, ; -20.648276, ; -28.763975,  
; -33.455621, ; -34.963536, ; -42.710982, ];
```

% Fuel Map

```
engine.fuel_map_speed_radps = [ 0.0000000, ; 36.651914, ; 77.911534,  
; 88.717108, ; 96.636591, ; 104.57137, ; 131.17514,  
; 156.89384, ; 182.47688, ; 209.28168, ; 259.25151,  
; 310.88848, ; 363.69599, ; 415.79592, ; 470.78624,  
; 562.86868, ; 654.49847, ; 680.67841, ];  
engine.fuel_map_torque_Nm = [ -39.930000, ; -37.902269, ; -22.223091, ;  
2.2382484, ; 9.6968903, ; 19.390515, ; 29.585804, ;  
39.678512, ; 44.696351, ; 49.575295, ; 59.666747, ;  
69.613486, ; 79.590022, ; 89.729121, ; 99.509874, ;  
109.82373, ; 119.55478, ; 129.52949, ; 138.60774, ;  
150.27497, ; 169.72169, ; 183.07981, ; 195.87002, ;  
211.47169, ];  
engine.fuel_map_gps = [  
0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,  
0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,  
0.0000000, 0.0000000, 0.058039063, 0.088665051, ;  
0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,  
0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,  
0.0000000, 0.013360001, 0.12168356, 0.15397475, ;  
0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000, 0.0000000,
```

Process for Generating Engine Fuel Consumption Map

(Mazda SKYACTIV 2.0L engine using Tier 2 fuel)

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0.0000000,	0.0000000,	0.0050985097,	0.028191796,	0.059167501,	0.091781211,	0.17321426,
0.29104061,	0.44620647,	0.61309570,	0.66035506,	;		
0.022419888,	0.066118981,	0.12037259,	0.13400166,	0.14396259,	0.15393584,	0.18721528,
0.22173433,	0.25763838,	0.29589460,	0.37226642,	0.46883910,	0.59162565,	0.70668604,
0.86164753,	1.1303949,	1.3926907,	1.4674745,	;		
0.030407712,	0.084471339,	0.14728538,	0.16484983,	0.17788400,	0.19104192,	0.23599347,
0.28186167,	0.32918730,	0.37693253,	0.46829312,	0.58077884,	0.71768889,	0.86088126,
1.0442761,	1.3425503,	1.6360371,	1.7198299,	;		
0.040288383,	0.10946246,	0.18750730,	0.20936401,	0.22547117,	0.24169369,	0.29754575,
0.35486960,	0.41549028,	0.47856803,	0.58927824,	0.72248556,	0.88251761,	1.0626647,
1.2828148,	1.6195878,	1.9547663,	2.0505360,	;		
0.048906350,	0.13869632,	0.23833014,	0.26187543,	0.27935162,	0.29710084,	0.36108262,
0.43037763,	0.50176810,	0.57649070,	0.71261007,	0.87104270,	1.0700009,	1.2950711,
1.5256663,	1.9129233,	2.2941356,	2.4029648,	;		
0.055150218,	0.15991875,	0.27536641,	0.30512193,	0.32692595,	0.34889090,	0.42572836,
0.50302783,	0.58381018,	0.67190231,	0.83705987,	1.0240714,	1.2614891,	1.5301854,
1.7716451,	2.2065535,	2.6350781,	2.7573971,	;		
0.057524478,	0.16968113,	0.29411137,	0.32653364,	0.35032942,	0.37423890,	0.45608070,
0.54007217,	0.62736790,	0.72122221,	0.90174225,	1.1049829,	1.3573418,	1.6413685,
1.8992488,	2.3537193,	2.8061617,	2.9353765,	;		
0.059597358,	0.17908131,	0.31272939,	0.34760975,	0.37312805,	0.39870783,	0.48555519,
0.57674122,	0.67067152,	0.76964326,	0.96584913,	1.1848647,	1.4500508,	1.7489794,
2.0240752,	2.4972878,	2.9732083,	3.1092179,	;		
0.063386373,	0.19881927,	0.35186217,	0.39208927,	0.42158458,	0.45114229,	0.55144432,
0.65731175,	0.76260841,	0.87171340,	1.1034260,	1.3528216,	1.6393113,	1.9719881,
2.2822800,	2.7962393,	3.3222055,	3.4727682,	;		
0.069008141,	0.22104229,	0.39329138,	0.43879755,	0.47219361,	0.50568857,	0.61867722,
0.73811467,	0.86131881,	0.98894637,	1.2398808,	1.5180477,	1.8328188,	2.1829442,
2.5312122,	3.0933119,	3.6729243,	3.8390340,	;		
0.078879819,	0.24826754,	0.43997393,	0.49064760,	0.52785257,	0.56519505,	0.69185546,
0.82338387,	0.96041579,	1.1073166,	1.3803941,	1.6827478,	2.0255206,	2.3971664,
2.7757976,	3.3931153,	4.0318575,	4.2149719,	;		
0.095080589,	0.28276400,	0.49508982,	0.55107053,	0.59213789,	0.63331513,	0.77201890,
0.91591853,	1.0662052,	1.2269432,	1.5269549,	1.8485786,	2.2242960,	2.6175915,
3.0208572,	3.7004961,	4.4045571,	4.6063631,	;		
0.11765755,	0.32320127,	0.55546387,	0.61673991,	0.66170854,	0.70681000,	0.85856450,
1.0089628,	1.1673594,	1.3432879,	1.6718654,	2.0087700,	2.4198732,	2.8370972,
3.2602103,	4.0015906,	4.7720354,	4.9928227,	;		
0.14943916,	0.37372782,	0.62737194,	0.69360509,	0.74211468,	0.79069844,	0.95376306,
1.1120507,	1.2790447,	1.4770947,	1.8234602,	2.1912393,	2.6330637,	3.0727560,
3.5242731,	4.3269562,	5.1684929,	5.4096011,	;		
0.18689562,	0.42795397,	0.70201054,	0.77474029,	0.82814199,	0.88170858,	1.0618452,
1.2306682,	1.3929291,	1.5728683,	1.9631294,	2.3635350,	2.8360564,	3.2964340,
3.7771192,	4.6443882,	5.5512189,	5.8108398,	;		
0.23202583,	0.49129522,	0.78549205,	0.86387944,	0.92150094,	0.97938243,	1.1763117,
1.3736502,	1.5421497,	1.7075100,	2.1013316,	2.5457334,	3.0335217,	3.5189878,
4.0374783,	4.9831318,	5.9520578,	6.2290670,	;		
0.27693246,	0.55557952,	0.86897197,	0.95126619,	1.0116168,	1.0721225,	1.2759054,
1.4764671,	1.6654479,	1.8413728,	2.2443869,	2.7171732,	3.2164492,	3.7297579,
4.2872299,	5.3051494,	6.3237003,	6.6144954,	;		
0.33626856,	0.64444137,	0.98625965,	1.0735990,	1.1373595,	1.2010457,	1.4113812,
1.6099851,	1.8126397,	2.0216898,	2.4579374,	2.9525978,	3.4673659,	4.0290019,
4.6505251,	5.7417235,	6.8106723,	7.1154779,	;		

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```
0. 42186651, 0. 79013389, 1. 2027903, 1. 3101986, 1. 3888331, 1. 4675356, 1. 7295128,  
1. 9724616, 2. 1954870, 2. 3948985, 2. 9810353, 3. 5030277, 4. 0198859, 4. 6917533,  
5. 4060615, 6. 5509762, 7. 6507696, 7. 9643189, ;  
0. 46705022, 0. 88435659, 1. 3532842, 1. 4757730, 1. 5655096, 1. 6553912, 1. 9563022,  
2. 2466793, 2. 5363257, 2. 8417249, 3. 4976268, 4. 0204642, 4. 6672979, 5. 3231378,  
6. 0182287, 7. 1502069, 8. 2402703, 8. 5510762, ;  
0. 50390545, 0. 97183214, 1. 4989212, 1. 6371824, 1. 7385456, 1. 8401339, 2. 1813481,  
2. 5137449, 2. 8476212, 3. 2009833, 3. 8531441, 4. 4679786, 5. 2814233, 5. 9669526,  
6. 6422477, 7. 7427513, 8. 8091599, 9. 1133951, ;  
0. 54424179, 1. 0777381, 1. 6798843, 1. 8380107, 1. 9539458, 2. 0701346, 2. 4601098,  
2. 8372806, 3. 2116521, 3. 6021171, 4. 3237310, 5. 1005942, 5. 9354565, 6. 7019252,  
7. 4205916, 8. 4808107, 9. 5061338, 9. 7991452, ];
```

```
engine.refuel_profile_mult = [1.0, 1.3, 1.0];  
engine.refuel_profile_time_secs = [0 0.1 8];  
engine.refuel_limit_gps = 0.2;  
engine.refuel_min_defuel_duration_secs = 1.5;
```

```
engine.acceleration_penalty_gpradps2 = 0.007;  
engine.acceleration_penalty_squelch_gps = 0.1;
```

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

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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; and (c) utilized updated fuel map grid generation method, regenerated the fuel map grid points and recalculated fuel consumption.