

Fleet-Level Modeling of Real World Factors Influencing Greenhouse Gas Emission Simulation in ALPHA

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ABSTRACT

The Environmental Protection Agency's (EPA's) Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) tool was created to estimate greenhouse gas (GHG) emissions from light-duty vehicles. ALPHA is a physics-based, forward-looking, full vehicle computer simulation capable of analyzing various vehicle types with different powertrain technologies, showing realistic vehicle behavior, and auditing of internal energy flows in the model.

In preparation for the midterm evaluation (MTE) of the 2017-2025 light-duty GHG emissions rule, ALPHA has been updated utilizing newly acquired data from model year 2013-2016 engines and vehicles. Simulations conducted with ALPHA provide data on the effectiveness of various GHG reduction technologies, and reveal synergies that exist between technologies. The ALPHA model has been validated against a variety of vehicles with different powertrain configurations and GHG reduction technologies.

This paper will present an overview of the laboratory benchmarking that was done to support validation of the ALPHA model. The paper discusses a variety of real world factors that influence the simulation of fuel economy and GHG emissions that are often overlooked. Updates have been made to the ALPHA model to reflect additional losses such as tire slip and more detailed representations of the electrical system and accessory loads. The characterization of a core set of future technologies is examined, focusing on developing generic calibrations for driver behavior, transmission gear selection and torque converter lockup that are representative across a wide range of vehicles and transmissions. Finally, the paper illustrates how a set of core future technologies can be used to model GHG emissions from future vehicle fleets.

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INTRODUCTION

During the development of the light-duty (LD) greenhouse gas (GHG) standards for the model years (MY) 2017-2025, Environmental Protection Agency (EPA) utilized a 2011 LD vehicle simulation study [1] from the global engineering consulting firm, Ricardo, Inc. This study provided a round of vehicle simulations to predict the effectiveness of future advanced technologies. Use of data from this study for the final rule is documented in the August 2012 EPA and NHTSA Joint Technical Support Document [3].

The 2017-2025 LD GHG rule required that a comprehensive advanced technology review, known as the midterm evaluation (MTE), be performed to assess any potential changes to the cost and the effectiveness of advanced technologies available to manufacturers during MY2022-2025. EPA developed the Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) model [2] to enable the simulation of current and future vehicles, and as a tool for understanding vehicle behavior, greenhouse gas emissions and the effectiveness of various powertrain technologies. For GHG emissions, ALPHA calculates a vehicle's grams of CO₂ per mile

based on test fuel properties and vehicle fuel consumption. No other emissions are calculated at the present time, but future work on other emissions is not precluded.

The work behind this paper was performed by EPA's National Center for Advanced Technology (NCAT), located at its National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. NCAT engineers have further developed ALPHA as an in-house research tool to explore in detail current and future advanced vehicle technologies. ALPHA is being updated to more accurately model light-duty vehicle behavior. To validate the performance of ALPHA, EPA has performed in-depth vehicle benchmarking involving conventional and hybrid vehicles.

Focus

This paper reviews EPA's overall program to benchmark and validate ALPHA using more than 25 recent model year vehicles, engines and transmissions. It also focuses in detail on the approach of using ALPHA with a core set of current and future technologies to model CO₂ emissions from future fleets. After closely matching the behavior of specific validation vehicles, observed losses are converted into a simpler, more generic form to establish more generic parameters.

vehicle operation and fuel use. These general patterns are applied in ALPHA to allow for a clearer comparison of component effectiveness across various technology packages and vehicle classes. The calibration of the model essentially blends the unique control strategies and behavior of the individual vehicles used to validate the model (without overlooking fuel required to meet vehicle and powertrain performance requirements observed during vehicle benchmarking) and provides a more appropriate calibration for fleet level GHG modeling.

While ALPHA has been used to confirm and update, where necessary, efficiency data from the 2011 LD vehicle study, its primary use as an in-house research tool for the MTE is to study in detail the operation of current model year vehicles and to model advanced vehicle technology application in future vehicle fleets. Using this approach allows EPA engineers to configure characterizations of future technologies, while following manufacturers' operating and integration rules discovered through laboratory testing.

It should be noted, while the estimates of CO₂ reduction potential presented in this paper show a promising potential for vehicles to achieve the light-duty GHG standards for model years 2022 to 2025, the data and analyses in this paper were not used to make any conclusions or decisions regarding the MTE for the light-duty GHG rule. While this paper does include data similar to that used in the MTE to provide context, the purpose of the paper is to share information about EPA's approach to modeling and the progress made towards predicting CO₂ emissions from various technologies for future fleets, not to provide final results associated with the MTE.

The overarching goal of the paper is to explain ALPHA's approach to modeling to predict GHG emissions from future vehicles discussing the fundamental four following steps:

- Step 1. Benchmarking recent model year vehicles, engines, and transmissions:** This paper begins with a brief review of the specific vehicles, engines and transmissions that were benchmarked in EPA's laboratory in support of this work.
- Step 2. Validating ALPHA using data from specific vehicles, engines and transmissions:** To validate the performance of ALPHA, EPA completed many individual vehicle validations using in-depth newly acquired vehicle, engine, and transmission benchmarking data from 25 conventional and hybrid vehicles from MY2013-2016. The paper discusses a variety of factors that influence the simulated fuel economy and GHG emissions. ALPHA has been refined and updated to more accurately model light-duty vehicle behavior, to include new technologies and accurately simulate their losses.
- Step 3. Characterizing a core set of future engine and transmission technology:** The paper describes the core set of engines and transmissions that were used to make predictions of CO₂ emissions from future vehicles.
- Step 4. Using ALPHA to model GHG emissions from future fleets equipped with core future technologies:** This paper illustrates how ALPHA was configured to use the set of core future technologies to predictively model future vehicle fleets. It focuses on the generic calibrations for driver behavior,

engine operation, transmission gear selection and torque converter lockup that are representative across a wide range of vehicles, engines and transmissions.

BENCHMARKING RECENT MY VEHICLES, ENGINES, AND TRANSMISSIONS (STEP 1)

In preparation for the MTE, EPA refined and revalidated ALPHA using newly acquired data from MY2013-2016 engines and vehicles. During 2014-2016, EPA has been involved with the testing of over 25 different types of conventional and hybrid vehicles/engines across a wide range of powertrains and segments. An overview of the types of vehicles, engines and transmissions in EPA's testing program was provided in an earlier SAE paper describing powertrain technology package modeling [4], and is summarized below.

- 8 vehicles benchmarked with naturally aspirated (NA) gasoline direct injection (GDI) engines (4 w/Atkinson)
- 7 vehicles benchmarked with gasoline turbocharged engines
- 3 vehicles benchmarked with diesel turbocharged engines
- 4 vehicles benchmarked with port fuel injection (PFI) engines
- 4 engine dyno benchmarks with NA engines
- 5 engine dyno benchmarks with turbocharged engines
- 5 transmission benchmarks with six-speed automatic (6AT) and eight-speed automatic (8AT) transmissions

The vehicles/engines were chosen based on EPA's need to evaluate key technologies in cars, SUVs and pickup trucks. Each vehicle was extensively instrumented to better characterize powertrain inefficiencies, and ultimately yield better predictions of technology effectiveness. To explain its vehicle benchmarking process EPA authored a paper describing the test process and benchmarking data of a 2013 GM Malibu [4]. Since this paper was published, EPA has continued benchmarking more vehicles and refining its test methods.

In addition to vehicle level benchmarking EPA also conducted component-level benchmarking of several engines in EPA engine dynamometer test cells. This testing made it possible to generate full fuel consumption maps for use in ALPHA. Several papers have been authored, describing test process and data from several engines [6, 7, 8].

As part of its transmission benchmarking program, EPA has tested five transmissions to specifically obtain torque loss data for use in ALPHA. EPA has authored several papers describing its transmission benchmarking and subsequent analysis [9, 10, 11].

VALIDATING ALPHA & COMPONENT INPUTS (STEP 2)

To validate the ALPHA model a subset of the benchmarked vehicles from step 1 were selected based on the advanced technologies employed and the completeness and robustness of test data. The vehicles are presented in [Table 1](#) along with references regarding their benchmarking and/or validation.

Table 1. Vehicles and data sources for ALPHA validation activities

		Conventional Vehicle	Engine	Trans	Ref
Turbocharged Engines	Car	2015 Volvo S60 T5	2.0/ I4 Turbo	8AT	
		2013 Mercedes E350	3.0/ V6 ETEC Diesel	7AT	[12]
	Truck SUV	2013 Ford Escape	1.6/ I4 EcoBoost	6AT	
		2015 Ford F-150	2.7/ V6 EcoBoost	6AT	[14]
Naturally Aspirated Engines	Car	2013 Chevrolet Malibu	2.5/ I4 Ecotec GDI	6AT GM 6T40	[4]
		2013 Chevrolet Malibu Eco	2.4/ I4 Ecotec GDI	6AT GM 6T40	
		2013 Altima SV	2.5/ I4	Jatco CVT8	[13]
		2014 Mazda 3 (US)	2.0/ I4 SKYACTIV	6AT	[7]
		2014 Dodge Charger 5-spd	3.6/ V6 Pentastar	5AT w5A580	[9]
		2014 Dodge Charger 8-spd	3.6/ V6 Pentastar	8AT 845RE	[9]
	Truck SUV	2014 RAM 1500 HFE	3.6/ V6 Pentastar	8AT 845RE	
		2014 Chevy Silverado 1500 2WD	4.3/ Ecotec V6	6AT 6L80	[8,11]

The goal when validating individual vehicles within ALPHA is to verify that the model accurately represents the test data at both the vehicle and component levels. To this end, the validation compares not just overall UDDS and HWFET fuel consumption, but time series data for fuel, speed, and torque measurements throughout the powertrain.

The initial step in ALPHA validation involves integrating the available benchmark data for the appropriate parameters. Two types of inputs are necessary for ALPHA simulation. The first input data type consists of direct measurements of physical quantities. Examples of physical quantities include the engine's steady-state fuel map, transmission gear ratios, and transmission gear loss information. For most of these quantities a component-level benchmarking is preferred to gather the most detailed and highest quality data.

The second type of input needed for the validation is vehicle-level data that defines vehicle behavior. This input data is generally related to how the manufacturer chose to calibrate the electronic controls within the vehicle. An example of this type of input would be the transmission gear selection strategy. These inputs generally require calibration to create similar behavior. The specific calibration uses test data metrics to characterize the similarity of the behavior along with sufficient test data to cover the range of operating conditions that might be simulated.

All vehicle behavioral inputs, including transmission gear & torque converter lockup strategies, are used to ensure the simulation matches test data as closely as possible. Beginning at the wheels and working up to the engine, the available benchmarking test data is compared with speed and torque values from the simulation. Discrepancies are identified, examined further, and corrected. After the speeds, torques and fuel rates are corroborated, the behavioral inputs can be replaced with appropriate algorithms, such as ALPHASHIFT for gear selection, and calibrated to match the observed behavior.

ALPHA Model Subsystem Descriptions

Using the validation results, a number of the subsystem models within ALPHA were refined to better emulate the physics and more easily tune parameters within the model with available benchmarking data. Many ALPHA inputs play a role in determining powertrain efficiency and fuel consumption. The following sections provide a description of the various component models, looking at what data are used as inputs to ALPHA, and which of the ALPHA inputs play a significant role in determining fuel consumption. An overall breakdown of energy flows in the model, showing where the various losses are, can be found at the end of this section.

Dynamic Lookup Tables

One unique feature of ALPHA is the use of dynamic lookup tables. These special lookup tables provide interpolation similar to a normal Simulink 1D or 2D lookup, but allow the dimensionality and signals used for lookup to be determined at run time. This allows for component loss data within the model to be parameterized in a manner that corresponds directly to the available test data. For example, a detailed transmission map may have had its losses characterized by gear number, input speed, input torque, hydraulic line pressure and temperature using a five dimensional lookup, while other testing might have yielded a much simpler two dimensional map utilizing only input torque and speed. ALPHA can accept either map without physically altering the Simulink structure. Dynamic lookup tables are a powerful tool for improving model fidelity when highly detailed data is available, but also allow the model to run with coarse or simplified data when needed.

Comparison of Simulation with Torque Measurements

It is important to note that the torque signals within the model cannot be directly compared with test data from a torque meter. The method ALPHA uses to compute angular acceleration involves passing the torque and inertia measurements down to the integrator for that rotational body. To compare with measured test data, the torque signal must be compensated with the acceleration and inertia of the upstream components.

Engine Subsystem

The engine model is based around a steady-state fuel map covering all engine speed and load conditions. Curves representing maximum and minimum torque versus engine speed constrain the use of the map to points that lie within the engine's operating envelope. To determine the location on the fuel map used at each time step of the simulation, first the engine speed is calculated from the physics of the downstream speeds. Next, the torque demand is calculated from the driver model accelerator demand, an idle speed controller, and requests relating to torque management during transmission shifts.

A simple engine torque response model is implemented to emulate the air-path dynamics and turbocharger behavior. The model consists of two first order transfer functions, the time constants of which were calculated from transient testing on an engine dynamometer with a variety of engines. The first corresponds to boosted operation and limits increases in engine torque production with a time constant of

around 0.7 seconds. The second transfer function represents the air path dynamics of throttle and intake manifold with a time constant of approximately 0.2 seconds. The in-cylinder combustion processes are not modeled.

The operating speed and torque are used to interpolate a steady state fuel map. A deeper explanation of the engine model and how some of the fueling adjustments are derived is available in [14]. The following description summarizes the methodologies described in that paper.

One fuel consumption adjustment included in the ALPHA engine subsystem is a power-rate based transient adjustment. Use of a steady-state fuel map for simulation has been shown to underestimate fuel consumption. Actuator dynamics and maintaining stable operation lead to this reduced efficiency. Within ALPHA this adjustment is characterized by the rate of change in engine power as a multiplier on the base steady-state fuel map. During more aggressive driving cycles such as the US06 this adjustment increases fuel consumption 2.0% to 2.5%, while for the less aggressive cycles such as the FTP or HWFET it only adds 0.6% to 1.1%.

A second fuel consumption adjustment is included for transmission upshifts. During shift events, modern vehicles modify engine torque output in coordination with the transmission to provide a smooth shift, but at the cost of increased fuel consumption. During a transmission upshift, the decelerating inertia of the engine via the transmission clutches would yield a brief surge in torque at the wheels accelerating the vehicle. To smooth out this behavior the engine torque is reduced by a similar amount. On a spark ignition (SI) engine this is usually accomplished via retarding spark timing, as it allows the engine to return to normal operation quickly. This change in spark timing causes the engine to operate with lower efficiency. In ALPHA this behavior is simulated by reducing torque to smooth out the gear shift, but using the unadjusted torque for interpolating the fuel map. This results in overall cycle fuel consumption increases of 0.2% to 1.0%, depending upon the vehicle and test cycle.

A third fueling adjustment within the engine model is associated with deceleration fuel cut-off (DFCO). Following longer periods of DFCO additional fuel is required to maintain proper catalyst operation. This additional fueling is characterized from time series chassis test data as a multiplier on the base fuel that decays over a specified time period, usually in the range of a few seconds. Depending upon the vehicle and drive cycle this adjustment adds 0.2% to 0.5% to the cycle fuel consumption.

For engines that utilize cylinder deactivation (CDA) to reduce fuel consumption, separate fuel maps were created with and without cylinder deactivation. Multiple options are available to determine when transitions between the two maps occur. Logic can be constructed to switch based on appropriate speed and load, with limitations for vehicle conditions like transmission gear. Alternatively, recorded test data can be used to command the transitions to match what was observed during chassis dynamometer testing. Another simple option is to estimate the percentage of time CDA was active when operating in an area it is available, then

interpolate the two maps. All three methods were developed for ALPHA and yield similar results, but for simplicity, the two-map interpolation method was chosen for EPA fleet modeling.

It should also be noted that the engine subsystem includes an adjustment for CDA transitions. Spark timing is retarded to smooth out the transition while cylinders are deactivated or brought back online which leads to momentarily reduced efficiency and additional fuel consumption. Based upon EPA's testing of the 2014 Chevrolet Silverado about 0.4% additional fuel was consumed as result of these transitions.

Transmission Subsystem

The ALPHA transmission subsystem features different variants representing the major types of transmissions (automatic transmission [AT], manual transmission [MT], continuously variable transmission [CVT], and dual clutch transmission [DCT]) that are currently in use in LD vehicles. The different transmission models are built from similar components, but each features a unique control algorithm to emulate behaviors observed during vehicle benchmarking.

ALPHA features multiple speed integrators, located at each of the points in the driveline where rotational inertias may become decoupled. The torque and inertia from each component pass downstream from the engine through the transmission to the wheels. Whenever a disconnection point, such as the transmission gearbox, becomes decoupled the integrator at that location activates, computing the speed for the upstream components. If a coupling is locked up, the torques and inertias continue to be passed down to the next disconnection point or the vehicle speed integrator. This allows the physics of the system to be accurately simulated, losses associated with clutch slip to be computed, and the energy audit to be properly accounted.

Clutch & Dual Clutch

The ALPHA clutch model can be modulated during launch and provides an appropriate delay during engagement. Torque is conserved across the clutch during engagement, with the speed differential between input and output representing energy loss. The clutch modulation during launch necessitates a control algorithm to manage clutch slip and is calibrated based on observed data. Two clutches are bundled together to create the dual clutch module for the dual clutch transmission.

Gearbox

The gearbox model for ALPHA has been developed with the goal of simulating realistic operation during shifts for all types of transmissions. The gearbox contains gear ratios which properly scale both torque and rotational inertia through the ratio change. Power loss within the gearbox can be applied via dynamic lookup tables for either torque loss or efficiency. These loss tables are generally parameterized via commanded gear, input speed, input torque, and/or line pressure. Data used to fill the loss tables typically come from component benchmarking, examples of which can be found in [9, 11].



Documents

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The gearbox rotational inertias are split between a common input inertia, common output inertia and a gear specific inertia. The common inertias represent rotational inertia always coupled to the input or output shafts. The gear specific inertias, used for planetary automatic transmissions, are added or removed as gears are engaged or disengaged. There is an additional load placed on the powertrain associated with spinning up each gear specific inertia, and when each gear is disengaged the kinetic energy contained within the gear specific inertia is discarded and treated as a loss.

Hydrodynamic Torque Converter

The torque converter model in ALPHA simulates a lockup-type torque converter. The torque multiplication and resulting engine load are calculated via torque ratio and K-factor curves that vary as a function of speed ratio across the torque converter. The lockup behavior of the torque converter is accomplished by integrating a clutch model similar to the one discussed earlier in this section. While controlled torque converter clutch slip can be simulated, it is simpler to model this behavior as lockup with slightly reduced efficiency.

Proper torque converter selection plays a role in determining fuel economy as it determines the engine speed and load during launch. When available for validation activities, component benchmarking data of torque converter torque ratio and K-factor curves versus slip ratio are used. Otherwise measurements at stall are used to scale generic curves. It has been observed that torque converters are more similar than different and minor differences in K-factor curves have little effect on fuel consumption as long as the stall K-factor is reasonable for a given application.

The torque converter model also contains a pump loss torque that is implemented via a dynamic lookup table to simulate the power required to operate the pump on an AT or CVT. When possible, this loss is measured separately during the component benchmarking process, and is generally represented as a function of torque converter input speed and transmission line pressure.

Transmission Gear Selection & Torque Converter Lockup

Transmission gear selection and torque converter lockup strategies represent inputs that must be calibrated to match observed data. ALPHA includes a variety of forms in which the calibrations can be represented. Observed data can be applied directly, shifting when it was observed in the test vehicle. Classic table based shift algorithms are available as well as options like the EPA developed ALPHAsift algorithm.

The ALPHAsift algorithm employs a rule based approach utilizing the engine torque curve and fuel map to select the minimum fuel consumption gear, but still provide torque and power reserves as a traditional transmission calibration would. The algorithm also allows downshifts due to high driver demand. A detailed description of the basic shifting strategy can be seen in [15] although development has continued since publication. ALPHAsift calibration parameters can be quickly tuned to create a shifting strategy that attempts to optimize

efficiency and emulate benchmark data for a particular engine and transmission combination. This calibration can then be applied to simulations of different drive cycles or altered vehicle characteristics

The CVT transmission model uses a similar ALPHAsift-CVT algorithm for determining gear ratio selection. The algorithm identifies the operational points that minimize fuel consumed for any requested power, and then attempts to maintain operation on those points. This method also has constraints for minimum engine speed and the rate at which the gear ratio can be changed.

Driveline Subsystem

The driveline subsystem encompasses all the components that connect the transmission to apply force at the wheels. ALPHA has the capability to simulate multiple axle configurations, consisting of both driven and passive axles. The simulation of multiple axles does not add fidelity to the results as concepts like weight transfer are not simulated. As a result, most simulations are conducted with a mathematically equivalent single axle to improve simulation efficiency.

Axle Losses

The axle model within ALPHA has loss maps that can be configured as component efficiency or as a direct torque loss via dynamic lookup tables. For front wheel drive vehicles, these axle/final drive losses are generally contained within the transmission, as the transaxle is tested as a single unit with the transmission itself. Rear wheel drive vehicles are simulated with separate axle losses, often a fixed mechanical efficiency.

The axle loss maps within ALPHA could be utilized to simulate additional spin and churning losses within the axle. However, for light-duty vehicles ALPHA usually simulates roadload forces via the coastdown target ABCs. The axle spin losses are present within the ABCs as they represent one of the forces decelerating the vehicle during the coastdown test. Simulating them within the axle model would double count the losses. The ALPHA model does offer the ability to simulate roadload via aerodynamic drag and tire rolling resistance instead of ABCs. In this context including measured axle spin losses would be prudent.

Brakes

The brake model applies a torque directly proportional to the brake pedal position signal from the driver model. The maximum braking torque available is scaled with vehicle mass and tire radius to yield an equivalent maximum deceleration rate. The model also includes logic to coordinate braking when used in a hybrid to maximize the energy recovered during regenerative braking events.

Tires

The tire model handles the transfer of torque from the axles to force at the interface of the tire and driving surface. Two losses are present within the tire model. A rolling resistance force applied using the tire's rolling resistance coefficient and a portion of the vehicle mass carried by the axle. The rolling resistance is omitted when simulating roadload via coastdown ABC coefficients.

The ALPHA tire model also accounts for losses associated with slip that occur between the tire and the surface on which it is traveling. The relationship between tractive force and tire slip was derived from literature [16] and has been shown to correlate well with test data. An example of this relationship is plotted in Figure 1. For fuel economy simulation within ALPHA the wheel forces and tire slip are relatively low, allowing the tire slip to be computed from wheel torque by interpolating the red portion of the curve, which corresponds to wheel slip values of -14% to 14%. Force at the wheel is normalized by the vehicle mass such that the maximum tractive force corresponds to a 1 g acceleration. The normalization factor is tunable if the simulated tire slip differs from observations during testing.

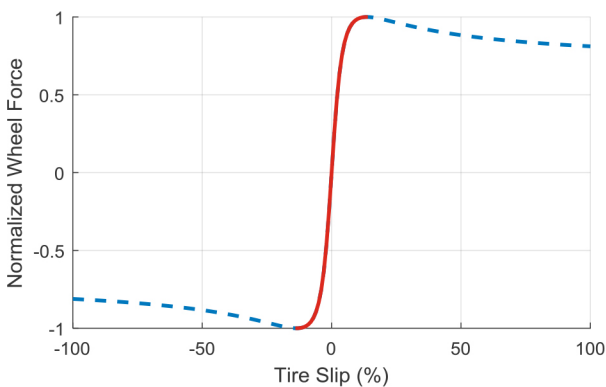


Figure 1. Sample relationship of wheel force versus tire slip, ALPHA uses the solid red portion of the line

Vehicle Subsystem

The vehicle subsystem represents the chassis of the vehicle being simulated. Roadload losses may be represented either by aerodynamic drag coefficient, frontal area and rolling resistance in the tire model, or as it is commonly generalized for light duty vehicles via coastdown target ABCs. For emission testing, the roadload force for a vehicle is expressed by a formula being equal to $A + Bv + Cv^2$, where v is the vehicle speed and the A, B and C coefficients are derived from an actual vehicle coastdown process and are used for setting up a chassis dynamometer to emulate the vehicle's on-road operation. ALPHA includes the ability to simulate road grade as well, however this feature is not used for this study. After applying these forces, the net force at the wheels can be used to compute vehicle speed and distance traveled.

When using transmission component testing loss data within ALPHA, an important consideration is that a portion of the transmission spin losses measured in component testing also contribute to the vehicle coastdown target ABC coefficients. If raw transmission test data and the target ABC coefficients are both used in vehicle simulation, this portion of the drivetrain losses will be double-counted.

The losses in question can be characterized on the test stand by measuring the spin loss at the transmission output while the transmission is in neutral, as it would be during the coastdown. Using these torque measurements, a corresponding force at the tires versus vehicle speed can be obtained. This relationship can then be used to adjust to original coastdown ABC coefficients for use within ALPHA simulations.

Table 2 shows examples of the original ABC coefficients for a select few vehicles that have been simulated within ALPHA, and their ABC values after being adjusted for use in ALPHA simulations based on transmission spin loss testing. Correcting the ABC coefficients for use in ALPHA is preferred to altering the transmission losses as it enables actual transmission output shaft torque measurements to be compared with the simulation data.

Table 2. Examples of original and neutral-drag adjusted ABC roadload coefficients

Vehicle Transmission		A lbs	B lbs/mph	C lbs/mph ²
2012 Chevrolet Malibu 6T40	Orig	28.62	0.1872	0.01828
	Adj	28.058	0.11183	0.01828
2014 Chevrolet Silverado 6L80	Orig	31.030	0.6234	0.03087
	Adj	30.288	0.26161	0.03397
2014 Dodge Charger 845RE	Orig	41.87	0.0217	0.01993
	Adj	33.527	0.1308	0.0190

The shift in the A and B coefficients for the 845RE transmission appears to be quite large. This change appears to be related to different neutral transmission clutch arrangements observed as vehicle speed changed during the coastdown.

Electrical & Accessories Subsystems

To properly account for losses associated with electrical accessory loads and the results of technologies like start-stop, ALPHA includes the ability to simulate the complete electrical system including battery, starter motor, alternator and accessory electrical loads.

Battery Model

The battery model for ALPHA was created after extensive literature review of battery models, particularly for hybrid vehicle applications. The same battery model structure is used for both conventional and hybrid vehicles, with different calibrations used to simulate different battery chemistries. Calibrations were generated from published literature or benchmark testing for both open circuit voltage and transient behavior. The simulated battery also features a thermal model, with the output current limited at extremes in temperature or state of charge. [17, 18, 19, 20]

Starter

The engine starter is a simplified electric motor with fixed efficiency and is commanded via a Boolean activation signal. The operation of the starter is characterized by a desired cranking speed and a maximum available torque, which is scaled to match the engine specifications. Cranking speed is maintained by a proportional integral controller with the output limited by the torque capacity. The mechanical power required and efficiency then determine the electrical current consumed. During starting, the transmission is placed in neutral to prevent excessive load on the electrical system as would occur in an AT if the transmission were in gear and the torque