

# Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) Tool User's Guide for Off-Cycle Credit Evaluation

# Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) Tool User's Guide for Off-Cycle Credit Evaluation

Assessment and Standards Division  
Office of Transportation and Air Quality  
U.S. Environmental Protection Agency

## NOTICE

*This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.*

## **1. Background**

The Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) was created by EPA as an analysis tool to estimate the Greenhouse Gas (GHG) emissions from Light-Duty (LD) vehicle sources. It is a physics-based, forward-looking, full vehicle simulator, which is capable of simulating various vehicle types and powertrain technologies. The software is a freely-distributed, desktop computer based application, built on MATLAB/Simulink.

The version 1.0 of the simulation tool consists only of conventional vehicles and should only be used for off-cycle technology evaluation, such as effects on GHG by electrical load reduction technology, road load reduction technology by active aerodynamics, and engine start-stop technology. The next version of the tool will include hybrid and electric vehicles, and can be used for various vehicle technology effectiveness evaluation purposes in addition to the off-cycle technology evaluation.

## **2. Introduction to ALPHA**

This section introduces the basics of the vehicle model in ALPHA and provides details on simulation inputs and parameters as well as the model architecture. First, the simulation tool is introduced in terms of its scope, capability, and model architecture, and detailed descriptions on predefined inputs and parameters are provided.

### **2.1. Vehicle Model**

#### **2.1.1. Scope and Capability**

As mentioned previously, the ALPHA tool was created for the LD GHG regulatory analysis purposes. It is capable of simulating a wide range of conventional and advanced engines, transmissions, and vehicle technologies over various driving cycles. The tool evaluates technology package effectiveness while taking into account synergy effects among vehicle components and estimates GHG emissions for various combinations of future technologies. Therefore, the simulation model is capable of providing reasonably (though not absolutely) certain predictions of fuel economy and GHG emissions of specific vehicles to be produced in the future. The model is also capable of simulating power-split and P2 hybrid vehicles as well as non-hybrid vehicles with a Dual-Clutch Transmission (DCT), under warmed-up conditions. However, the hybrid vehicle simulation models are not included in this first version of the tool. The application of the ALPHA version 1.0 should only be limited to evaluating certain off-cycle technologies and their impacts on GHG improvements. Additional simulation capabilities such as automatic transmissions, cold-start conditions, and other hybrid architectures including PHEV and electric vehicles are being pursued by EPA for future use.

#### **2.1.2. Model Architecture**

The ALPHA is a full vehicle simulator that uses the same physical principles as commercially available vehicle simulation tools (such as Autonomie, AVL-CRUISE, GT-Drive, Ricardo-EASY5, etc.). In order to ensure transparency of the models and free public access, EPA has developed the tool in the MATLAB/Simulink environment with a completely open source code of the vehicle model. For the 2017 to 2025 GHG rule, EPA used the simulation tool in a more limited manner: to quantify the amount of GHG emissions reduced by improvements in A/C systems and off-cycle technologies, as explained in Chapter 2 of the Regulatory Impact Analysis (RIA).

All vehicle models in ALPHA consist of three levels: system level, component level, and functional level. There are six systems in the model: Ambient, Driver, Electric, Engine, Transmission, and Vehicle. Some of the systems (e.g. Electric, Engine, Transmission, and Vehicle) consist of components, each of which represents a physical entity that makes up the system. Functions are mathematical equations that represent the systems and/or components. The overall architecture of the vehicle model is summarized in Table 1. Further details on the model architecture can be found in Chapter 2 of RIA.

<b>System</b>	<b>Component Models</b>
Ambient	N/A
Driver	N/A
Electric	Accessory (electrical)
Engine	Accessory (mechanical), Cylinder
Transmission	Clutch, Gear
Vehicle	Final Drive, Differential, Axle, Tire, Chassis

**Table 1.** High-Level Architecture of Vehicle Model

## **2.2. Simulation Inputs and Parameters**

Although the vehicle model in ALPHA is flexible in its architecture and formation that the user can simulate any type of vehicles by defining desired powertrain and vehicle inputs, EPA has decided to pre-define many of the simulation inputs and model parameters in order to limit the tool's application to the off-cycle technology evaluations. The following sections describe these pre-defined simulation inputs and model parameters included in the version 1.0 of ALPHA.

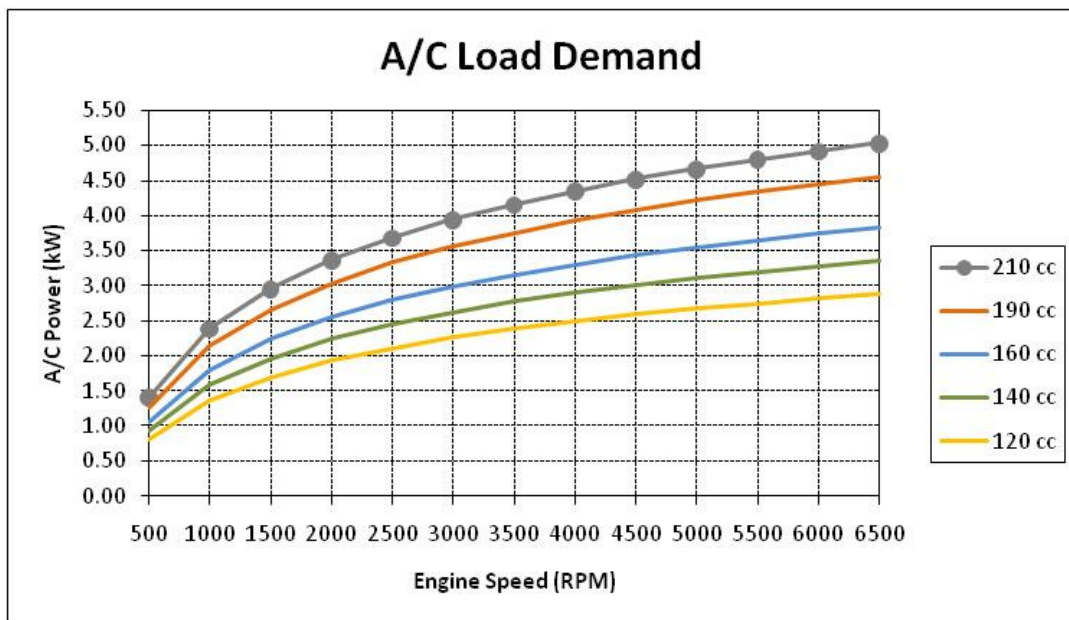
### **2.2.1. Ambient Condition**

As described in Chapter 2 of RIA, the Ambient system defines surrounding environment conditions, such as pressure, temperature, and road gradient, where vehicle operations are simulated. By default, the environmental conditions defined in this system are in accordance with the standard SAE practices – air temperature of 25°C, air pressure of 101.325 kPa, and air density based on the Ideal Gas law which results in a density of 1.20 kg/m<sup>3</sup>. The road gradient is set to 0 %, indicating a vehicle moving on a flat surface.

### **2.2.2. Electric System**

For the purpose of evaluating A/C as well as off-cycle technologies, the APLHA has modeled the electrical system as a constant power consumption device as a function of the vehicle category. It basically represents the power loss associated with the starter, alternator, and other electrical accessories. This type of simplification was made since the purpose of the tool was A-B comparisons only, i.e. relative difference between case A and case B on GHG emissions.

As the base load from electrical components, EPA assumed 153 W for all vehicle types. For simulating the A/C load, on the other hand, EPA adopted the power curves of A/C compressors with displacement of 210 cc, published by an A/C equipment supplier, Delphi. Also, in an effort to characterize an average A/C compressor load in the presence of widely varying environmental conditions in the United States, EPA adopted data from the National Renewable Energy Laboratory (NREL) to estimate environmental conditions associated with typical vehicle A/C usage. In order to associate each vehicle type with appropriate A/C compressor size, EPA scaled the curve based on the displacement volume ratio. For determining indirect A/C impact on fuel consumption increase for various vehicle types, EPA estimated A/C compressor sizes of 120 cc, 140 cc, 160 cc, and 190 cc for small, medium, large passenger cars, and light-duty pick-up truck, respectively. By taking into account these compressor sizes relative to 210 cc, EPA created A/C load curves for the four vehicle types, as shown in Figure 1. As for the A/C fan load, EPA assumed 250 W for all vehicle types. More details on the A/C compressor modeling can be found in Chapter 2 of RIA.



**Figure 1.** Representative A/C Compressor Load Curves

### 2.2.3. Engine and Transmission

The types of engines and the corresponding torque and fuel maps are pre-defined by EPA. Similarly, the transmission parameters such as number of gears, gear ratios, and shifting schedules are pre-determined and stored as inputs in ALPHA. There are two types of engines defined in the simulation tool: Baseline Engine and EGR Boost Engine. On the other hand, there is only one transmission type modeled in the tool: Dual-Clutch Transmission (DCT). Table 2 shows these parameters defined in the engine and transmission systems.

Vehicle Type	Small-Size Car	Medium-Size Car	Large-Size Car	Pick-Up Truck
Engine Displacement Volume (L)	1.5	2.4	3.5	5.4
Engine Idle/Redline Speed (RPM)	770 / 6500	680 / 6000	600 / 6400	575 / 5000
Engine Inertia (kg-m <sup>2</sup> )	0.075	0.12	0.175	0.25
Transmission Gear Number	6-speed	8-speed	8-speed	8-speed
Transmission Gear Ratio	4.148, 2.370, 1.556, 1.155, 0.859, 0.686	4.700, 3.130, 2.100, 1.670, 1.290, 1.000, 0.840, 0.670	4.700, 3.130, 2.100, 1.670, 1.290, 1.000, 0.840, 0.670	4.700, 3.130, 2.100, 1.670, 1.290, 1.000, 0.840, 0.670
Transmission Gear Efficiency	0.912, 0.927, 0.925, 0.923, 0.917, 0.910	0.930, 0.940, 0.947, 0.948, 0.946, 0.943, 0.940, 0.935	0.930, 0.940, 0.947, 0.948, 0.946, 0.943, 0.940, 0.935	0.930, 0.940, 0.947, 0.948, 0.946, 0.943, 0.940, 0.935
Transmission Inertia (kg-m <sup>2</sup> )	0.204	0.204	0.204	0.204

**Table 2.** Engine and Transmission Input Parameters

### 2.2.4. Driveline and Vehicle

Similar to other systems mentioned previously, the simulation parameters defining driveline and vehicle are also pre-determined by EPA. It is important to note again that this type of simplification was made since the purpose of the tool was A-B comparisons only, i.e. relative difference between a case without an off-cycle technology and a case with an off-cycle technology on GHG emissions. Table 3 shows these parameters defined in the vehicle system. It should be noted that the road-load in ALPHA can be represented by either  $C_d/C_{rr}$

or ABC coast-down coefficients. It is up to the user which road-load model is used for desired vehicle simulation and analysis.

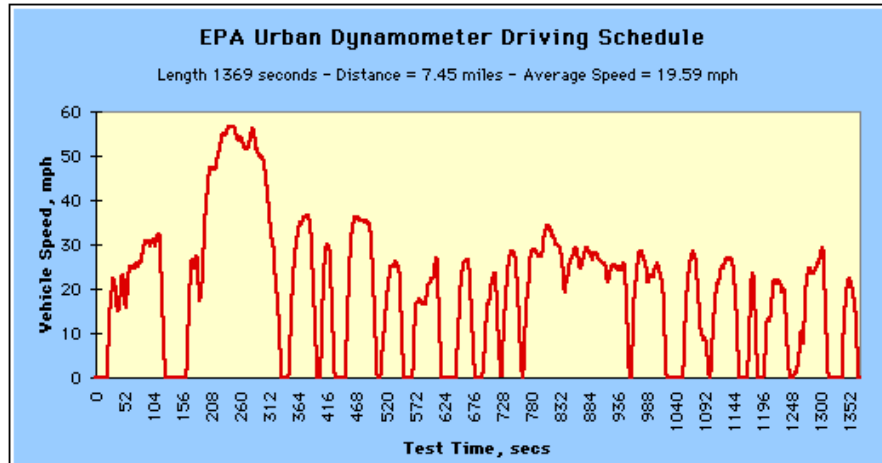
Vehicle Type	Small-Size Car	Medium-Size Car	Large-Size Car	Pick-Up Truck
Final Drive Ratio	4.24	3.39	2.87	3.73
Axle/Tire Inertia (kg-m <sup>2</sup> )	0.56	0.90	0.97	1.00
Tire Rolling Resistance, $C_{rr}$	0.00774	0.01060	0.01717	0.02074
Tire Radius (m)	0.282	0.320	0.342	0.382
Vehicle Weight (lb)	2625	3625	4000	6000
Vehicle Frontal Area (m <sup>2</sup> )	2.29	2.30	2.40	3.27
Aerodynamic Drag Coefficient, $C_d$	0.29	0.30	0.33	0.41
Coast-Down Coefficient, A (N)	90.3768	170.9230	305.5040	553.5369
Coast-Down Coefficient, B (N/(m/s))	0	0	0	0
Coast-Down Coefficient, C (N/(m/s) <sup>2</sup> )	0.4000	0.4154	0.4768	0.8072

**Table 3.** Driveline and Vehicle Input Parameters

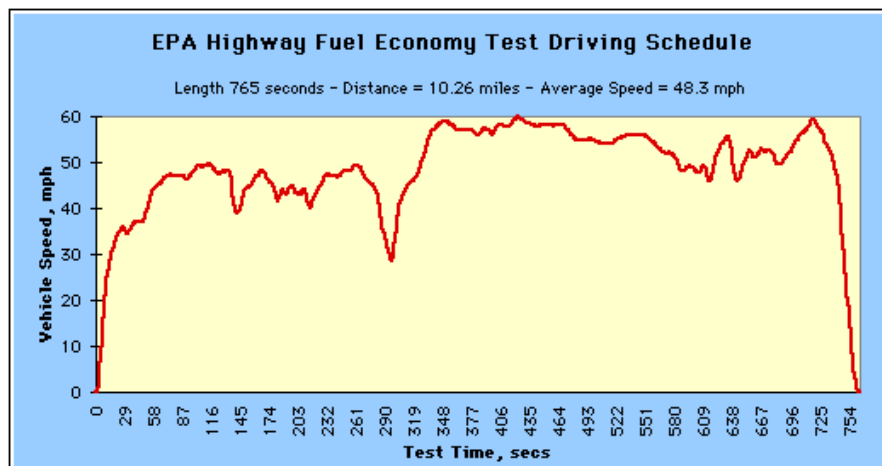
#### 2.2.5. Driving Cycles

The ALPHA is designed to simulate five driving cycles: FTP, Highway, US06, LA92, and SC03. The FTP (Federal Test Procedure) cycle in ALPHA basically represents the UDDS (Urban Dynamometer Driving Schedule) cycle, which simulates in-city driving conditions. The Highway driving cycle represents highway driving conditions under 60 mph whereas the US06 cycle is a high acceleration, aggressive driving schedule, going over well over 60 mph. The LA92 cycle is often called the Unified driving schedule, and was developed as an emission inventory improvement tool. Compared to the FTP, the LA92 has a higher top speed, a higher average speed, less idle time, fewer stops per mile, and a higher maximum rate of acceleration. Finally, the SC03 cycle is a supplemental driving cycle designed to test air conditioning systems. These driving cycles are shown Figure 2 to Figure 6, respectively.

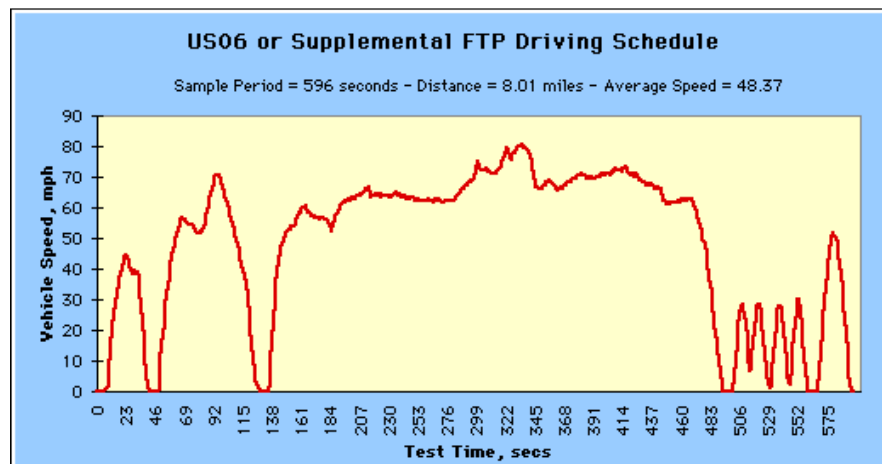




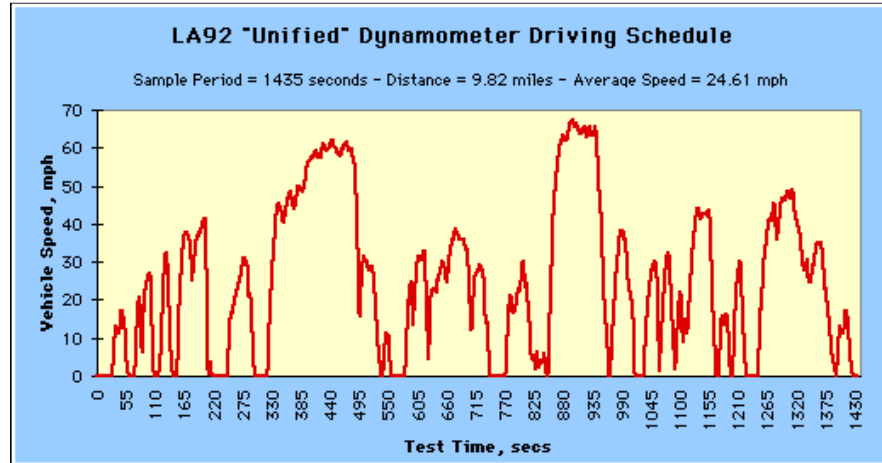
**Figure 2. FTP Driving Cycle**



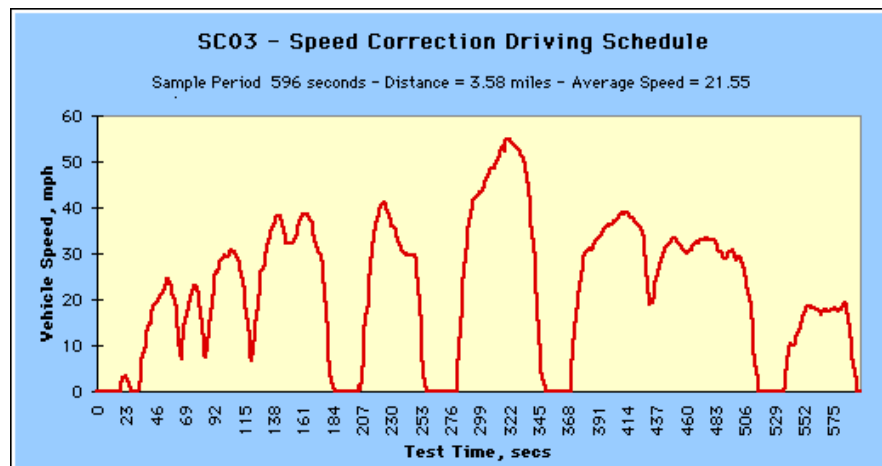
**Figure 3. Highway Driving Cycle**



**Figure 4. US06 Driving Cycle**



**Figure 5. LA92 Driving Cycle**



**Figure 6. SC03 Driving Cycle**

### **3. Instruction for Simulation Run**

This section describes the user instructions for how to install and use the ALPHA tool. The general instructions are first given, and then specific examples are provided along with simulation results.

#### **3.1. ALPHA Installation**

##### **3.1.1. Computing System Requirement**

There are certain computational requirements that a user should have in order to install and use ALPHA properly. A computing system used for running the tool needs to have at least 1 GB of RAM and 1 GB of free disk space. It should have a window-based operating system with R2011b MATLAB applications installed. It must have a minimum of MATLAB version 7.13, Simulink version 7.8, and Stateflow version 7.8. It also must have Microsoft Office Excel 2007 or later, which is required to write and read simulation output files.

##### **3.1.2. File Structure**

The user can download the tool package stored in a zip file (ALPHA\_v1p0.zip) from an EPA website, <http://www.epa.gov/otaq/climate/alpha.htm>. After unzipping in a desired folder location, the user should see one figure file 'ALPHA\_offcyc\_gui.fig' which represents the Graphical User Interface (GUI), one Simulink file 'ALPHA\_v1p0.mdl' which is the vehicle model, and several p-codes which define all necessary model parameters as well as control the entire simulation process. In the folder, the user should also see two subfolders, namely 'drive\_cycles' and 'param\_files'. The folder 'drive\_cycles' consists of mat-files, which represent the five specific driving cycles: FTP, Highway, US06, LA92, and SC03. On the other hand, the folder 'param\_files' contains p-codes which define all model parameters for ambient condition, driver response, electrical load, engine maps, transmission shifting schedules, and vehicle-related information.

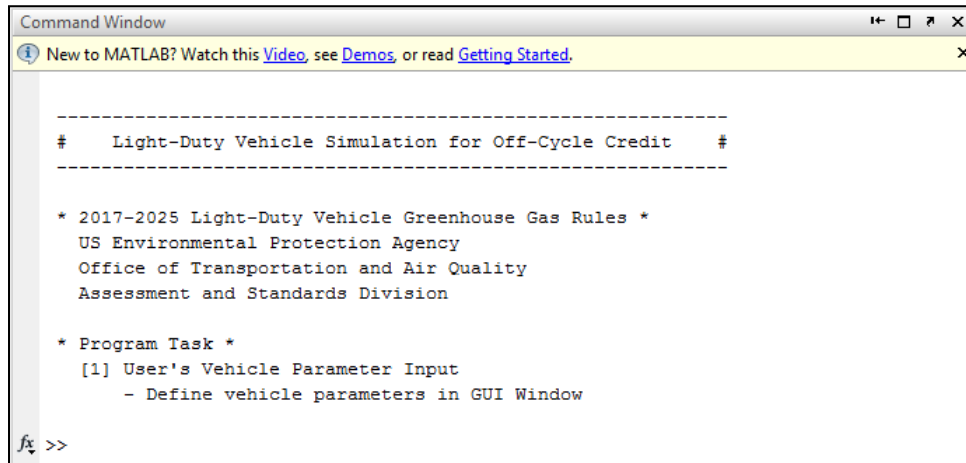
#### **3.2. ALPHA Run**

##### **3.2.1. General Instruction**

In order to launch the ALPHA tool and run vehicle simulations, the user must follow the steps described in detail below.

### 3.2.1.1. GUI Launch

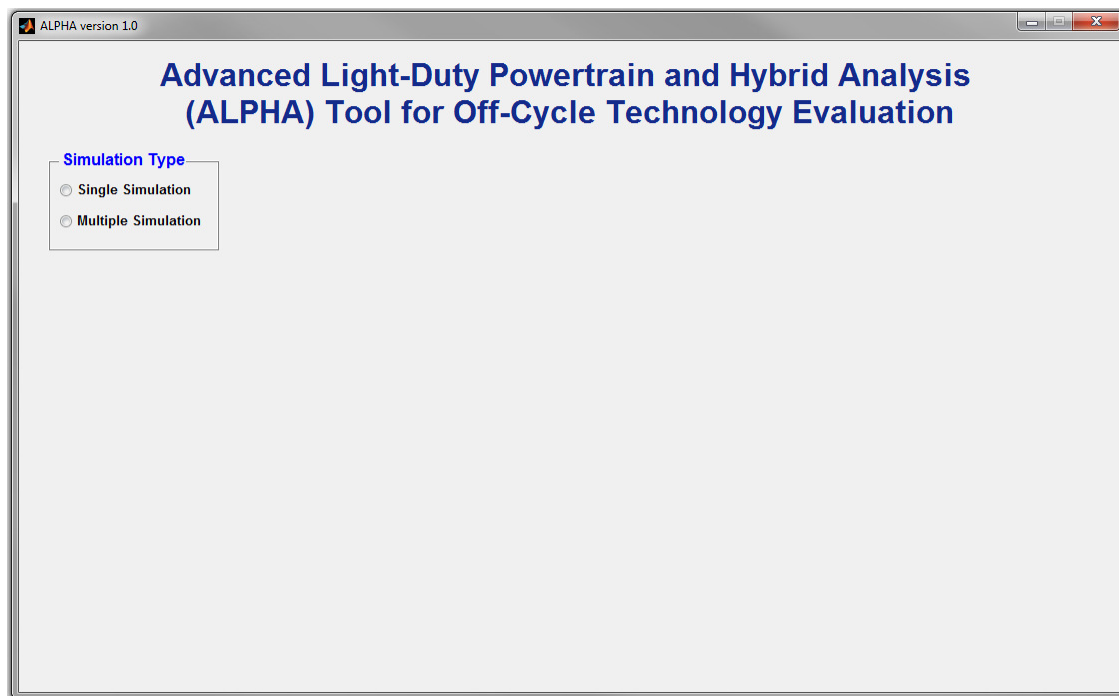
- Launch MATLAB and change the working directory to the folder where the ALPHA files are located.
- In the MATLAB command window, run the p-code 'ALPHA\_offcyc\_sim' by typing the name and hitting the 'Enter' key.
- After running the p-code, the command window displays the following message as shown in Figure 7, and the GUI appears as shown in Figure 8.



The image shows a MATLAB Command Window. At the top, there is a yellow banner with the text: "New to MATLAB? Watch this [Video](#), see [Demos](#), or read [Getting Started](#)." Below the banner, the command window displays the following text:

```
-----  
#   Light-Duty Vehicle Simulation for Off-Cycle Credit   #  
-----  
  
* 2017-2025 Light-Duty Vehicle Greenhouse Gas Rules *  
US Environmental Protection Agency  
Office of Transportation and Air Quality  
Assessment and Standards Division  
  
* Program Task *  
[1] User's Vehicle Parameter Input  
    - Define vehicle parameters in GUI Window  
  
fx >>
```

**Figure 7.** Command Window Display



**Figure 8.** Initial Display of ALPHA GUI

### 3.2.1.2. Simulation Setup

- The user can select either the ‘Single Simulation’ option or the ‘Multiple Simulation’ option. Upon the selection, the GUI provides a full display of the simulation options as shown in Figure 9.
  - The ‘Single Simulation’ runs a pair of simulations, one without any off-cycle technology and another one with a desired off-cycle technology. This simulation option only lets the user run the simulation for one vehicle type, one engine type, and one driving cycle with or without the A/C on.
  - The ‘Multiple Simulation’ runs several pairs of simulations, each pair consisting of one simulation without any off-cycle technology and another one with a desired off-cycle technology. This simulation option lets the user run a batch of vehicle simulations for any vehicle types, any engine types, and any driving cycles with or without the A/C on.

The screenshot displays the ALPHA version 1.0 GUI. The title is "Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) Tool for Off-Cycle Technology Evaluation". The interface is organized into several sections:

- Simulation Type:** Radio buttons for "Single Simulation" (selected) and "Multiple Simulation".
- Driving Cycle:** Radio buttons for "FTP", "Highway", "US06", "LA92", and "SC03".
- Vehicle Type:** Radio buttons for "Small-Size Car", "Mid-Size Car", "Large-Size Car", and "Pick-Up Truck". Each type has input fields for "Vehicle Weight [lb]", "Frontal Area [m2]", and "Tire Rolling Resistance, Crr", each with a "Default" button.
- Engine Type:** Radio buttons for "Baseline Engine" and "EGR Boost Engine".
- Air Condition:** Radio button for "A/C On".
- Off-Cycle Technology:**
  - Electrical Load [W]:** Input fields for "Without Off-Cycle Technology" and "With Off-Cycle Technology".
  - Active Aerodynamics, Cd:** Input fields for "Without Off-Cycle Technology" and "With Off-Cycle Technology".
  - Active Aerodynamics, ABC:** Input fields for "Without Off-Cycle Technology" and "With Off-Cycle Technology", each with sub-inputs A, B, and C.
  - Start-Stop:** Radio button.
- Run Button:** A large green button labeled "RUN".

**Figure 9.** Full Display of ALPHA GUI

- The user can select a vehicle type, an engine type, and a driving cycle for the ‘Single Simulation’ case whereas the user may select more than one choice in each of the categories for the ‘Multiple Simulation’ case.
  - For vehicle type, there are currently four vehicle types represented in the current version of ALPHA: small-size car, mid-size car, large-size car, and pick-up truck.

Details of these vehicle types were discussed in Chapter 2 of this documentation. The next version of ALPHA will include more vehicle types.

- For engine type, there are currently two engine types represented in the current version of ALPHA: baseline engine and EGR boost engine. Details of these engine types were discussed in Chapter 2 of this documentation. The next version of ALPHA will include more advanced engine types.
- For driving cycle, there are currently five driving cycles considered in the current version of ALPHA: FTP, Highway, US06, LA92, and SC03. Details of these driving cycles were discussed in Chapter 2 of this documentation. The next version of ALPHA may include additional driving cycles.
- For each vehicle type, the user can enter desired vehicle parameters such as vehicle weight [lb], frontal area [ $\text{m}^2$ ], and tire rolling resistance ( $C_{rr}$ ). If these parameter values are not entered, then default values are used for simulation. These default values were provided in Chapter 2 of this documentation. Even if the word 'Default' is deleted and the spaces are left blank, the default vehicle weight, frontal area, or tire rolling resistance values will still be used during simulation.
- For the air condition (A/C), however, the user can simulate only one case of either A/C on or A/C off for both 'Single Simulation' and 'Multiple Simulation' cases.

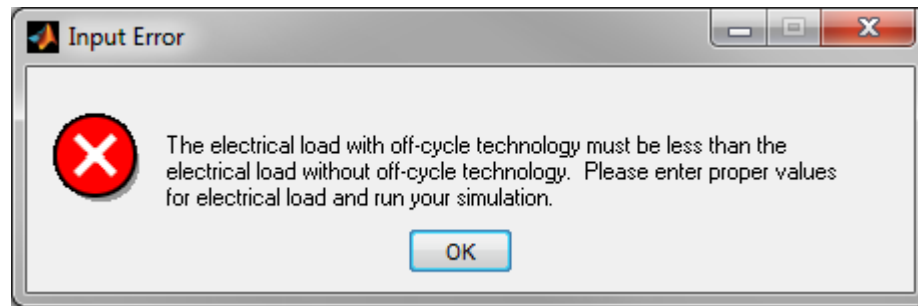
#### 3.2.1.3. Off-Cycle Technology Input

- ALPHA is designed to evaluate three off-cycle technologies: a technology that reduces electrical load to the engine, a technology that improves vehicle aerodynamics, and a technology that turns off the engine during vehicle stops.
- For the 'Multiple Simulation' mode as well as the 'Single Simulation', only one off-cycle technology can be selected for analysis via vehicle simulation. If none of the off-cycle technologies is selected, an error message will appear as shown below.



- In order to evaluate the effect of the electrical load reduction technology, the user must select the 'Electrical Load' in the off-cycle technology panel of the GUI. After a selection is made, then the user must enter desired values of the electrical load in Wattage.

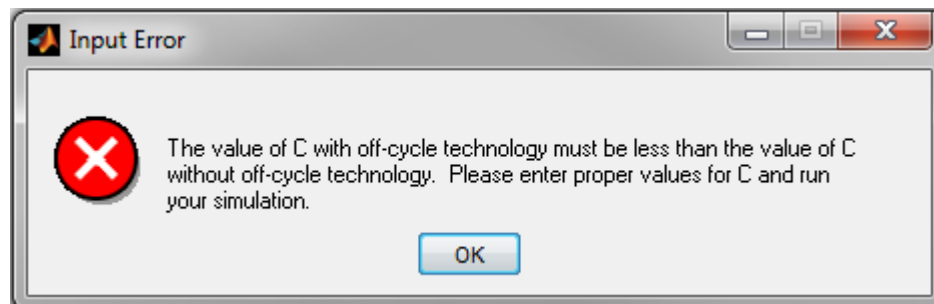
- The value of electrical load with the off-cycle technology must be smaller than one without it. Otherwise, an error message will appear as shown below.



- In order to evaluate the effect of the vehicle aerodynamic reduction technology, the user must select only one of the options, 'Active Aerodynamics, Cd' or 'Active Aerodynamics, ABC', in the off-cycle technology panel of the GUI. After a selection is made, the user must enter desired values of the appropriate aerodynamic coefficients.
  - When the 'Active Aerodynamics, Cd' option is selected, the value of  $C_d$  with the off-cycle technology must be smaller than one without it. Otherwise, an error message will appear as shown below.

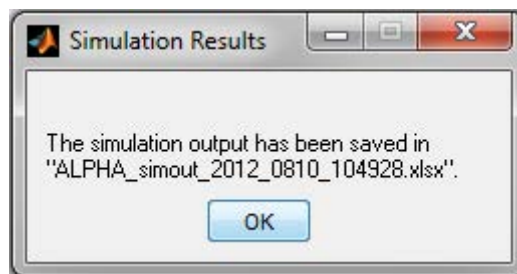


- When the 'Active Aerodynamics, ABC' option is selected, the value of C with the off-cycle technology must be smaller than one without it. Otherwise, an error message will appear as shown below. It is recommended that the values of A and B are kept the same in order to evaluate effects of aerodynamics only.



#### 3.2.1.4. Simulation Run

- After all selections are made and proper inputs are given in terms of 'Simulation Type', 'Driving Cycle', 'Vehicle Type', 'Engine Type', 'Air Condition', and 'Off-Cycle Technology', the user must click 'RUN' button in order to start the simulation.
- After the simulation is completed, the tool provides the simulation results by:
  - Displaying fuel economy and GHG emissions in the MATLAB command window,
  - Displaying plots of the vehicle speed trace following the desired driving cycle(s),
  - Creating an output file in excel format and saving it in the same directory where the ALPHA files are located. A message appears as shown below, indicating an output file has been created after simulation runs.



#### 3.2.2. Example Run

In this section, two examples of simulation runs are provided, one for 'Single Simulation' and the other one for 'Multiple Simulation'. The step-by-step procedures of setting up and executing the simulations are described, and examples of the simulation outputs are provided.

##### 3.2.2.1. Single Simulation

- Run ALPHA by typing 'ALPHA\_offcyc\_sim' in the MATLAB command window and hitting the 'Enter' key. The GUI appears as shown in Figure 8.
- In the 'Simulation Type' panel, select the 'Single Simulation'. Then, the GUI displays the full simulation options as shown in Figure 9.
- Select desired simulation options in 'Driving Cycle', 'Vehicle Type', 'Engine Type', and 'Air Condition'. For 'Vehicle Type', the user may enter desired vehicle weight, frontal area, and tire rolling resistance other than the default values.
  - In this example, FTP Cycle, Mid-Size Car (with 3500 lb of vehicle weight, 2.4 m<sup>2</sup> of frontal area, and 0.01050 of tire rolling resistance), Baseline Engine, and A/C Off are selected.
- Select desired off-cycle technology to evaluate. Enter proper values for the selected off-cycle technology.



- In this example, the ‘Active Aerodynamics, Cd’ option is selected. For this option, 0.30 of  $C_d$  without off-cycle technology and 0.28 of  $C_d$  with off-cycle technology are used.
- With the above selections for simulation setup and off-cycle technology inputs, the GUI appears as shown in Figure 10.
- Click ‘RUN’ button to run the simulation. After completing the simulation, the tool generates the following results.
  - In the command window, the fuel economy and GHG emission results are displayed as shown in Figure 11.
  - The simulated vehicle speed traces are plotted with comparisons to the selected driving cycle as shown in Figure 12.
  - An output file is created in Microsoft excel format. The name of the output file shows exactly when the file was created following a naming convention of ‘ALPHA\_simout\_YYYY\_MMDD\_hhmmss.xlsx’, where YYYY indicates the year, MM indicates the month, DD indicates the day, hh indicates the hour, mm indicates the minute, and ss indicates the second when the file was created by the ALPHA tool. An example of the output file in excel format is shown in Figure 13. The output file provides the simulation inputs as well as the outputs.

**ALPHA version 1.0**

## Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) Tool for Off-Cycle Technology Evaluation

**Simulation Type**

☒ Single Simulation

☐ Multiple Simulation

**Driving Cycle**

☒ FTP

☐ Highway

☐ US06

☐ LA92

☐ SC03

**Vehicle Type**

☐ Small-Size Car

Vehicle Weight [lb]  Frontal Area [m2]  Tire Rolling Resistance, Crr

☒ Mid-Size Car

Vehicle Weight [lb]  Frontal Area [m2]  Tire Rolling Resistance, Crr

☐ Large-Size Car

Vehicle Weight [lb]  Frontal Area [m2]  Tire Rolling Resistance, Crr

☐ Pick-Up Truck

Vehicle Weight [lb]  Frontal Area [m2]  Tire Rolling Resistance, Crr

**Engine Type**

☒ Baseline Engine

☐ EGR Boost Engine

**Air Condition**

☒ A/C On

**Off-Cycle Technology**

☐ Electrical Load [W]

Without Off-Cycle Technology

With Off-Cycle Technology

☒ Active Aerodynamics, Cd

Without Off-Cycle Technology

With Off-Cycle Technology

☐ Active Aerodynamics, ABC

Without Off-Cycle Technology

With Off-Cycle Technology

☐ Start-Stop

**RUN**

**Figure 10.** Example GUI for Single Simulation

```

#   Light-Duty Vehicle Simulation for Off-Cycle Credit   #
-----

* 2017-2025 Light-Duty Vehicle Greenhouse Gas Rules *
US Environmental Protection Agency
Office of Transportation and Air Quality
Assessment and Standards Division

* Program Task *
[1] User's Vehicle Parameter Input
    - Define vehicle parameters in GUI Window
[2] LD Vehicle Simulation
    - Run simulations for user-defined driving cycle(s)
[3] Result Display
    - Display simulation results on MPG & GHG

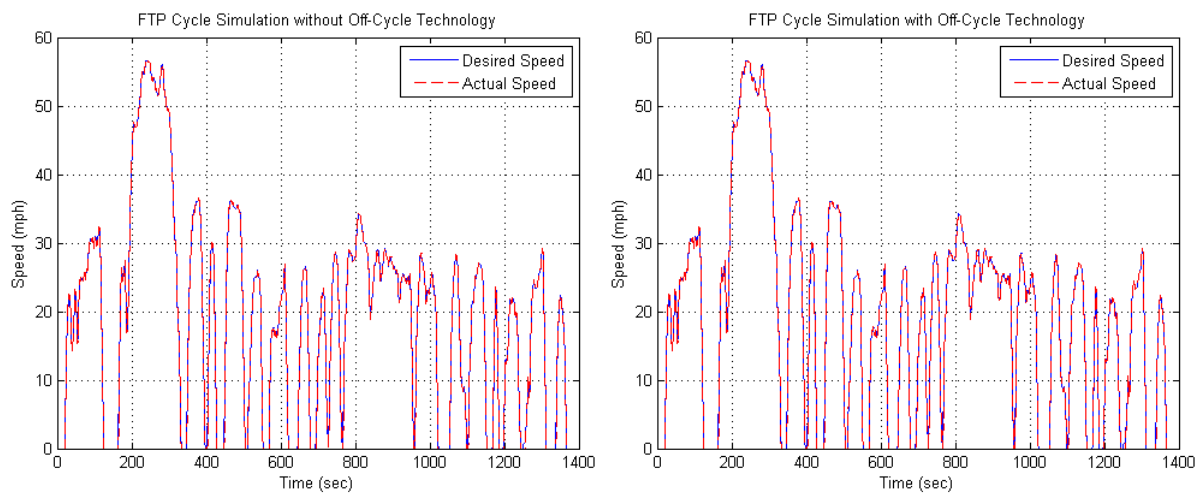
* Simulation Result without Off-Cycle Technology *
>> Mid-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =    0.85 %
Fuel Economy                  = 26.84 mpg
GHG Emission                  = 331.07 g/mile

* Simulation Result with Off-Cycle Technology *
>> Mid-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =    0.85 %
Fuel Economy                  = 26.97 mpg
GHG Emission                  = 329.55 g/mile

-----
#                               END OF PROGRAM                               #
-----

```

**Figure 11.** Example of Single Simulation Output in Command Window



**Figure 12.** Example of Vehicle Speed Trace Output

	A	B
1	<b>Simulation Parameters</b>	
2	Simulation Type	Single
3	Vehicle Type	Medium Car
4	Vehicle Weight [lb]	3500
5	Vehicle Frontal Area [m <sup>2</sup> ]	2.40
6	Tire Rolling Resistance, Crr	0.01050
7	Driving Cycle	FTP
8	Engine Type	Baseline
9	Air Condition	Off
10		
11	<b>Off-Cycle Technology (OCT)</b>	
12	<b>&gt;&gt; Active Aerodynamics</b>	
13	Cd without OCT	0.30
14	Cd with OCT	0.28
15		
16		
17		
18		
19		
20	<b>Simulation Outputs</b>	
21	Fuel Economy without OCT [mpg]	26.84
22	Fuel Economy with OCT [mpg]	26.97
23	GHG Emission without OCT [g/mi]	331.07
24	GHG Emission with OCT [g/mi]	329.55

**Figure 13.** Example of Single Simulation Output File

### 3.2.2.2. Multiple Simulation

- Run ALPHA by typing 'ALPHA\_offcyc\_sim' in the MATLAB command window and hitting the 'Enter key'. The GUI appears as shown in Figure 8.
- In the 'Simulation Type' panel, select the 'Multiple Simulation'. Then, a GUI similar to Figure 9 will appear on the screen.
- Select desired simulation options in 'Driving Cycle', 'Vehicle Type', 'Engine Type', and 'Air Condition'. For 'Vehicle Type', the user may enter desired vehicle weight, frontal area, and tire rolling resistance other than the default values.
  - In this example, all of driving cycles, vehicle types, and engine types are selected along with the A/C on option.
  - For Mid-Size Car, 3500 lb of vehicle weight, 2.4 m<sup>2</sup> of frontal area, and 0.01050 of tire rolling resistance are used. For Pick-Up Truck, 5800 lb of vehicle weight, 3.2 m<sup>2</sup> of frontal area, and 0.02050 of tire rolling resistance are used. For Small-Size Car and Large-Size Car, however, the default values are used.

- Select desired off-cycle technology to evaluate. Enter proper values for the selected off-cycle technology.
  - In this example, the ‘Electrical Load’ option is selected. For this option, 150 W of electrical load without off-cycle technology and 120 of electrical load with off-cycle technology are used.
- With the above selections for simulation setup and off-cycle technology inputs, the GUI appears as shown in Figure 14.

**Figure 14.** Example GUI for Multiple Simulation

- Click ‘RUN’ button to run the simulation. After completing the simulation, the tool generates the following results.
  - In the MATLAB command window, the fuel economy and GHG emission results are displayed. A portion of the simulation result display is shown in Figure 15 as an example.
  - The simulated vehicle speed traces are plotted with the scheduled vehicle speed from the selected driving cycles. Examples of US06 cycles are provided in Figure 16.
  - An output file is created in excel format based on the same naming convention as in the ‘Single Simulation’ case. A portion of the output file is shown in Figure 17 as an example.

```

-----
#   Light-Duty Vehicle Simulation for Off-Cycle Credit   #
-----

* 2017-2025 Light-Duty Vehicle Greenhouse Gas Rules *
US Environmental Protection Agency
Office of Transportation and Air Quality
Assessment and Standards Division

* Program Task *
[1] User's Vehicle Parameter Input
    - Define vehicle parameters in GUI Window
[2] LD Vehicle Simulation
    - Run simulations for user-defined driving cycle(s)
[3] Result Display
    - Display simulation results on MPG & GHG

* Simulation Result without Off-Cycle Technology *
>> Small-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   1.81 %
Fuel Economy                 =   31.23 mpg
GHG Emission                 =  284.60 g/mile

* Simulation Result with Off-Cycle Technology *
>> Small-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   1.80 %
Fuel Economy                 =   31.34 mpg
GHG Emission                 =  283.55 g/mile

* Simulation Result without Off-Cycle Technology *
>> Mid-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   1.26 %
Fuel Economy                 =   23.83 mpg
GHG Emission                 =  372.93 g/mile

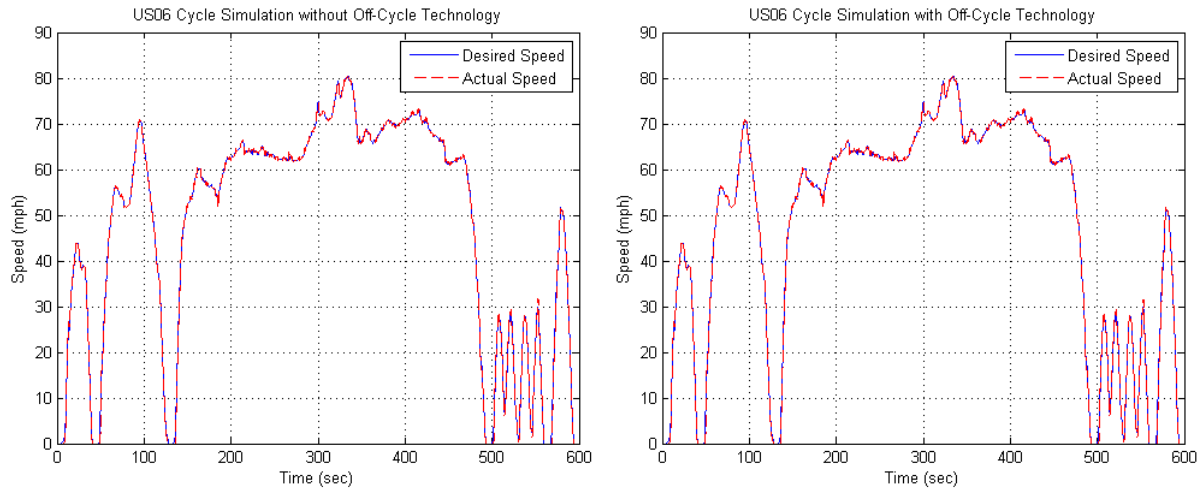
* Simulation Result with Off-Cycle Technology *
>> Mid-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   1.24 %
Fuel Economy                 =   23.89 mpg
GHG Emission                 =  371.94 g/mile

* Simulation Result without Off-Cycle Technology *
>> Large-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   2.39 %
Fuel Economy                 =   19.42 mpg
GHG Emission                 =  457.67 g/mile

* Simulation Result with Off-Cycle Technology *
>> Large-Size Car, FTP Cycle, Baseline Engine
Percent Time Missed by 2mph =   2.36 %

```

**Figure 15.** Example of Multiple Simulation Output in Command Window



**Figure 16.** Example of Vehicle Speed Trace Output

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	<b>Simulation Parameters</b>												
2	Simulation Type	Multi 1	Multi 2	Multi 3	Multi 4	Multi 5	Multi 6	Multi 7	Multi 8	Multi 9	Multi 10	Multi 11	Multi 12
3	Vehicle Type	Small Car	Medium Car	Large Car	Truck	Small Car	Medium Car	Large Car	Truck	Small Car	Medium Car	Large Car	Truck
4	Vehicle Weight [lb]	Default	3500	Default	5800	Default	3500	Default	5800	Default	3500	Default	5800
5	Vehicle Frontal Area [m2]	Default	2.40	Default	3.20	Default	2.40	Default	3.20	Default	2.40	Default	3.20
6	Tire Rolling Resistance, Crr	Default	0.01050	Default	0.02050	Default	0.01050	Default	0.02050	Default	0.01050	Default	0.02050
7	Driving Cycle	FTP	FTP	FTP	FTP	Highway	Highway	Highway	Highway	US06	US06	US06	US06
8	Engine Type	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
9	Air Condition	On	On	On	On	On	On	On	On	On	On	On	On
10													
11	<b>Off-Cycle Technology (OCT)</b>												
12	>> Electrical Load Reduction												
13	Load without OCT [W]	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
14	Load with OCT [W]	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
15													
16													
17													
18													
19													
20	<b>Simulation Outputs</b>												
21	Fuel Economy without OCT [mpg]	31.23	23.83	19.42	13.76	45.53	38.86	29.56	19.86	27.32	23.30	19.15	12.95
22	Fuel Economy with OCT [mpg]	31.34	23.89	19.44	13.77	45.62	38.92	29.60	19.87	27.38	23.32	19.19	12.96
23	GHG Emission without OCT [g/mi]	284.60	372.93	457.67	646.05	195.19	228.68	300.61	447.53	325.27	381.37	464.05	686.06
24	GHG Emission with OCT [g/mi]	283.55	371.94	457.04	645.21	194.82	228.32	300.26	447.16	324.57	381.08	463.09	685.79

**Figure 17.** Example of Multiple Simulation Output File