USER GUIDE FOR DATA VISUALIZATION TOOL

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Project: C000908
Archive: RD.11/478401.2
Date: 09 May 2012
Non-Confidential

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CAUTION

The Data Visualization Tool design space encompasses many combinations of vehicle class, engine, transmission, and other design parameters. Some combinations are unrealistic and hence may yield results that are not meaningful. While guidance is provided in the User Guide for suitable selections, the Data Visualization Tool itself will not allow some combinations. However, an automotive expert should be consulted for validity of the design choices and results.

EXECUTIVE SUMMARY

This User Guide is for the Data Visualization Tool version of 9 May 2012 (v09-May-2012), which was released by Ricardo on 10 May 2012 to the International Committee on Clean Transportation (ICCT) , as part of the study "Analysis of Greenhouse Gas Emissions Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025".

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1 INTRODUCTION

This User Guide is for the Data Visualization Tool version of 9 May 2012 (v09-May-2012), which was released by Ricardo on 10 May 2012 to the International Committee on Clean Transportation (ICCT) as part of the study "Analysis of Greenhouse Gas Emissions Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025". The User Guide is intended as a companion to the program report "Analysis of Greenhouse Gas Emissions Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025" (RD.12/96201.2; Ricardo, 2012), which provides a comprehensive description of the technology packages that constitute the design space embodied in the Data Visualization Tool. Additional technical background information may also be found in the report "Computer Simulation of Light Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020–2025 Timeframe" (RD.10/157405.8; Ricardo and SRA, 2011).

2 BACKGROUND

The Data Visualization Tool uses the Response Surface Model (RSM) set generated by the Complex Systems approach to represent the vehicle performance simulation results over the design space studied for light duty vehicles in the 2020–2025 timeframe (Ricardo, 2012; Ricardo and SRA, 2011). These simulations cover multiple variations of vehicle configuration, including several combinations of advanced powertrain and vehicle technologies in several LDV classes ranging from B Class Car through Light Commercial Vehicle. Vehicle configurations with unacceptable performance, such as combined fuel economy below a certain threshold or acceleration times longer than some benchmark value, can be excluded from further study. More information on the technology packages included in the design space may be found in the program reports by Ricardo (2012) and by Ricardo and SRA (2011).

The tool samples vehicle configurations from a selected subset of the design space by using Monte Carlo type capabilities to pick input parameter values from a uniform distribution. Defining selected portions of the design space and plotting the results visualizes the effect of these parameters on vehicle fuel economy and performance, allowing trade off analysis via constraints setting to be performed over a wide design space representing the 2020–2025 technologies as applied.

The Data Visualization Tool allows the user to assess efficiently the effects of various combinations of future technologies on GHG emissions and other vehicle performance metrics. The tool allows the user to query the RSM and investigate options leading to equivalent GHG emissions levels.

3 INSTALLING THE DATA VISUALIZATION TOOL

Ensure that you have the file "Data_Visualization_Tool_v09-May-2012.zip", and extract the files within to a directory on your computer. The files should include the following:

- Directory "ComplexToolData"
- Directory "lib"
- File "DatabaseSetup.cfg"
- File "ICCTComplexTool.jar"

Once you have extracted the files from the .zip archive, you can double-click on the ICCTComplexTool.jar (Executable JAR file) file to start it. The first time you extract the files, you should receive this message: "Please set up your database path."

From the main window, click on the "File" menu, then select "Preferences". Use the "Browse" button to pop up a navigation window. Navigate to the directory where you placed the "ComplexToolData" directory, double click on the directory "ComplexToolData" to open it, then click the "Open" button to close the navigation window. Click the "Close" button to close the Preferences menu and save your settings.

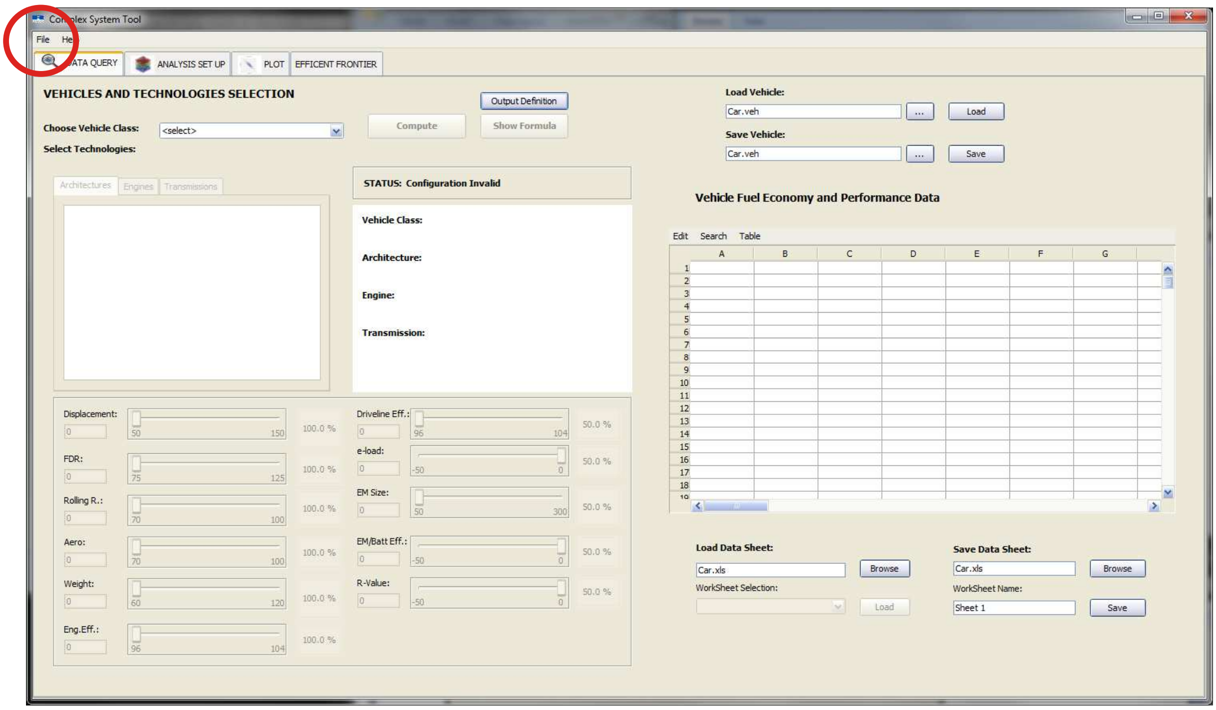


Figure 3.1: Setting up the Data Visualization Tool

4 DESIGN SPACE QUERY

The Design Space Query within the Data Visualization Tool allows the user to assess a specific vehicle configuration in the design space by selecting a platform, engine, and transmission, and by setting the continuous variables within the design space range. The generated performance results are then reported in a table that is exportable to Excel. The user can assess multiple vehicle configurations and compare them in Excel. The tool table also allows the user to apply spreadsheet formulas for quick, on-the-side computation. An example of the Design Space Query is shown in Figure 4.1.

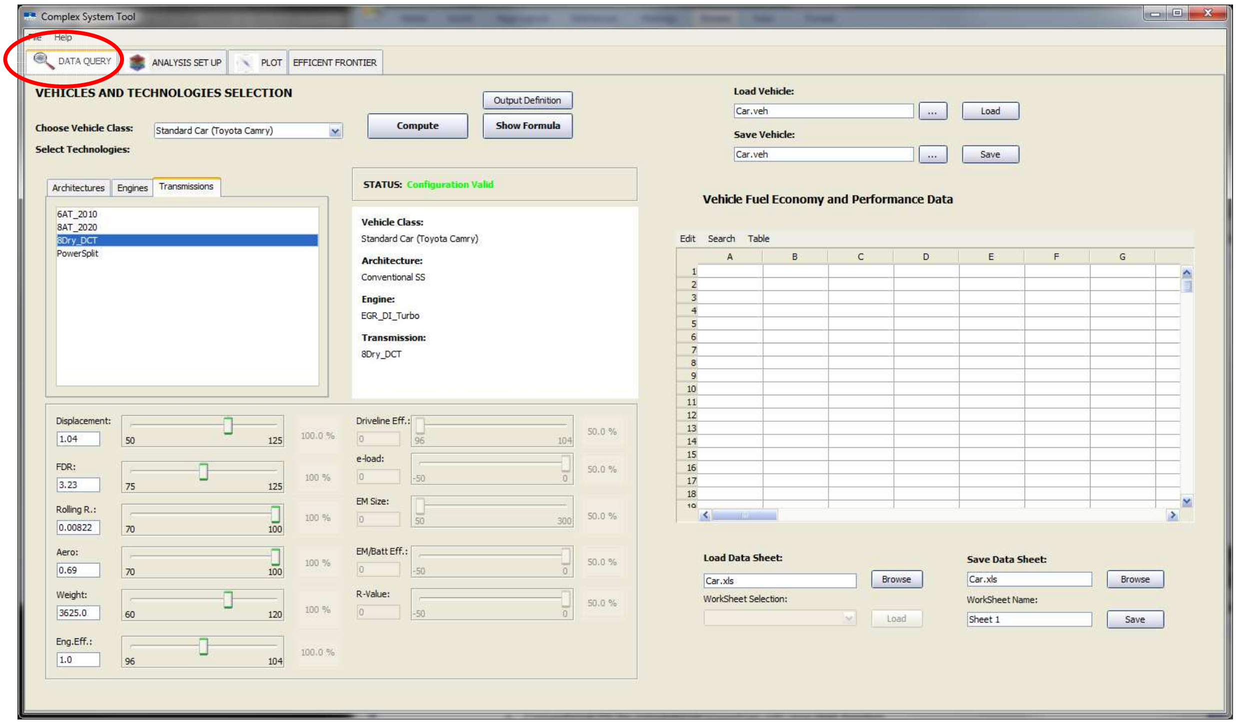


Figure 4.1: Design Space Query Screen

Process:

1. From the pull-down menu, choose a vehicle class: B Class, D Class, Small MPV, Full Size Car, Large N1, Truck, Large LD Truck, and C Class
2. From the "Architecture" tab, choose from:
    a. Conventional SS for conventional powertrain with stop-start function
    b. Hybrid P2 for the P2 Hybrid powertrain [*use with DCT only*]
    c. Hybrid PS for the Powersplit Hybrid powertrain
3. From the "Engines" tab, choose from:
    a. Baseline for the 2010 baseline engine **[Use only with 2010 transmission]**
    b. Stoich_DI_Turbo for the Stoichiometric DI Turbo gasoline engine
    c. Lean_DI_Turbo for the Lean/Stoichiometric switching DI Turbo gasoline engine
    d. EGR_DI_Turbo for the EGR DI Turbo gasoline engine
    e. 2020_EURO_Diesel for the Advanced European Diesel engine
    f. Diesel Baseline for the 2010 baseline European Diesel engines
    g. 2020_Diesel for the Advanced US Diesel engine

h. Atkinson_CPS for the Atkinson engine with CPS valvetrain
i. Atkinson_DVA for the Atkinson engine with DVA valvetrain

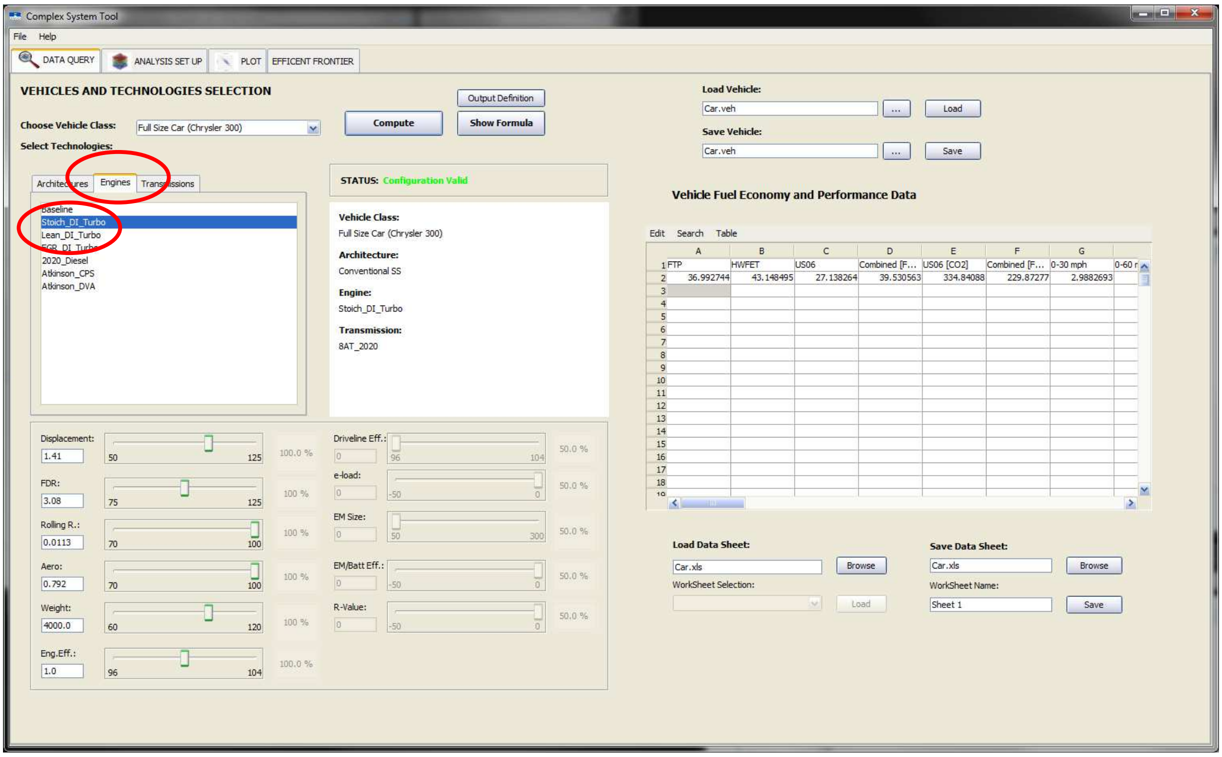


Figure 4.2: Design Query Engines Selection

4. From the "Transmissions" tab, choose from:
   a. 6AT_2010 for the 2010 baseline transmission **[Use only with baseline engine]**
   b. 6AT_2020 for the advanced six-speed automatic transmission [*B Class only*]
   c. 8AT_2020 for the advanced eight-speed automatic transmission
   d. 6Dry_DCT for the advanced six-speed DCT [*B Class only*]
   e. 8Dry_DCT for the advanced eight-speed DCT with dry clutch
   f. 8Wet_DCT for the advanced eight-speed DCT with wet clutch [*LHDT, LDT, and Large N1 only*]
   g. Powersplit for the Powersplit planetary gearbox [*only with Hybrid PS Architecture*]

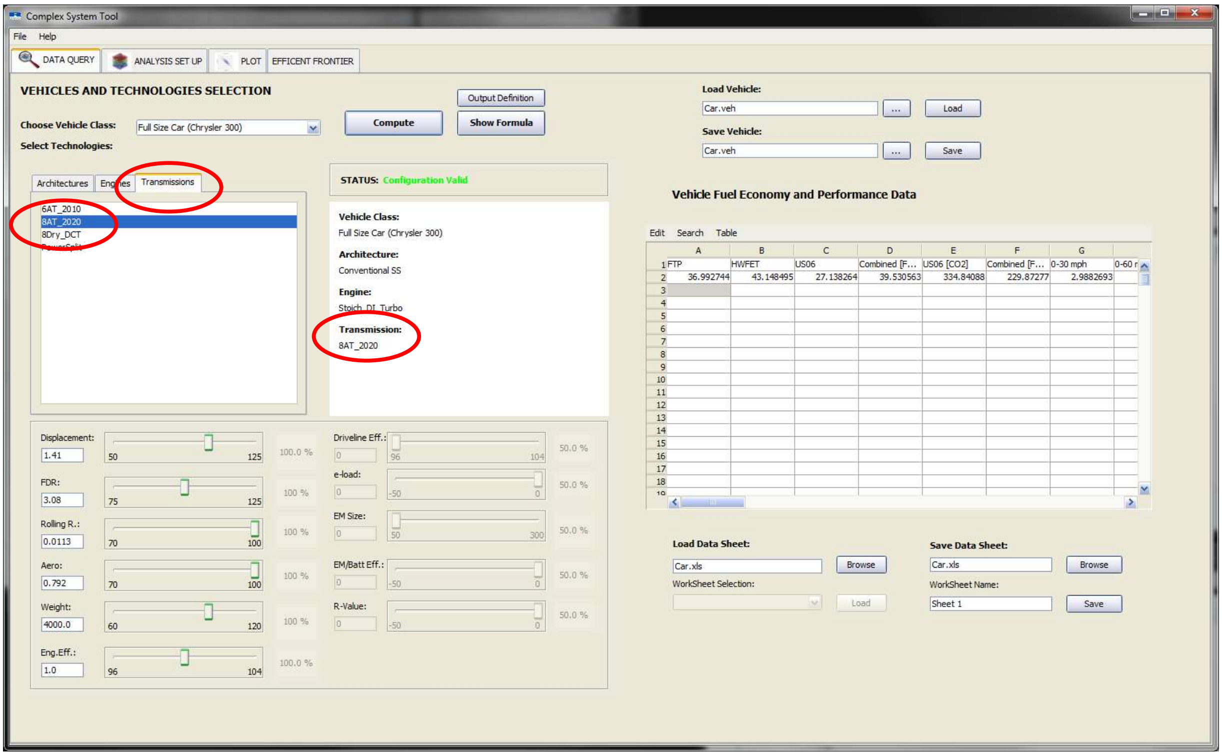


Figure 4.3: Design Query Transmissions Selection

5. Click on the "Output Definition" button to select the outputs desired.
   a. Default are Fuel economy values from the FTP, HWFET, and US06 cycles
   b. Choose among Combined (for CAFE comparisons), CO_2 emissions, and performance metrics
   c. Press "Save & Close" button to close dialog box

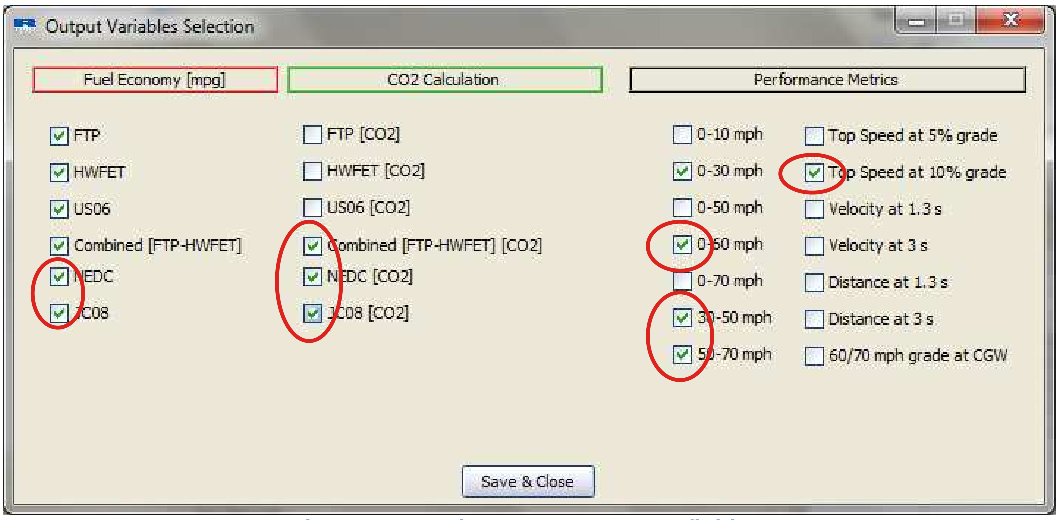


Figure 4.4: Design Query Output Definition

6. Adjust continuous vehicle parameters using the slider bars.
    a. Slider bars are in % from nominal value. Nominal value is displayed in the box under the variable name. *Only active variables have a white box; grayed boxes are inactive.*
    b. Displacement is in liters
    c. FDR (Final Drive Ratio) is a ratio
    d. Rolling R parameter is dimensionless
    e. Aero is the aerodynamic drag, Cd.A (m^2)
    f. Weight is the vehicle mass in kg
    g. Eng Eff is an adjustment to the engine efficiency, which shifts the fuel consumption accordingly
    h. EM Size is the electric machine power in kW
7. Press the "Compute" button to generate results in the spreadsheet area on the center right of the Data Query screen.
8. Results can be copied directly out of the table or exported to a spreadsheet (.csv) file
    a. Save the results to an Excel file by clicking on "Save data Sheet → Browse" button [lower right of the screen], and in the pop up window navigate to the directory where the file is to be saved in the "Look In" field. Enter the file name in the "File Name" field. Click the "Open" button. The pop up window will disappear. Fill in the "Save data Sheet → Worksheet Name" field and click the "Save" button.
    b. Input parameters are shown as the scaling factor (%/100), not the actual parameter value.
    c. Previously saved data can be loaded by following "Load Data Sheet → Browse" button, choosing the appropriate file, and clicking the "Load" button. A pop up window will appear asking the user to confirm data loading.

Notes:

- Not all LDV classes have all powertrain architectures, engines, or transmissions. The tool will indicate whether a given combination is valid or not. Refer to the Simulation matrix in the Appendix for the combinations included in the design space.
- The Heavy LD Truck (LHDT class) has a 2010 baseline Diesel engine "2010_Diesel" that goes with the six-speed automatic transmission "AT_2010"
- For the Hybrid P2 Architecture, the user should choose the appropriate DCT (dry or wet)
- "Engines" and "Transmissions" tabs will become active only after the architecture selection is made.
- The baseline vehicles results are based on the default parameters only; therefore, changing the parameters using the slider bars will not change the reported results.

5 DESIGN SPACE ANALYSIS

A more comprehensive survey of the design space can be conducted using the Design Space Analysis in the Data Visualization Tool, which allows the user to assess the performance of multiple vehicle configurations from a significant portion of the design space simultaneously. Each design is generated by selecting a vehicle platform, engine, and transmission, and then by selecting ranges for the continuous input variables. Several of these design space analyses may be compared against each other to understand the effects of one or more parameters on vehicle performance. Figure 5.1 shows the screen where the design space analysis is set up. For each of the continuous variables, values are generated using a Monte Carlo analysis from a uniform distribution over the range selected.

Process:

1. From the pull-down menu, choose a vehicle class: B Class, D Class, Small MPV, Full Size Car, Large N1, Truck, Large LD Truck, and C Class
2. From the "Architecture" tab, choose from:
    a. Conventional SS for conventional powertrain with stop-start function
    b. Hybrid P2 for the P2 Hybrid powertrain [*use with DCT only*]
    c. Hybrid PS for the Powersplit Hybrid powertrain
3. From the "Engines" tab, choose from:
    a. Baseline for the 2010 baseline engine **[Use only with 2010 transmission]**
    b. Stoich_DI_Turbo for the Stoichiometric DI Turbo gasoline engine
    c. Lean_DI_Turbo for the Lean/Stoichiometric switching DI Turbo gasoline engine
    d. EGR_DI_Turbo for the EGR DI Turbo gasoline engine
    d. 2020_Diesel for the Advanced European Diesel engine
    e. Diesel Baseline for the 2010 baseline European diesel engines
    e. 2020_Diesel for the Advanced US Diesel engine
    f. Atkinson_CPS for the Atkinson engine with CPS valvetrain
    g. Atkinson_DVA for the Atkinson engine with DVA valvetrain
4. From the "Transmissions" tab, choose from:
    a. 6AT_2010 for the 2010 baseline transmission **[Use only with baseline engine]**
    b. 6AT_2020 for the advanced six-speed automatic transmission [*B Class only*]
    c. 8AT_2020 for the advanced eight-speed automatic transmission
    d. 6Dry_DCT for the advanced six-speed DCT [*B Class only*]
    e. 8Dry_DCT for the advanced eight-speed DCT with dry clutch
    f. 8Wet_DCT for the advanced eight-speed DCT with wet clutch [*LHDT, LDT, and Large N1 only*]
    g. Powersplit for the Powersplit planetary gearbox [*only with Hybrid PS Architecture*]
5. Click on the "Output Definition" button to select the outputs desired.
    a. Default are Fuel economy values from the FTP, HWFET, and US06 cycles
    b. Choose among Combined (for CAFE comparisons), CO_2 emissions, and performance metrics
    c. Press "Save & Close" button to close dialog box
6. Adjust the continuous vehicle parameters using the slider bars in the "Variable" tab after clicking on the desired variables in check boxes.
    a. Slider bars are in % from nominal value. Nominal value is displayed in the box under the variable name. *Only active variables have a white box; grayed boxes are inactive.*
    b. Displacement is in liters
    c. FDR (Final Drive Ratio) is a ratio
    d. Rolling R (rolling resistance) parameter is dimensionless
    e. Aero is the aerodynamic drag, Cd.A (m^2)
    f. Weight is the vehicle mass in kg
    g. Eng Eff is an adjustment to the engine efficiency, which shifts the fuel consumption accordingly
    h. EM Size is the electric machine power in kW

   i. The 2010 baseline vehicles have fixed results based on the nominal values; therefore, defining parametric ranges will not affect the reported results.
7. Once all the variables are selected, fill in the "Number of Designs" field. [Values from 500 to 5000 are reasonable]. Choose the color by clicking on "Choose Color" button and selecting any desired color from the pop up window. Clicking on "OK" or "Cancel" or "Reset" button closes the pop up window.
8. To set up the plots, click on "Design List Name Field" on the top right of the screen and enter a name—for example, LDT_example. Then click on the "+" button. The name "LDT_example" will appear in a window under "Plot Set Up" and will be highlighted. It is important to have this name highlighted when additional designs are added next.
9. Fill in a meaningful name in the "Name of Design" field [bottom left of screen] and click on the "Generate" button. The computations of Monte Carlo analysis will complete in a few seconds. The progress can be monitored on the bar next to the "Generate" button. Once the design is generated, the name of the design will appear on the "Design" list on the top right portion of the screen. **CAUTION:** The "Generate" button will be grayed out if the combination is not valid; some combinations indicated as valid will not generate meaningful results. Please refer to the Simulation Matrix in the Appendix to see which combinations of vehicle class, architecture, engine, and transmission were included in the study.
10. Repeat steps 1-9 for new designs that need to be compared.
11. Any design can be deleted by first selecting the design and clicking on the "Delete Selected" button. A pop up window will ask for confirmation on decision to delete and gives options of yes/no/cancel.
12. **CAUTION:** The "Clear All" button deletes all the Designs that are shown in the window under "Plot Set Up". However, the user can reload the designs using the "Results Database" button.
13. Constraints are set by choosing the variable by check box and setting values in the minimum and maximum fields.
14. The "Reset Constraint" button reverts back to the values chosen in the original design for the range of values.
15. The "Results Database" button allows the user to look at all the designs that are in the directory where the designs are stored [Complex tools Results database is default]. The user can choose a design from the database and click on the "Load and Close" button to close the pop up window. Similarly, the user can delete a design from the database.

Once generated, the results at the design points are stored and may be plotted to visualize the effects of varying vehicle parameters over the design space. By carefully building a design and varying the parameters, the user can gain an understanding of the effect of each technology and the interactions between technologies. Figure 5.1 shows an example of Design Space analysis set-up. Figures 5.2–5.4 show examples of plots from one design space analysis, and Figure 5.5 an example of a second design space analysis.

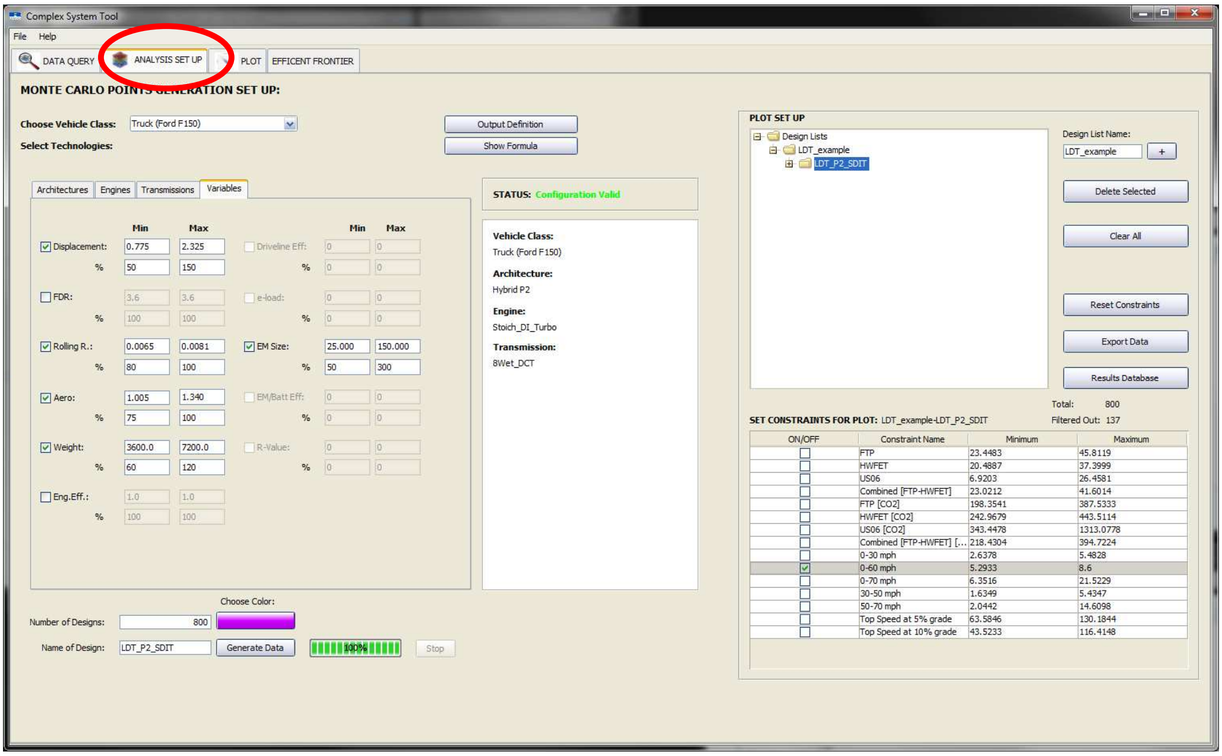
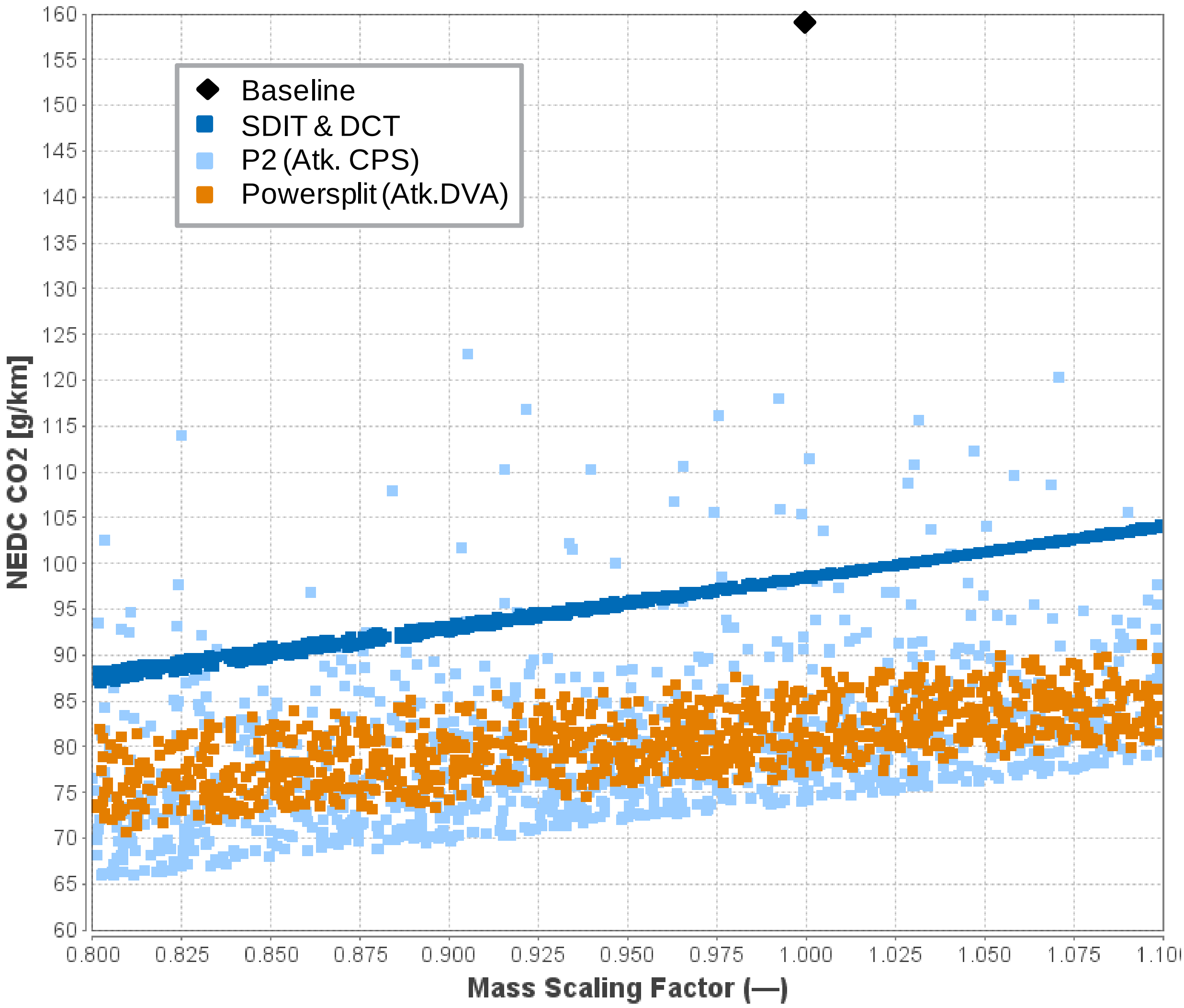


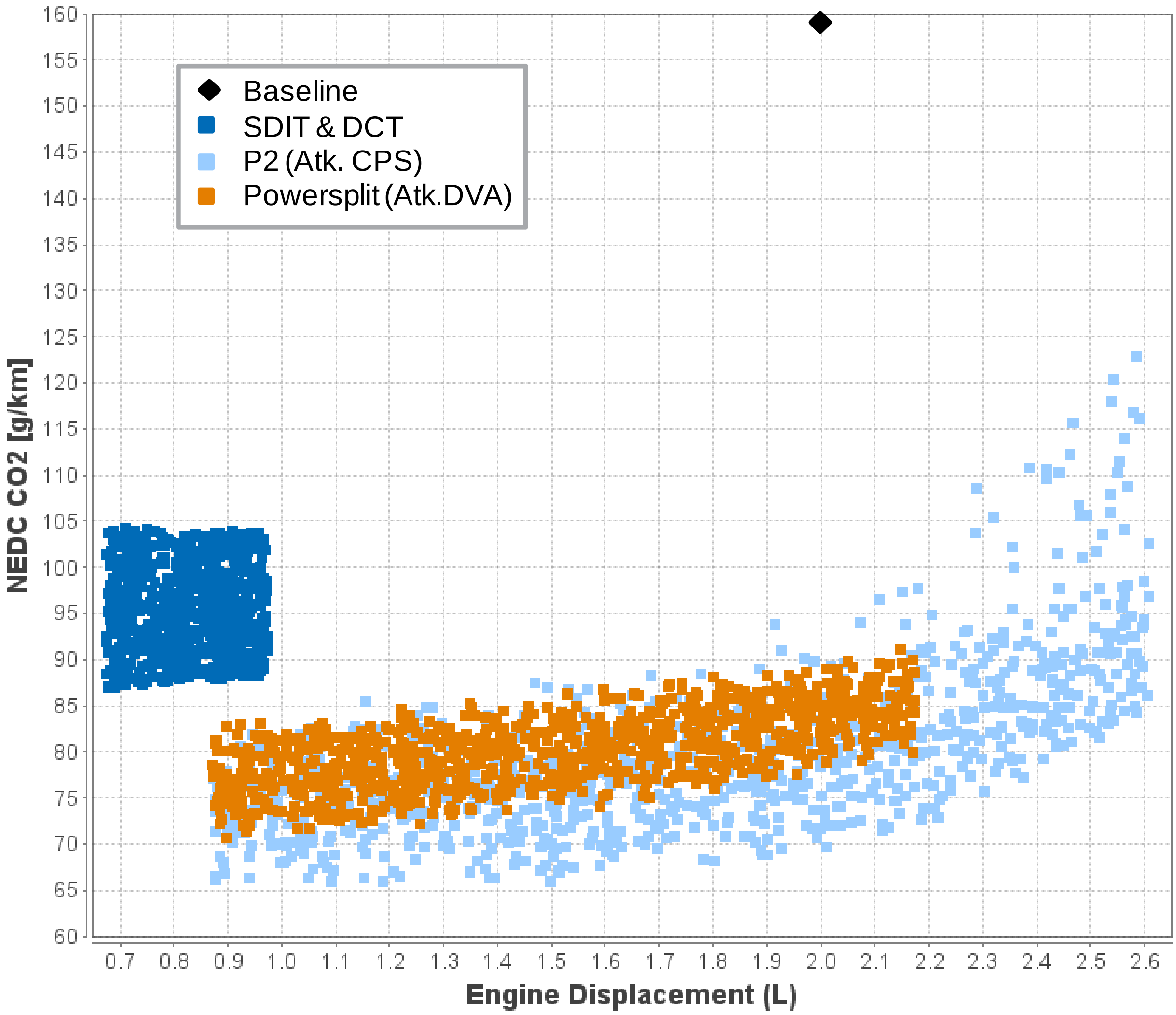
Figure 5.1: Design Space Analysis Screen

Figures 5.2–5.4 are from a design space analysis where a 2010 baseline C Class vehicle is compared with three advanced vehicle configurations: Stoichiometric DI Turbo SI engine with eight-speed dry clutch DCT; P2 Hybrid with Atkinson (CPS) engine; and Powersplit hybrid with Atkinson (DVA) engine. In this example, engine displacement was varied from 50% to 125% of nominal, and the vehicle mass was varied from 80% to 110% of the nominal C Class test weight, from 1270 to 1620 kg. Also, the rolling resistance and aerodynamic drag parameters were at 90% of the nominal value. The plot in Figure 5.2 illustrates the effect of vehicle mass on CO_2 emissions (in g/km) over the NEDC



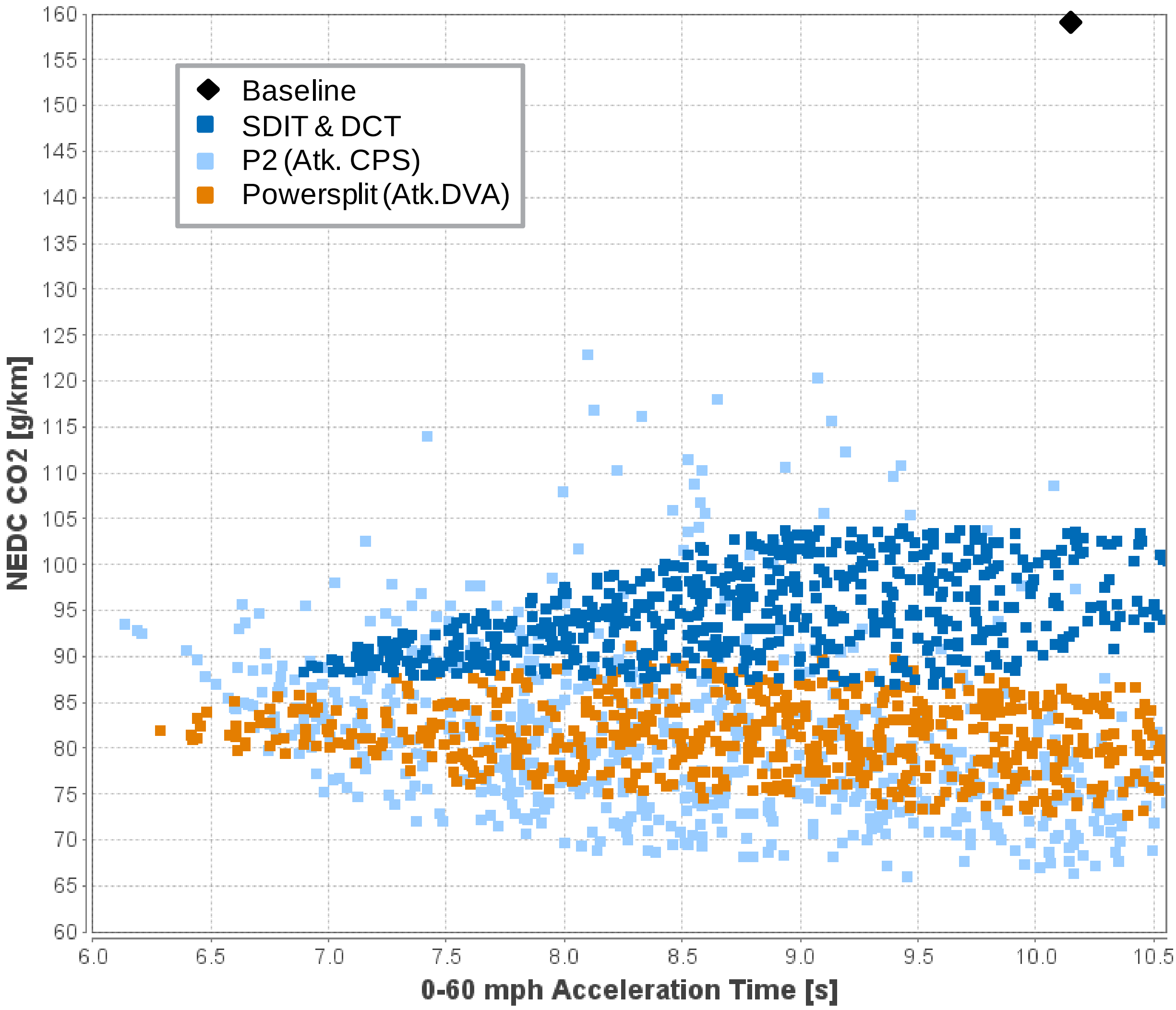
5.2: C Class vehicle Design Space Analysis example varying engine displacement and vehicle mass with conventional powertrain, P2 hybrid, or Powersplit hybrid.

Figure 5.3 illustrates the effect of engine displacement on CO_2 emissions (in g/km) over the NEDC for three advanced C Class vehicle configurations. The 2010 C Class (SI engine) baseline is also shown for comparison. For each type of engine, the displacement is varied from 50% to 125% of nominal, the value at which the 0–60 mph acceleration performance is equivalent to the baseline. Differences in absolute displacement reflect differences in the underlying power density of the three engines.



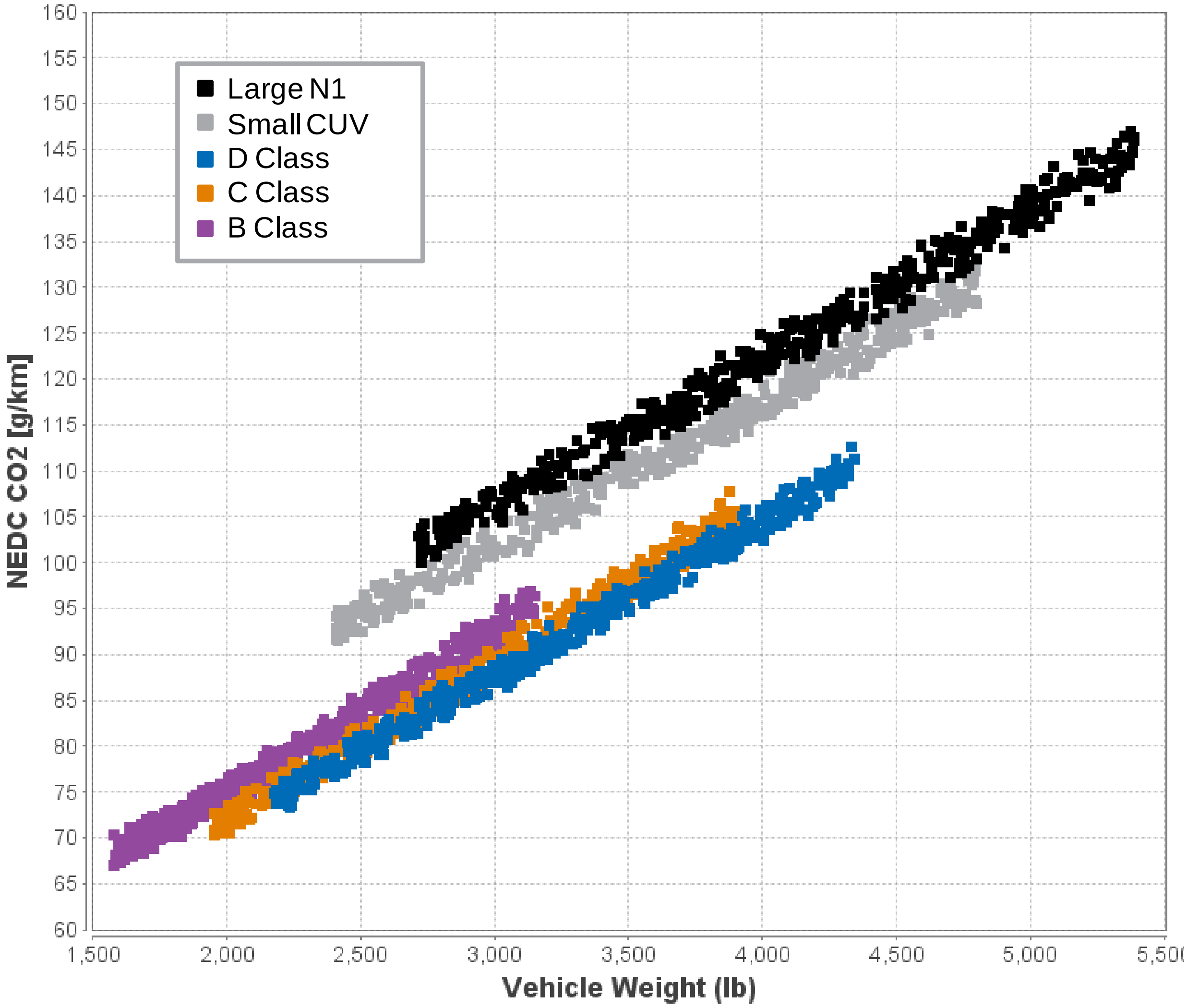
5.3: C Class vehicle Design Space Analysis Example varying engine displacement and vehicle mass with conventional powertrain, P2 Hybrid, or Powersplit hybrid.

Figure 5.4 shows the correlation between 0–60 mph acceleration time and CO_2 emissions (in g/km) over the NEDC for three advanced C Class vehicle configurations. The 2010 C Class (SI engine) baseline point is also shown for comparison. Shorter acceleration times reflect the effects of lower vehicle mass and larger engines, as power increases linearly with engine displacement. Note that the design space includes configurations with worse performance (longer acceleration times) than the baseline.



5.4: C Class vehicle Design Space Analysis example varying engine displacement and vehicle mass with conventional powertrain, P2 hybrid, or Powersplit hybrid.

The example in Figure 5.5 compares the CO_2 emissions over the NEDC performance for five LDV classes as a function of vehicle weight. All of the vehicles have the lean-stoichiometric switching DI Turbo engine with DCT. The engine displacement was varied from 95% to 100% of nominal, and the rolling resistance and aerodynamic drag factors were each varied from 80% to 90% of nominal for each vehicle class.



5.5: Design Space Analysis example comparing greenhouse gas emissions across vehicle classes with respect to vehicle weight.

6 PLOTTING DESIGN SPACE ANALYSIS RESULTS

The Design Space Analysis described in Section 5 sets up the various designs—combinations of vehicle, engine, transmissions, and the range of parameter values for each design. The next tab "Plot" allows the user to set up the variables to be plotted and viewed in the Data Visualization Tool.

Process:

1. Click on Plot tab. In the "Plot Page Set Up" window, fill in the "number of rows" and "number of columns" fields, and indicate whether the plots should use results with units or dimensionless scaling factors.
2. In the "Plots" section, click on the check boxes to choose the designs to compare and plot. The user can also choose to show values otherwise excluded by the constraints.
3. Clicking on the "Set" button will show the plot grid.
4. Below the "Set" button, there are three fields. In the first field, choose "all plots" or design name.
    a. In the second field choose the x-axis variable of the plot. Clicking inside this field will display a list of options. [Displacement, FDR, rolling Resistance, and Aero are some examples of good choices for x-variables. These variables are set up in step 6 of the Design Analysis setup]
    b. In the third field, choose the y-variable of the plot. [FTP, HWFET, US06, and Top speed at 5% grade are some examples of y-variables. These variables are set up in Output option in step 5 of the Design Analysis setup]
5. The user has to fill in x and y variables for each plot.

An example plot screen with 2 rows and 2 columns is shown in Figure 6.1

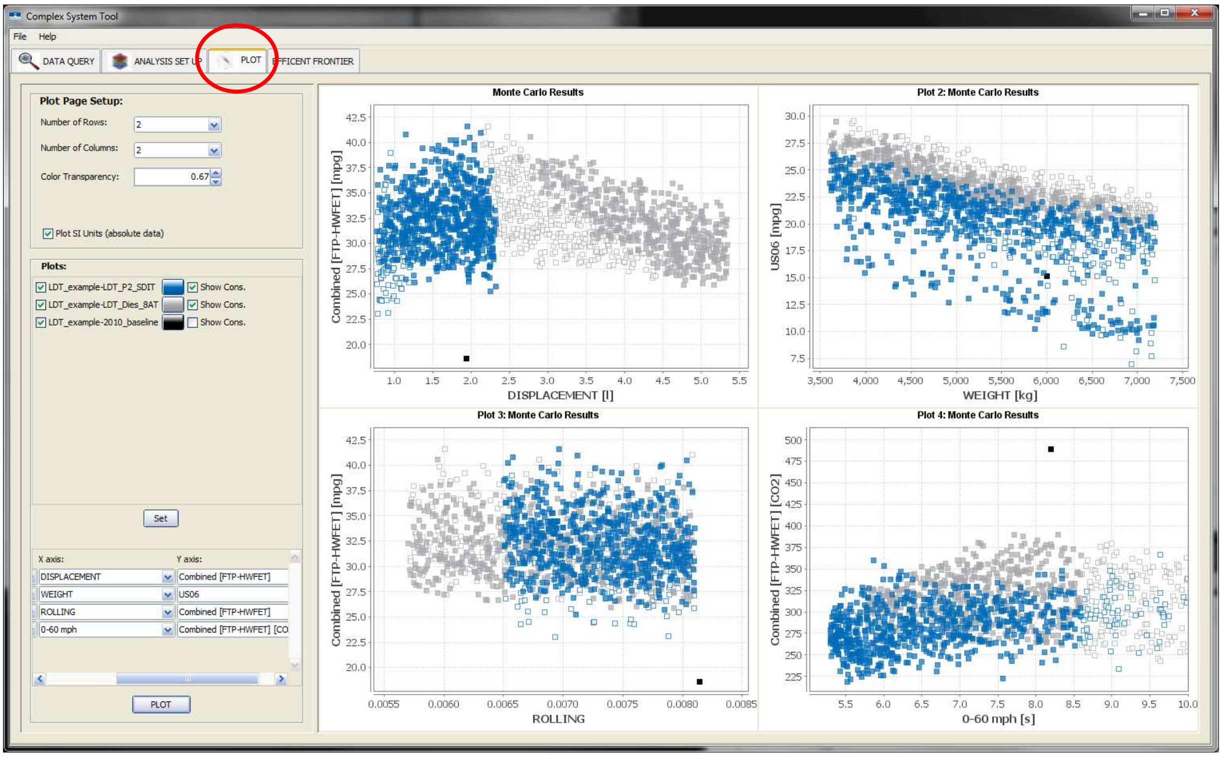


Figure 6.1: Design Comparison: Light Duty Truck with Stoichiometric DI Turbo Engine with Either Eight-Speed Automatic or P2 Hybrid

Once generated, the results at the design points are stored and may be plotted to visualize the effects of varying vehicle parameters over the design space. By carefully building a design and varying the parameters, the user can gain an understanding of the effect of each technology and the interactions between technologies.

7 EFFICIENT FRONTIER

Part of assessing the selected regions of the design space is to find configurations that balance efficiency and performance. The Data Visualization Tool identifies an Efficient Frontier, which is the bound of the sampled design space that has the most desirable performance. The user must first define a dataset using the Design Space Analysis, described above in Section 5, and then select the Efficient Frontier tab in the Data Visualization Tool.

Process:

1. Click on "Efficient Frontier" tab
2. Select the desired design in the "Design" field by clicking on the arrow button and selecting the desired design by clicking on it.
3. The "Performance Metric" is chosen from the available choices by clicking on the arrow button and then clicking on the desired metric.
4. Next choose the "Driving schedule" among the choices first by clicking the arrow and then clicking on the drive cycle.
5. The user can choose the "granularity %" and can also show only the frontier.
6. Lastly, click on the "Show efficient Frontier button". The design points and the efficient frontier line connecting the most desirable performance points will appear on the window

An example of the "Efficient Frontier" screen is shown in Figure 7.1. The Efficient Frontier is marked out in red, and the user can click on the data points along the frontier to discover the vehicle configurations that lie on the frontier.

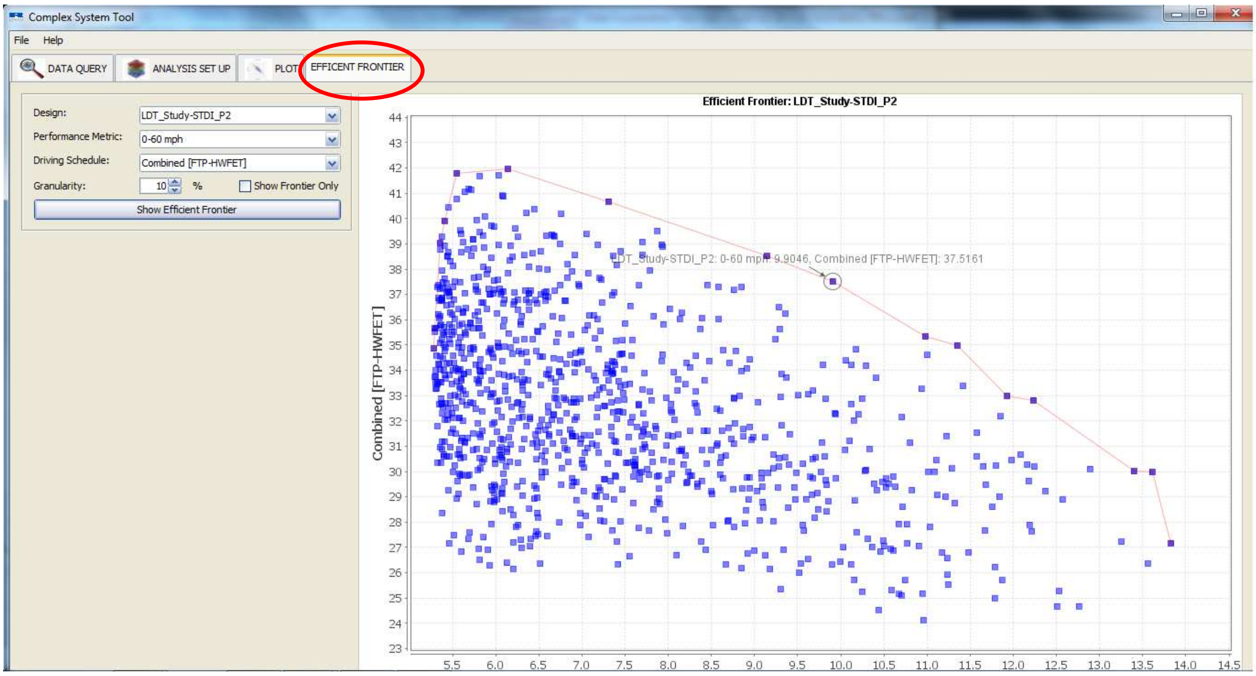


Figure 7.1: Efficient Frontier Screen: Light Duty Truck with Stoichiometric DI Turbo Engine in P2 Hybrid

8 CONCLUSIONS

The Data Visualization Tool allows EPA and other stakeholders to examine efficiently the design space developed through the program's complex systems modeling approach and to assess trade-offs between various vehicle configurations and their performance. The tool provides the necessary functionality to assess specific vehicle designs or more comprehensively explore the design space.

9 REFERENCES

1. Environmental Protection Agency, 2010, "Test Car List Data Files", available from www.epa.gov/oms/tcldata.htm.

2. Ricardo, 2012, *Analysis of Greenhouse Gas Emission Reduction Potential of Light Duty Vehicle Technologies in the European Union for 2020–2025*. Ricardo report RD.12/96201.2.

3. Ricardo and PQA, 2008, *A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies*. EPA Report 420-R-08-004a.

4. Ricardo and SRA, 2011, *Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020–2025 Timeframe*. EPA Report 420-R-11-020.

10 APPENDIX

Vehicles were assessed using three basic powertrain configurations: conventional stop-start, P2 hybrid, and Input Powersplit hybrid. Each vehicle class considered in the study was modeled with a set of technology options, as shown in Figure 10.1 for the baseline and conventional powertrains and in Figure 10.2 for the hybrid powertrains. Each of the 2020 engines marked for a given vehicle class in Figure 10.1 was paired with each of the advanced transmissions marked for the same vehicle class. Figures 10.1 and 10.2 also show the ranges of the continuous parameters—expressed as a percentage of the nominal value—used in the DoE study for the conventional and hybrid powertrains, respectively. The ranges were kept purposely broad, to cover the entire span of practical powertrain design options, with some added margin to allow a full analysis of parametric trends.

			Advanced Engine				Advanced Transmission				
Vehicle Class	**Baseline Engine & 2010 6-Speed Automatic Trans.**	**2010 Diesel & 2010 6-Speed Automatic Transmission**	**Stoich DI Turbo with CPS**	**Lean DI Turbo with CPS**	**EGR DI Turbo with CPS**	**2020 Diesel**	**6-Speed Automatic**	**6-Speed Dry DCT**	**8-Speed Automatic**	**8-Speed Dry DCT**	**8-Speed Wet DCT**
Small Car	X		X	X	X	X	X	X			
Standard Car	X		X	X	X				X	X	
Small MPV	X		X	X	X				X	X	
Full Size Car	X		X	X	X	X			X	X	
Large MPV	X		X	X	X	X			X		X
LDT	X		X	X	X	X			X		X
LHDT	X	X	X	X	X	X			X		X

Parameter	DoE Range (%)	
Engine Displacement	50	125
Final Drive Ratio	75	125
Rolling Resistance	70	100
Aerodynamic Drag	70	100
Mass	60	120

Figure 10.1: Baseline and Start-Stop Simulation Matrix

Vehicle Class	Hybrid Architecture		Advanced Engine				
	P2 Hybrid with 2020 DCT	Input Powersplit	Stoich DI Turbo with CPS	Lean DI Turbo with CPS	EGR DI Turbo with CPS	Atkinson with CPS	Atkinson with DVA
Small Car	X	X	X	X	X	X	X
Standard Car	X	X	X	X	X	X	X
Small MPV	X	X	X	X	X	X	X
Full Size Car	X	X	X	X	X	X	X
Large MPV	X	X	X	X	X	X	X
LDT	X		X	X	X	X	X
LHDT							

Parameter	DoE Range (%)			
	P2 Hybrid		Powersplit	
Engine Displacement	50	150	50	125
Final Drive Ratio	75	125	75	125
Rolling Resistance	70	100	70	100
Aerodynamic Drag	70	100	70	100
Mass	60	120	60	120
Electric Machine Size	50	300	50	150

Figure 10.2: P2 and Input Powersplit hybrid simulation matrix

DISCLAIMER

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