Chapter 4: Vehicle Simulation Model

4.1 Purpose and Scope

4.1.1 Methods to Assess a Truck's Greenhouse Gas Emissions

An important aspect of a regulatory program is to determine the environmental benefits of heavy duty truck technologies through testing and analysis. There are several methods available today to assess greenhouse gas emissions from trucks. Truck fleets today often use SAE J1321 test procedures to evaluate emissions changes based on paired truck testing.[1] Light duty trucks are assessed using chassis dynamometer test procedures.[2] Heavy duty engines are evaluated with engine dynamometer test procedures.[3] Most large truck manufacturers employ various computer simulation methods to estimate truck efficiency. Each method has advantages and disadvantages. This section will focus on the use of truck simulation modeling.

4.1.2 Simulation Model Will Be Used to Certify Class 2b-8 Vehicles

The simulation model will be the primary tool used to certify Class 2b through Class 8 heavy-duty, non-hybrid truck GHG emissions. The advantages of modeling are:

- The simulation tool can model a wide range of vehicle types.
- The vehicle components can be easily changed to match the features of a given vehicle.
- The entire configuration of the vehicle can also be changed, so the same program can model a Class 4 pickup and delivery truck and a Class 7 or 8 combination truck with appropriate input parameter changes. This allows the agencies to use the same program to develop and certify all of the heavy duty vehicles.
- The modeling tool also accommodates different drive cycles.
- It can significantly reduce truck manufacturer's burden to conduct heavy-duty chassis dynamometer tests.

4.1.3 Chapter Overview

The scope of this chapter will discuss truck simulation models and their feasibility, the truck simulation tool, and application of models to develop certification options.

4.2 Model Code Description

4.2.1 Engineering Foundations of Model

A number of commercially available heavy-duty vehicle simulation tools are based on MATLAB/Simulink-based programs that can model a wide variety of vehicles, from medium-duty to Class 8 trucks.[4,5] Generally, each vehicle component is depicted by a generic Simulink model that can be modified using an initialization file.[6] The user can utilize pre-determined initialization files for a given component, or modify them to reflect their particular situation. The following section describes the system required to model a heavy-duty non-hybrid truck. Once the vehicle has been specified, the user selects a drive cycle (which they can also modify) and runs the program.

EPA has developed a forward-looking MATLAB/Simulink-based model [TEST] for Class 2b-8 vehicle compliance.

4.2.2 Vehicle Model Architecture

Table 4-1 outlines the Class 2b-8 vehicle compliance model architecture, which is comprised of six systems: Ambient, Driver, Electric, Engine, Transmission, and Vehicle. With the exception of "Ambient" and "Driver," each system consists of two to four component models. The function of each system and their respective component models, wherever applicable, is discussed in this section.

Table 4-1: Vehicle Model Architecture

System	Component Models
Ambient	none
Driver	none
Electric	Starter; Electrical Energy System; Alternator; Accessory (electrical)
Engine	Cylinder; Accessory (mechanical)
Transmission	Clutch / Torque Converter; Gearbox
Vehicle	Chassis; Final Drive

Ambient – This system defines ambient conditions such as pressure, temperature, and road gradient, where vehicle operations are simulated.

Driver – [TEST] is a forward-looking driving model. Rather than constantly matching the exact drive cycle, the driver model considers the current speed and the desired future speed to try to predict the necessary power required to close the gap and follow the driving trace. If the driver misses the target, a different power request is sent to the engine and/or brakes are applied. This search for the proper vehicle speed occurs at every simulation time step. The feedback loop uses a PID controller.

The "Electric" system consists of four components: *Starter, Electrical Energy System, Alternator, and Electrical Accessory*

Starter – This models the starter for the engine, which is identical for most vehicles.

Electrical Energy System – [TEST] simulates a standard 12 or 24 volt lead-acid battery, which provides currents to the starter and electrical systems for engine starting, lighting, and vehicle controls. This module estimates State-of-Charge (SOC), internal ohmic resistance and open circuit voltage, voltage and current of electrical energy storage system.

Alternator – This models the alternator that generates electricity for the battery and electrical system. The model calculates voltage and current of the AC alternator based on alternator performance maps and charge control strategy.

Electrical Accessory – All vehicles have a number of electrical loads, some of which are necessary to operate the vehicle. The engine control unit (ECU), fuel injectors and fuel pump for instance are electrical loads that are constantly on the battery, and these are already taken into account in the fuel map.

The "Engine" system consists of two components: *Cylinder and Mechanical Accessory*

Cylinder – The cylinder model is based on a fuel map and torque curves at wide open throttle (full load) and closed throttle (no load). In the absence of a closed throttle torque curve, the model uses a generic curve calculated from parameters such as engine displacement. The engine fuel map features three sets of data: engine speed, torque, and fueling rate at pre-specified engine speed and torque intervals. It is not a physics-based model and does not attempt to model in-cylinder combustion process. The engine torque and speed are used to select a fuel rate based on the fuel map. This map is adjusted automatically by taking into account three different driving types: acceleration, braking, and coasting. The fuel map, torque curves, and the different driving types can be adjusted by the user, but there are a number of default engines pre-programmed into [TEST].

Mechanical Accessory – Most vehicles run a number of accessories that are driven *via* mechanical power from the engine. Some of these accessories are necessary for the vehicle to run, like the coolant pump, while others are only used occasionally and at the operator's discretion such as the air conditioning compressor. Some heavy-duty vehicles also use Power Take Off (PTO) to operate auxiliary equipment, like booms, and these would also be modeled as a mechanical accessory.

Both the manual and automatic "Transmission" systems consist of two components: a manual transmission which has a *Clutch* and a *Gearbox* and an automatic transmission which has a *Torque Converter* and a *Gearbox*

Clutch / Torque Converter – These component models simulate the clutch for a manual transmission and a torque converter for an automatic transmission. Maps using engine output speed and torque as inputs are employed to model the efficiency of the torque converter.

Gearbox – The same gearbox model is used for both manual and automatic transmission models, and the number of gears and gear ratios can be specified by the user. This component model consists of a map using gearbox speed and torque as inputs to model the efficiency of each gear.

The "Vehicle" system consists of two components: *Chassis and Final Drive*

Chassis – This portion models the shell of the vehicle including the tires. The drag coefficient, mass of the vehicle, frontal area and other parameters are housed in this component. For tire simulation, the user specifies the configuration of each axle on the vehicle, including the number of tires, the tire diameter and the rolling resistance.

Final Drive – The gear ratio for the differential can be specified directly by the user. The efficiency is defined by a map based on the transmission output speed and torque.

4.2.3 Capability, Features, and Computer Resources

The EPA/NHTSA vehicle compliance tool is a flexible simulation platform that can model a wide variety of vehicles from Class 2b to Class 8 trucks. The key to this flexibility is the MATLAB component files that can be modified or adjusted. Parameters such as vehicle weight, fuel map settings, and tire radius for instance can all be changed in this fashion. Since this simulation tool is created for compliance purposes, manufacturers cannot alter any default settings or select alternative drive cycles. Currently, [TEST] carries out vehicle simulation over three drive cycles: transient, 55 mph and 65 mph steady-state cycles, but is capable of incorporating others if necessary.

After running the simulation, [TEST] tracks information about each component and about the system as a whole. Information like CO_2 emissions, fuel consumption, and fidelity to the drive cycle are immediately available on the results screen. The output from each run can be saved as a PDF and an Excel file that are to be submitted to the agencies.

The system requirements for [TEST] include a minimum RAM of 1 GB, MATLAB, Simulink and Stateflow (version 2009b or later), and approximately 250 MB of disk storage.[7,8,9] The simulation takes between 30 seconds to 1 minute to run per drive cycle, depending on the cycle duration. No license is required to run the program other than for MATLAB, Simulink, and Stateflow. Although the source code is available to users, all of the component initialization files, control strategies and the underlying MATLAB/Simulink-based models should remain fixed and shall not be manipulated by the users for compliance purposes. The agencies expect the manufacturers to submit both the inputs and the modeling results in compliance with agency regulations in good faith.

4.3 Feasibility of Using a Model to Simulate Testing

4.3.1 Procedure for Model Validation

Use of a model requires that it is validated to actual test data to assure accuracy. Validation is considered successful when the differences between the simulation and the test data are within the error limits of the test data. Before the model is validated, a quality assurance check for the input data needs to be made, which includes the following steps.

- Alignment of data from different sources such as dynamometer emissions benches, portable emissions measurement systems, or engine control units;

- Ensuring that the vehicle and engine powertrain parameters, such as vehicle weight, transmission, driveline, tire, and inertia for various rotational parts etc., represent the actual vehicle being modeled;

- Selection of the proper sensor when the same parameter is recorded by different sources and calibration of the sensors to the same reference value;

- Quantification of the uncertainty of each sensor.

After the operating conditions of the vehicle components have been successfully reproduced by the model, the final results of the vehicle simulation are compared with results of a representative vehicle test. If the difference is within the test error, the model can be considered validated and can be used for vehicle simulations.

4.4 EPA and NHTSA Vehicle Compliance Model

While several existing heavy-duty vehicle simulation models are widely accepted by the research community and industry, one drawback is that their codes are not designed for the proposed regulatory program. For heavy-duty vehicles to be manufactured in the 2014-2017 timeframe, the proposed compliance approach is done through simulation based on a few user input parameters, including rolling resistance, aerodynamic drag coefficient, and vehicle weight. The comprehensive input structures with many commercially available models that are well beyond the current compliance needs may present an unnecessarily steep learning curve to the users. Therefore, EPA and NHTSA have sought to develop a forward-looking, compliance-focused vehicle model internally. The following section describes this compliance model which is to undergo a peer review process in the coming months.

4.4.1 Vehicle Model for 2014-17 Time Frame

After the agencies established the list of required input parameters from vehicle manufacturers for tractor and vocational truck certification, EPA proceeded with the development of a heavy-duty truck simulation package which produces GHG output comparable to many sophisticated forward-looking models, but eliminates the multitude of features that are needed for research and development, but that are overly complicated and not required for certification purposes.

Certification-geared truck models have been created in MATLAB/Simulink environment for vehicles with both manual and automatic transmissions. MATLAB scripts are also created, which control pre- and post-processing of truck simulations. The function of the MATLAB pre-processing scripts is to gather all the necessary component model parameters, including agency-defined fuel maps as well as manufacturer inputs (e.g., Cd, Crr, etc.). Once all the parameters are downloaded into the MATLAB workspace, the MATLAB/Simulink/Stateflow model is run to generate GHG emissions and fuel consumption for each of the three drive cycles after which the post-processing MATLAB scripts perform the calculation of individual cycle and cycle weighted fuel economy, fuel consumption and CO_2 emissions as per the EPA/NHTSA regulatory scheme in mile/gallon, gallon/ton-mile, gram CO_2/ton-mile and generate graphs displaying how the certifying vehicle follows the three drive cycle simulations. Based on the general truck usage pattern, EPA and NHTSA have defined three sets of cycle weighting factors for use in the ten regulatory classes. Table 4-2 shows that these weightings are specific to sleeper cab (long distance, typically >500 miles cruising), day cab (<~100 miles cruising), and vocational trucks (stop and go operation).

Table 4-2: Drive Cycle Weightings

DRIVE CYCLES & WEIGHTINGS:	SLEEPER CAB	DAY CAB	VOCATIONAL TRUCK
Transient	5%	19%	42%
55 mph Cruise	9%	17%	21%
65 mph Cruise	86%	64%	37%

Linking the pre- and post-processing functions to the MATLAB/Simulink-based vehicle compliance model, a MATLAB based Graphical User Interface (GUI) has also been created. This GUI allows the user to select truck type and input required parameters. Upon providing all the information requested by the GUI, the manufacturer then clicks “RUN” after which all their selections and entries will be fed into the corresponding MATLAB/Simulink-based model without the user ever directly interacting with the underlying model codes. Figure 4-1 shows the GUI with ten model categories which is flexible and easy to use for certification of heavy-duty vehicles in any of the twelve regulatory classes.

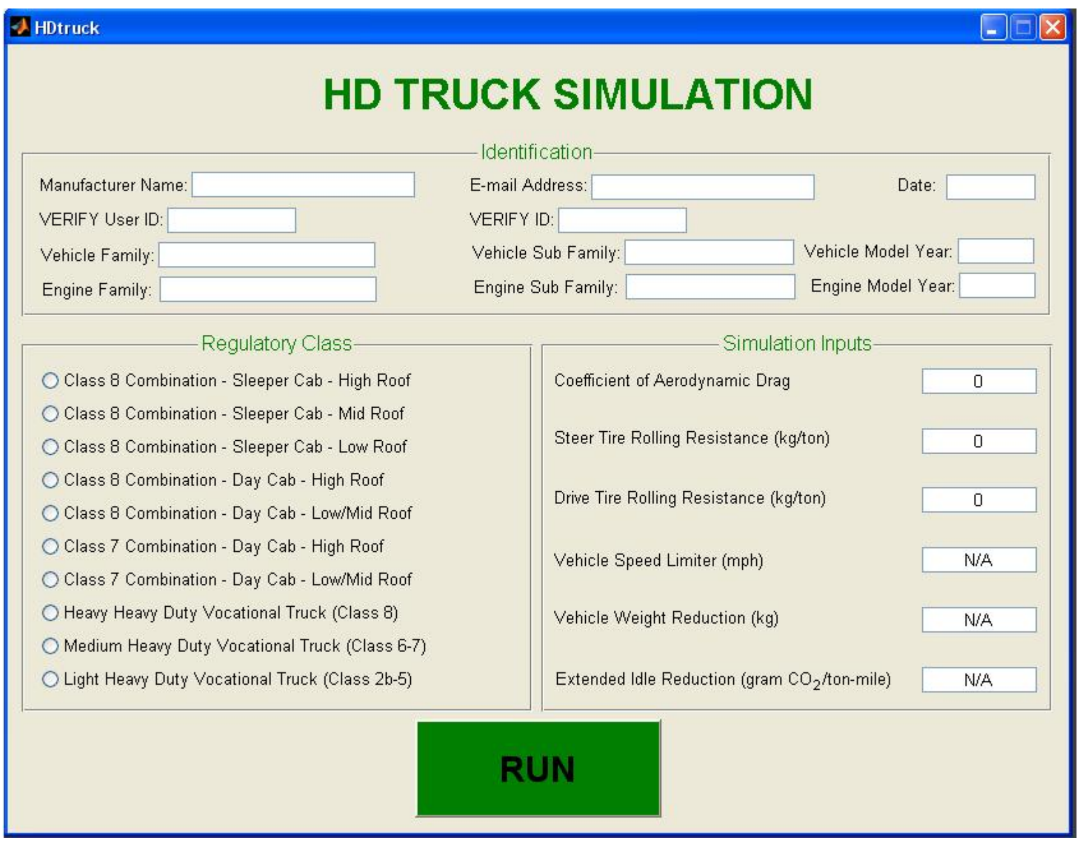

Figure 4-1: Graphical User Interface (GUI)

4.4.2 Standardized Model with Same Default Input Parameters for Each Truck Class

As discussed in Chapter 2, EPA and NHTSA have identified many possible technologies which can achieve GHG emissions and fuel consumption benefits for Class 7/8 combination tractors, which the agencies have grouped into nine distinct regulatory classes. However, some technologies may create detrimental effects due to their usage pattern and some may be too complex to model. For example, it may be difficult to accurately model those improvements which are based on each manufacturer's proprietary control strategies. Therefore, EPA and NHTSA have narrowed down the list of technologies based on their GHG emissions and fuel consumption reduction potential or modeling complexity for the 2014-17 timeframe and is proposing three input parameters plus up to three adjustments to be used in the combination tractor simulation models.

For Class 2b to Class 8 vocational trucks as defined by GVW, the myriad truck types on the road today make it challenging to group them into manageable categories for compliance purposes. However, most of these trucks operate predominantly in an urban setting with transient (stop-and-go) rather than steady state operation. Improvements in vocational truck aerodynamic features are likely to generate little GHG emissions and fuel consumption benefits compared to those for line-haul trucks whose operation are often at high cruising speeds. On the other hand, advanced technologies such as hybrid systems are likely to result in greater fuel economy benefits for these vocational truck classes as these technologies have been shown to improve fuel efficiency especially for stop and go operations[10]. Therefore, the agencies encourage the production of hybrid systems for trucks that fall under these vocational categories in which the GHG emissions and fuel consumption benefits associated with these systems are assessed per procedures outlined in Chapter 3. For non-hybrid conventional diesel trucks, EPA and NHTSA have grouped vocational trucks into three separate classes based on their shared attributes: light-heavy (LH), medium-heavy (MH), and heavy-heavy (HH), reflecting Classes 2b, 3, 4, or 5, Classes 6 or 7, and Class 8, respectively. Thus, for the 2014-17 timeframe, the vocational truck models follow a similar path as combination truck models, but with a limited set of technologies, i.e., two input parameters.

4.4.3 List of Required Truck-Specific Input Parameters for Class 7/8 Combination Truck Models

The Class 7/8 combination truck models developed by the agencies assume each Class 7/8 tractor is combined with a specific type of trailer that best matches the certifying tractor roof height. Combination tractors belonging to any of the nine regulatory classes are to be certified under seven model categories, i.e., two Class 7 day cab, three Class 8 sleeper cab, and two Class 8 day cab truck models. Manufacturers are required to provide EPA and NHTSA with the following parameters for certification:

1. Aerodynamic drag coefficient (Cd)

2. Steer tire rolling resistance coefficient (Crr, steer tires)

3. Drive tire rolling resistance coefficient (Crr, drive tires)

4. Weight reductions through lower weight wheels and tires

5. Governed vehicle speed, if less than 65 mph

6. Idle reduction technology, if any, for Class 8 sleeper tractors only

The manufactures shall conduct appropriate testing per procedures described in Chapter 3 and Preamble Section 2 for Cd and Crr for both steer and drive tires.

4.4.4 List of Required Truck-Specific Input Parameters for Class 2b-8 Vocational Truck Models

For Class 2b to 8 vocational trucks, the manufacturers would be required to provide EPA and NHTSA with the same set of parameters as those required for combination trucks except items #1, # 4, #5 and #6 for certification. Items #2 and #3 are required for certification. The agencies plan to use predefined, standardized Cd for the three vocational truck models.

4.4.5 List of Default Input Parameters for Class 7/8 Combination Truck Models

Though many technologies can potentially achieve GHG emission and fuel consumption reductions, EPA and NHTSA realize that for the proposed timeframe, some may be too complex to model (e.g., hybrid control) while others require standardization. For example, the calculation of GHG and fuel consumption benefits due to aerodynamic improvements is coupled with truck frontal area. To better capture the GHG emission and fuel consumption benefits in the simulation model as well as to avoid unintended consequences in the real-world, the agencies have identified a set of parameters that are consistent across various manufacturers for this rulemaking period. EPA and NHTSA propose to standardize the truck frontal area, truck total and payload weight, gear box and its efficiency, final drive ratio, engine/transmission/wheel inertia, accessory load, axle base, tire radius, trailer tire coefficient of rolling resistance (Crr, trailer tires), and engine fuel map. The agencies are adopting standardized input parameters that were developed by EPA, for use in the simulation model for all seven model categories of combination trucks. The specific values of these parameters are listed in Table 4-3.

Frontal Area – For Class 8 sleeper cabs, the frontal areas for high-, mid-, and low-roof tractors were estimated to be 9.8, 6.6 and 6 square meters, respectively. For either a Class 7 or Class 8 day cab, the frontal areas are assumed to be 9.8 and 6 square meters for high- and low/mid-roof tractors, respectively.

Truck Weight – It is assumed that the empty weight will vary by cab configuration and a standard weight for each category has been developed. For Class 8 trucks, the total weight ranges from 65,500 to 70,500 lbs, and for Class 7 trucks, 46,500 to 50,000 lbs. The payload capacity is assumed to be 19 and 12.5 tons for Class 8 and Class 7 trucks, respectively.

Gear Box and Efficiency – The typical Class 8 and Class 7 combination tractors have 10 speed manual transmissions. The respective gear ratios for Class 8 and Class 7 combination tractors are: 14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1 and 11.06, 8.19, 6.05, 4.46, 3.34, 2.48, 1.83, 1.36, 1, 0.75. The same set of efficiencies is utilized for each of these models, ranging from 0.96 to 0.98.

Final Drive Ratio – As above, a typical configuration is a 10 speed manual transmission with a final drive ratio of approximately 2.64 and 3.73 for Class 8 and Class 7 tractors, respectively.

Inertia – The engine inertia for Class 7 and Class 8 tractors are taken to be 3.36 and 4.17 $kg\text{-}m^2$, respectively. The transmission inertia for all combination tractors is 0.2 $kg\text{-}m^2$ and the axle inertia for Class 8 and Class 7 tractors are 300 and 240 $kg\text{-}m^2$, respectively.

Accessory Load – It is assumed that all combination trucks carry an electrical load of 360 watts and a mechanical load of 1,000 watts.

Axle Base –Class 8 tractors have 1 steer and 2 drive axles, while Class 7 tractors have 1 steer and 1 drive axle. The trailer used for both Class 7 and Class 8 cabs in simulation modeling has 2 axles.

Tire Radius – The static loaded tire radius for all combination trucks is 489 mm (or 515 mm, unloaded).

Trailer Tire Coefficient of Rolling Resistance (Crr, trailer tires) – The agencies assume 6.0 kg/ton for all trailer tires.

Engine Fuel Map – Two sets of representative engine maps have been created which are to be used by manufacturers for modeling combination and vocational truck GHG emissions and fuel consumption. The first set would be used for 2014-16 model years and represents engines which meet the 2014 engine standard. The second set would be used by truck manufacturers for 2017 model year and later compliance where the fuel maps represent engines which meet the 2017 model year engine standard. Each set consists of two separate maps, a 455 hp @ 1800 rpm (15 liter engine) and 350 hp @ 1800 rpm (11 liter engine), which are to be used for certification of Class 8 and Class 7 combination tractors. The process for engine fuel map development is described as follows.

Each of these projected maps is created by merging 2007-2009 model year heavy-duty engine data supplied by the heavy-duty manufacturers with those collected at the EPA test site *via* engine dynamometer testing, as per 40 CFR Part 1065.[11] The process of map generation is iterative and many factors are considered during data aggregation to ensure that the resulting, pre-2010 model year engine maps are consistent with those of the respective heavy-duty engine ratings sold in today’s market. These pre-2010 maps are subsequently adjusted to represent 2010 model year engine maps by using predefined technologies including SCR and other advanced systems that are being used in current 2010 production. These 2010 engine maps are further transformed into 2014 engine maps by judging the feasibility of incorporating various improved and/or promising technologies in these 2010 engines. Lastly, the 2017 model year fuel maps are developed with a similar method using a 2017 technology package. Details of the evaluation process by which the technologies can reduce engine CO_2 emissions or fuel consumption are discussed in Chapter 2.

Table 4-3: Combination Truck Modeling Input Parameters

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7
Regulatory Class	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Low/Mid Roof	Day Cab High Roof	Day Cab Low/Mid Roof
Fuel Map	15L - 455 HP					11L - 350 HP	
Gearbox	10 speed Manual	10 speed Manual	10 speed Manual	10 speed Manual	10 speed Manual	10 speed Manual	10 speed Manual
Gearbox Ratio	14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1					11.06, 8.19, 6.05, 4.46, 3.34, 2.48, 1.83, 1.36, 1, 0.75	
Gearbox Efficiency	0.96 0.96 0.96 0.96 0.98 0.98 0.98 0.98 0.98 0.98					0.96 0.96 0.96 0.96 0.98 0.98 0.98 0.98 0.98 0.98	
Engine Inertia ($kg\text{-}m^2$)	4.17	4.17	4.17	4.17	4.17	3.36	3.36
Transmission Inertia ($kg\text{-}m^2$)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
All Axle Inertia ($kg\text{-}m^2$)	300	300	300	300	300	240	240
Loaded Tire Radius (m)	0.4892	0.4892	0.4892	0.4892	0.4892	0.4892	0.4892
Body Mass (kg)	14742	13041	13154	14061	12474	11340	9752
Cargo Mass (kg)	17236	17236	17236	17236	17236	11340	11340
Total weight (kg)	31978	30277	30391	31298	29710	22680	21092
Total weight (lbs)	70500	66750	67000	69000	65500	50000	46500
Frontal Area (m^2)	9.8	6.6	6	9.8	6	9.8	6
Drag Coefficient	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Axle Base	5	5	5	5	5	4	4
Electrical Accessory Power (W)	360	360	360	360	360	360	360
Mechanical Accessory Power (W)	1000	1000	1000	1000	1000	1000	1000
Final Drive Ratio	2.64	2.64	2.64	2.64	2.64	3.73	3.73
Tire CRR (kg/ton)	= 0.425 × Trailer CRR + 0.425 × Drive CRR + 0.15 × Steer CRR						
Trailer Tire CRR (kg/ton)	6	6	6	6	6	6	6
Steer Tire CRR	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Drive Tire CRR	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input
Vehicle Speed Limiter	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input	OEM Input

A typical engine fuel map consists of three columns – engine speed, torque, and fueling rate in gram per second. Table 4-4 shows a small subset of a representative engine map in such a format. Essentially, the fueling rate is a function of engine speeds and loads. Displayed in Figure 4-2 is an example of the fueling rate contour as function of engine torque and speed for a Class 8 combination tractor with 455 hp rating. This map can be further processed to obtain other key engine performance information, such as brake specific fuel consumption (BSFC), as shown in Figure 4-3.

Table 4-4: A Small Subset of Fuel Map Input

SET MODE	SPEED (RPM)	TORQUE (NM)	FUEL RATE (g/s)
Idle	600	0	0.04
A100	1233	2100	14.77
B50	1514	1040	9.36
B75	1514	1559	13.72
A50	1233	1050	7.43
A75	1233	1575	10.78
A25	1233	525	4.26
B100	1514	2079	18.38
B25	1514	520	5.68
C100	1796	1805	19.71
C25	1796	451	6.94
C75	1796	1354	14.86
C50	1796	903	10.48

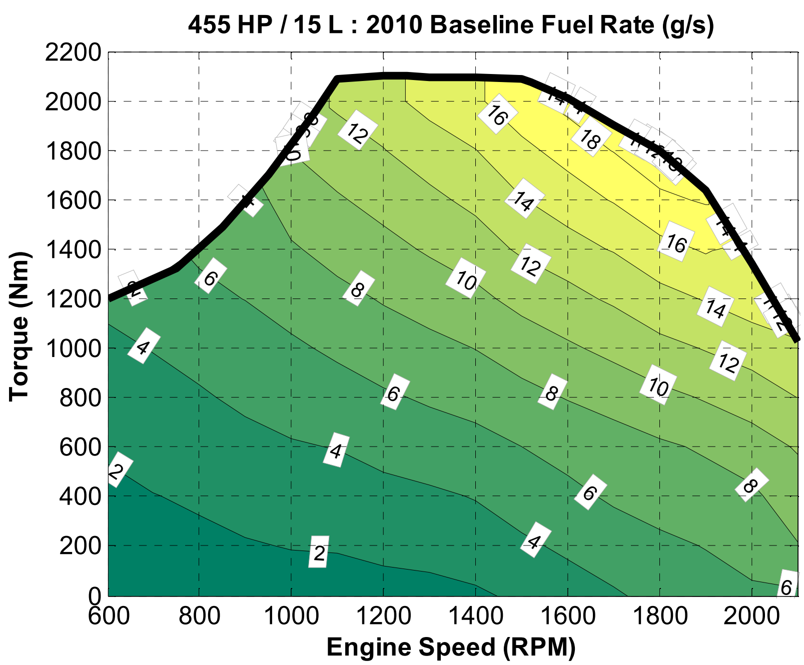

Figure 4-2: Fueling Rate (g/s) as a Function of Engine Torque and Speed for a Combination Tractor

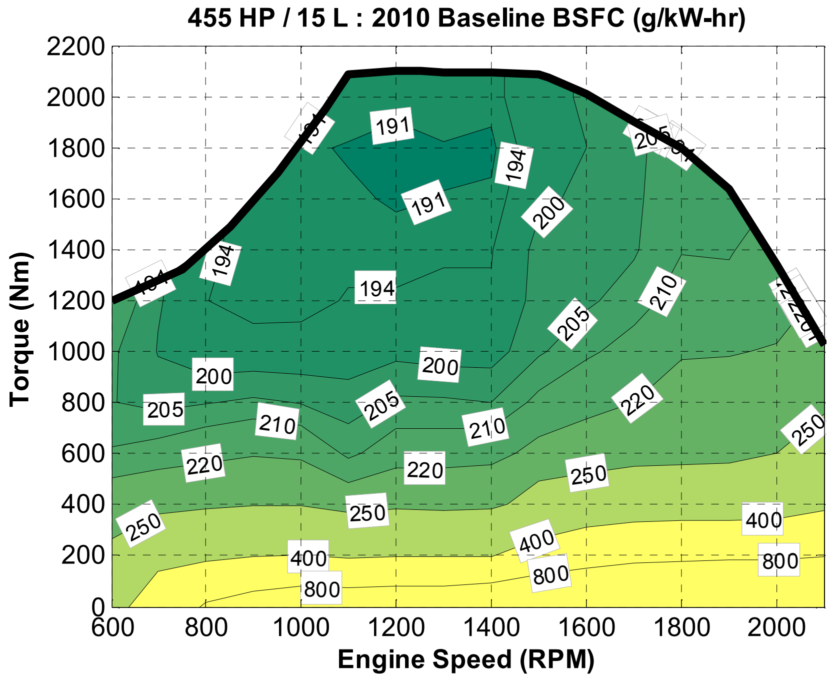

Figure 4-3: Class 8 Engine BSFC Map

4.4.6 List of Default Input Parameters for Class 2b-8 Vocational Truck Models

Likewise, EPA and NHTSA propose to standardize a set of parameters for the three Class 2b-8 vocational truck models, which the agencies refer to as Vocational Light-Heavy (VLH), Vocational Medium-Heavy (VMH), and Vocational Heavy-Heavy (VHH). These default parameters include the coefficient of aerodynamic drag, truck frontal area, truck total and payload weight, the gear box and its efficiency, final drive ratio, engine/transmission/wheel inertia, accessory load, axle base, tire radius, and the engine fuel map. Standardized input parameters to be used in the simulation model for all three vocational trucks have been developed. The specific values of these parameters are listed in Table 4-5.

Coefficient of Aerodynamic Drag (Cd) – A Cd of 0.6 for both VLH and VMH models and 0.7 for VHH, is adopted.

Frontal Area – For both VLH and VMH truck models, the frontal area is assumed to be 9 square meters, and for the VHH model 9.8 square meters.

Truck Weight – The total weight is established at 16,000, 25,150, and 67,000 lbs for VLH, VMH, and VHH models and the payload is 2.85, 5.6 and 19 tons, respectively, for VLH, VMH and VHH truck models[12].

Gear Box and Efficiency – A 10 speed manual transmission is adopted in the VHH truck model with gear ratios at: 14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1. A five speed automatic transmission is utilized for both VLH and VMH truck models with respective gear ratios of: 3.1, 1.81, 1.41, 1.0, 0.71 and 3.51, 1.9, 1.44, 1.0, 0.74. Gear efficiencies of the 5 speed automatic transmission range from 0.92 to 0.95.

Final Drive Ratio – The final drive ratio is 4.10, 3.54, and 2.64 for the VLH, VMH, and VHH truck models, respectively.

Inertia – For VHH, it is assumed the same engine and transmission inertia values as those used for a Class 8 combination tractor, while the axle inertia is 168 kg-m^2. For both the VLH and VMH truck models, the engine, transmission and axle inertia values are 2.79, 0.1 and 90 kg-m^2, respectively.

Accessory Load – It is estimated that all vocational trucks carry an electrical load of 360 watts and a mechanical load of 1,000 watts.

Axle Base – It is assumed that both the VLH and VMH models have 1 steer and 1 drive axle, while the VHH trucks have 1 steer and 2 drive axles.

Tire Radius – The static loaded tire radii for VLH, VMH, and VHH trucks are 381, 395, and 489 mm, respectively.

Engine Fuel Map – In addition to the two sets of Class 7 and Class 8 combination tractor engine maps, two sets of engine maps have been created which are to be used by manufacturers for modeling LH and MH vocational truck GHG emissions. The map created for use in Class 8 combination truck models (455 hp @ 1800 rpm) would also be used for the Vocational Heavy-Heavy truck model. Two sets of LH and MH engine maps, a 200 hp @ 2000 rpm (7 liter engine) and 270 hp @ 2200 rpm (also 7 liter engine), are to be used by manufacturers for certification of LH and MH vocational trucks in 2014-16 and in 2017, respectively.

The same methodology used for generating representative 2014 and 2017 Class 7 and Class 8 engine maps was also used for vocational map development. Figure 4-4 shows an example of the fueling rate contour as a function of engine torque and speed for a vocational truck with 270 hp rating.

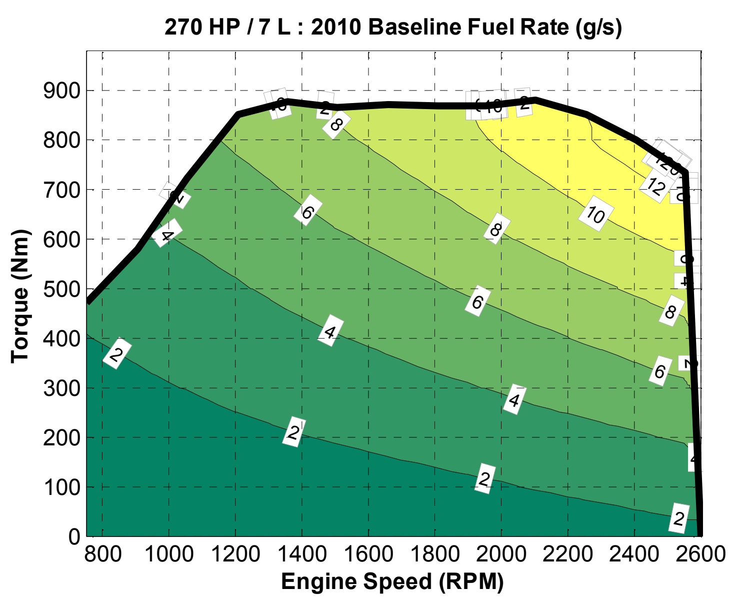

Figure 4-4: Fueling Rate (g/s) as a Function of Engine Torque and Speed for a Vocational Truck

Table 4-5: **Vocational Truck Modeling Input Parameters**

Model Type	Heavy Heavy-Duty	Medium Heavy-Duty	Light Heavy-Duty
Regulatory Class	Vocation Truck (Class 8)	Vocation Truck (Class 6-7)	Vocation Truck (Class 2b-5)
Fuel Map	15L - 455 HP	7L - 270 HP	7L - 200 HP
Gearbox	10 speed Manual	5 speed Automatic	5 speed Automatic
Gearbox Ratio	14.8, 10.95, 8.09, 5.97, 4.46, 3.32, 2.45, 1.81, 1.35, 1	3.51, 1.9, 1.44, 1.0, 0.74	3.1, 1.81, 1.41, 1.0, 0.71
Gearbox Efficiency	0.96 0.96 0.96 0.96 0.98 0.98 0.98 0.98 0.98 0.98	0.92 0.92 0.93 0.95 0.95	0.92 0.92 0.93 0.95 0.95
Engine Inertia (kg-m^2)	4.17	2.79	2.79
Transmission Inertia (kg-m^2)	0.2	0.1	0.1
All Axle Inertia (kg-m^2)	168	90	90
Loaded Tire Radius (m)	0.4892	0.395	0.381
Body Mass (kg)	13154	6328	4672
Cargo Mass (kg)	17236	5080	2585
Total weight (kg)	30391	11408	7257
Total weight (lbs)	67000	25150	16000
Frontal Area (m^2)	9.8	9	9
Drag Coefficient	0.7	0.6	0.6
Axle Base	3	2	2
Electrical Accessory Power (W)	360	360	360
Mechanical Accessory Power (W)	1000	1000	1000
Final Drive Ratio	2.64	3.54	4.1
Tire CRR (kg/ton)	= 0.5 × Drive CRR + 0.5 × Steer CRR		
Trailer Tire CRR (kg/ton)	Not applicable	Not applicable	Not applicable
Steer Tire CRR	OEM Input	OEM Input	OEM Input
Drive Tire CRR	OEM Input	OEM Input	OEM Input

4.5 Application of Model for Certification

Vehicle manufacturers are to demonstrate truck compliance using the [TEST] compliance models for the following vehicle types.

- Class 7/8 Combination Tractors: Manufacturers use one of seven predefined combination truck models to generate GHG emissions and fuel consumption.

- Class 2b-8 Vocational Trucks: Manufacturers use one of three predefined vocational truck models to generate GHG emissions and fuel consumption.

4.5.1 Class 7/8 Combination Tractors – Use One of Seven Applicable Combination Truck Models

As mentioned previously, EPA and NHTSA have defined three required input parameters and up to three allowable adjustments to be input to the simulation model to generate cycle-weighted GHG emissions and fuel consumption for certification. For Class 7/8 combination tractor certification, the manufacturer shall provide this information to the agencies in the graphical user interface.

For example, if the manufacturer plans to produce a Class 7 or 8 combination tractor in 2014 to 2017, appropriate testing shall be conducted to assess the vehicle aerodynamics and rolling features as per test procedures described in Chapter 3 and Preamble Section 2. For steer and drive tire rolling friction assessment, the manufacturer shall either conduct its own testing or obtain applicable test results from the tire manufacturer. The vehicle manufacturer needs to document the source of these test data for Cd and Crr (steer and drive tires) as part of the certification process.

If applicable, the vehicle manufacturer could exploit allowable credits or adjustments to reduce the GHG emissions and fuel consumption of the certifying vehicle by any or all of the following means: (1) restricting the top speed of the vehicle to below 65 mph (2) reducing the tractor weight to be less than the EPA-default body mass, and (3) installing special feature on the vehicle to reduce extended idle (applicable to sleeper cabs).

The quantification procedure to certify truck GHG emissions and fuel consumption using these adjustments are the following:

Vehicle Speed Limiter (VSL) – If the manufacturer limits the vehicle in-use top speed to below 65 mph with a Vehicle Speed Limiter device, a cycle reflecting the vehicle top speed shall be substituted for the 65 mph drive cycle for quantifying GHG emissions and fuel consumption over the high speed cruising cycle.

Weight Reduction – If the manufacturer uses alternate material for wheels and/or installs single wide tires in lieu of duals, it is very likely that the empty weight of the certifying Class 7/8 tractor body mass is less than that listed in Table 4-5. Therefore, the manufacturer is allowed to apply adjustments to the vehicle GHG emissions and fuel consumption calculation by reporting the difference between the EPA/NHTSA-defined tractor mass and the actual body mass. This adjustment is applied during the post-processing GHG emissions and fuel consumption calculation, in which one third of the mass reduction is added to the defined payload. This would essentially increase the denominator, i.e., payload, for all three cycle outputs, resulting in less overall gram CO_2/ton-mile or gallon/ton-mile.

Extended Idle Reduction Technology (applicable only to Class 8 sleeper cabs) – If the combination tractor is equipped with an extended idle reduction technologies with an Automatic Engine Shutoff system, then the manufacturer is allowed to subtract 5 grams/ton-mile GHG emissions and fuel consumption from the cycle-weighted GHG emissions and fuel consumption for certification. Table 4-6 lists some examples of these extended idle reduction technologies.

Table 4-6: Examples of Extended Idle Reduction Technologies

Automatic Engine Shutoff Only
Auxiliary Power Unit + Shutoff
Fuel Operated Heater + Shutoff
Thermal Storage Unit + Shutoff
Battery Air Conditioner + Shutoff
Truck Stop Electrification + Shutoff

4.5.2 Class 2b-8 Vocational Trucks – Use One of Three Applicable Vocational Truck Models

For Class 2b-8 vocational truck certification in the 2014-2017 timeframe, the manufacturer would conduct appropriate testing to assess the rolling features as per test procedures described in Chapter 3 and Preamble Section 2. The process for tire rolling friction assessment is identical to that required for combination truck, i.e. the manufacturer shall either conduct its own testing or obtain appropriate test results from the tire manufacturer. The vehicle manufacturer needs to document the source of these test data, i.e., Crr as part of the certification process.

The adjustments available to Class 7/8 combination tractors for reducing GHG emissions and fuel consumption are not applicable to any of the vocational truck classes.

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