Peer Review of ALPHA Full Vehicle Simulation Model

United States Environmental Protection Agency

Peer Review of ALPHA Full Vehicle Simulation Model

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

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EPA United States Environmental Protection Agency

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Contents

Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
ALPHA	Advanced Light-Duty Powertrain and Hybrid Analysis model
EPA	U.S. Environmental Protection Agency
FTP	Federal Test Procedure
ICCT	The International Council on Clean Transportation
ICF	ICF International
LDV	Light-Duty Vehicle
OTAQ	Office of Transportation and Air Quality
SAE	Society for Automotive Engineers
TAR	Technical Assessment Report
WAM	Work Assignment Manager

1. Introduction

As EPA's Office of Transportation and Air Quality develops its programs to control greenhouse gas (GHG) emissions from light-duty highway vehicles, there is a need to evaluate the effectiveness of technologies likely to be used to meet these standards. 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 ALPHA model uses the industry standard MathWorks software products MatLab, Simulink, and Stateflow version 2014a. The entire model and all subsystems are unlocked for complete transparency and is scheduled to be released to the public in 2016 along with the release of the 2017-2025 light-duty Technical Assessment Report (TAR). Conducting a comprehensive peer review of the model is an important step in gaining wide acceptance of this model by the light-duty automotive vehicle community.

This report details the peer review of the ALPHA Full Vehicle Simulation Model dated May 5th, 2016. A number of independent subject matter experts were identified and the process managed to provide reviews and comments on the methodologies used in the model. This peer review process was carried out under EPA's peer review guidelines[1].

This report is organized as follows:

- Chapter 2 details the selection of the peer reviewers
- Chapter 3 details the peer review process
- Chapter 4 shows comments grouped by charge question
- Appendix A provides resumes and conflict of interest statements for the six selected reviewers
- Appendix B provides the charge letter sent to the selected reviewers
- Appendix C, D and E provide the actual reviews submitted by the three selected reviewers/review team

[1] U.S. Environmental Protection Agency, Peer Review Handbook, 4th Edition with appendices. Prepared for the U.S. EPA by Members of the Peer Review Advisory Group, for EPA's Science Policy Council, EPA/100/B-15/001. Available at https://www.epa.gov/osa/peer-review-handbook-4th-edition-2015

2. Selection of Peer Reviewers

ICF International (ICF) compiled a list of 10 reviewers who would be capable of reviewing the ALPHA model. ICF contacted these potential reviewers to determine their availability to participate and obtained a CV. We also requested information about potential conflict of interest.

Based on the contacts and a qualitative analysis of the qualifications of each reviewer, ICF selected two reviewers and a review team with four members from ICCT led by John German. The six reviewers selected are listed in Table 2-1. Each had the necessary expertise, were available to review the report in a timely manner and had no conflict of interest. All were agreed upon by the EPA WAM.

Table 2-1. Final Reviewers

Reviewer	Contact Information	Necessary Expertise	Conflict of Interest
Sujit Das	Oakridge National Laboratory P: 865-946-1222 dass@ornl.gov	Yes	No
Shawn Midlam-Mohler	The Ohio State University P: 614-247-8650 midlam-mohler.1@osu.edu	Yes	No
John German (Lead reviewer for ICCT)	The International Council on Clean Transportation P: 202.534.1600 john@theicct.org	Yes	No
Francisco Posada	The International Council on Clean Transportation P: 202.534.1600 francisco@theicct.org	Yes	No
Oscar Delgado	The International Council on Clean Transportation P: 202.534.1600 oscar@theicct.org	Yes	No
Anup Bandivadekar	The International Council on Clean Transportation P: 202.534.1600 anup@theicct.org	Yes	No

Resumes and conflict of interest statements for the six reviewers can be found in Appendix A.

3. Peer Review Process

Once the six reviewers had been decided upon and approved by the EPA WAM, a charge letter (see Appendix B), the model files and supporting materials for the peer review were distributed via email. A teleconference was held with the reviewers to answer any questions. EPA provided additional documentation and published SAE papers that helped the reviewers understand the methods and data used in the model. An additional teleconference was held between one of the reviewers and EPA to address a technical issue that needed to be resolved to get the model to run on a specific computer. Each reviewer provided a written peer review in a timely manner. These were sent to ICF and the reviews were then forwarded by ICF directly to the EPA WAM.

ICF managed the peer review process to ensure that each peer reviewer had sufficient time to complete their review of the data analysis by the deliverable date. A two business day extension of the timeline was granted to two reviewers – one for an illness and another for a schedule conflict. ICF adhered to the provisions of EPA's Peer Review Handbook guidelines to ensure that all segments of the peer review conformed to EPA peer review policy.

4. Review Comments Grouped by Charge Letter Topic

In this section, review comments from the peer reviewers are grouped by charge letter topic. Full comments (including those in addition to the charge topics) can be found in Appendix C for Sujit Das, Appendix D for Shawn Midlam-Mohler and Appendix E for the ICCT team review. John German was the lead reviewer for ICCT, supported by Anup Bandivadekar, Oscar Delgado and Francisco Posada. The response of each reviewer by charge letter topic is shown below.

Topic 1: EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and whether the particular attributes found in resulting model embodies that purpose.

Sujit Das

1. The ALPHA model approach is a fairly simple forward-looking based on underlying physics used in other similar commercial packages available today. It consists of a simplified structure of total five modules, three for vehicle, and one each for engine and transmission. It is significantly more sophisticated in terms of its capability of estimating the CO2 and the resulting fuel consumption than the original lumped parameter model used by EPA in the original analysis of light-duty vehicle GHG emission standards. Concepts and methodologies implemented in a simplified MatLab/Simulink framework are consistent with other similar currently available models, although less complicated with the limited capability such as with the only CO2 emissions estimates.

   EPA Response: *The ALPHA model does not replace the Lumped Parameter Model but rather is used to inform its calibration. The ability to model criteria emissions is not a goal of ALPHA at this time. This feature could be added in the future if required.*

2. The modular nature of modeling framework provides the flexibility in using a technology specific from a list of available individually parametrized powertrain components collected by engine and chassis dynamometer testing to examine the vehicle performance of user-defined specific technology packages.

   EPA Response: *ALPHA uses MatLab Classes to define the most common powertrain objects to provide clean documentation (through MatLab doc) and to provide a consistent methodology for setting default parameter values when required.*

3. It is difficult to examine in detail the model approach due to a lack of detailed documentation. However, several peer review papers ~10 among which include seven recently published at the SAE 2016 Annual Congress related to benchmarking several types of engines and transmissions to generate inputs for use in ALPHA model have been published.

   EPA Response: *Since ALPHA is a modeling tool used by in-house EPA experts, its release to outside parties presents a different need to provide documentation that is sufficient to "observe and* *review" the model. ALPHA is not intended to be a commercial product or supported for wide external usage as a development tool. EPA has documentation necessary to observe the inputs, modeling assumptions & behavior, and outputs of the model. The model itself is largely straightforward and the MatLab Classes provide formatted documentation for most critical components.*

4. The model is completely input data driven, which need to be collected by either engine or chassis dynamometer testing by specific vehicle system technology case. The model application is thereby limited to the extent of validated data availability. The overall model performance is dictated by calibration of numerous technology-specific parameters used to determine final vehicle fuel economy and CO_2 emissions for various vehicle drive cycles.

   EPA Response*: Yes, the model is data-driven and care must be taken to provide reasonable input assumptions. However, not every input needs to come from specific test data. Data from the literature or other modeling (such as GT-POWER) can also be used to create or modify existing input data sets.*

5. A simplistic approach without any consideration of any aftertreatment is sufficient for CO_2 emissions estimation based on the actual fuel consumption.

   EPA Response*: A user of ALPHA must consider the underlying input data sources, including the criteria emissions performance of the engine(s) used to generate the engine fueling map(s). The model accounts for some extra fuel that is consumed during normal vehicle operation (referred within the model as engine transient fuel penalties) in part to account for operational concerns like drivability, NVH, and emission reduction strategies such as catalyst oxygen management after decel fuel cutoff.*

Shawn Midland-Mohler

1. No technical issues were found in the model that would impact its intended use. The main concern I have is in the overall fidelity of the model. The model reviewed has a decent level of fidelity – perhaps even greater than required for the intended use. An excellent example would be the use of 4-D maps of certain parameters in the transmission. The concern is on how one calibrates these maps to be representative of future technology. If one has the component on a test bench, then it is possible to extract these parameters, however, that is not the context in which this will be applied. The components being evaluated don't yet exist in physical form in many cases. One will be left to alter relatively complex non-physical models that are black-box models of complex physical behavior. I am not sure if all of the submodels will lend themselves for that type of activity. It can be done, but the question is what will the effort be to do so and how does one verify the results. A simpler model may be more appropriate in some cases.

   Alternately, calibrating the existing models from models of much higher fidelity may be an option as well. To completely understand this one would need to go through a couple of test cases to understand the overall process from a workflow perspective.

EPA Response: *The ALPHA model is designed to handle high fidelity input data if available. This high level of fidelity is typically available from component benchmarking. However, this level of fidelity is not required: lower fidelity data can also be used as needed. In fact, one of the more interesting features of the ALPHA model is its ability to adapt to data from varying sources with differing parameterizations. For example, if transmission losses are parameterized by line pressure and temperature versus, say, input torque only, then the model can reconfigure itself to handle either situation.*

ICCT

1. The model in its current form will be capable of performing its intended purpose of modeling technology benefits for most of the technologies that the agencies are considering. Moreover, the inclusion of CVT technologies as part of the modeling efforts shows the commitment by EPA to include all potential technology pathways to meet the targets. We do recommend that a table be added in the documentation that informs the reader of what technologies ALPHA is capable of modeling and what technologies are yet to be implemented in the model or the model is incapable to simulate.

   EPA Response*: Documentation of the technical aspects of ALPHA is included in the Draft Technical Assessment Report (TAR) and on the EPA ALPHA website (https://www.epa.gov/otaq/climate/alpha.htm).*

2. Some specific model elements that could be improved to better reflect technologies in the future that may be impacted as well by Tier 3/LEV III emission standards:

   Cold start operation modeling: ALPHA does not simulate or model cold-start operation, instead applying the adjustment factors derived by Ricardo for Ricardo’s 2011 modeling for EPA. This approach likely works fine for current, known technology, but it is likely inadequate for future engines with fast warm-up strategies, especially considering the upcoming changes to emission standards. There is also no ability to model other drive cycles with a cold start, as the adjustment factors are specific to the FTP.

   EPA Response*: ALPHA includes the ability to alter the “adjustment factors,” and EPA has implemented smaller fuel penalty factors to predict the effects of fast warm-up strategies. Although including a temperature model would theoretically result in higher fidelity modeling, it’s questionable whether the characteristics of future warm-up strategies would be known with enough accuracy that a temperature model would give better final results than adjusting the post-processed penalty factors as necessary. Using adjustment factors is an accepted modeling practice when specifically applied to the FTP. Two-cycle (FTP and HWFET) CO_2 emissions are the primary focus of the current version of ALPHA.*

3. Also, specifically relating to the correction factors for Bag 1, where the fuel consumed during this period is increased by around 16-17%, how does ALPHA correct the energy audit to account for this correction? Would that 16-17% extra be reflected on energy losses, thermal or mechanical? The effect of the correction on the energy audit should be described.

   ***EPA Response**: ALPHA simulates operation of warm vehicles and the energy audit correctly accounts for their energy usage. The adjustment factor used to predict the fuel consumption during cold start operation is applied in post-processing and does not affect the energy audit, which reflects energy flows calculated during the warm simulation only. We will clarify this in the ALPHA model documentation.*

4. According to the documentation review, ALPHA's stop/start modeling appears to be very simplistic. Their description says, "Alpha contains a sub-model for 12 volt electrical start-stop technology, which simulates shutting the engine off after vehicle has stopped moving for 0.1 second. During a simulation, the start-stop mode is disabled when the vehicle is assumed to be operating cold such as during the first 100 sec of bag 1 of the FTP cycle." Potential limitations of this approach to SS technology modeling are:

   No ability to do stop/start during coasting or deceleration (sailing).

   EPA Response*: Sailing is not a technology currently being modeled in ALPHA. The capability to simulate a true sailing mode may be added to a future version of ALPHA.*

5. The length of stop/start disablement after a cold start appears to be completely arbitrary. Note that actually modeling cold start operation, instead of using a simple adjustment factor, would fix this problem as well, although we recognize that this would require development of more sophisticated modeling.

   EPA Response*: As the locations of the FTP hills are fixed, the length of stop-start disablement is really only a decision of whether or not stop-start is active in between hills 1 and 2. Testing of MY2011-2015 vehicles equipped with start-stop technology has shown that, for some vehicles, start-stop technology is enabled between FTP hills 1 and 2, and for some it remains disabled. Because we expect OEMs to continue to reduce engine warm-up times, ALPHA assumes for the 2020 and later time frame that start-stop will be enabled during FTP hills 1 and 2. We will revisit this assumption if vehicle test data indicates otherwise.*

6. Engine scaling to maintain vehicle performance. ICCT's comments regarding this approach have two components, dealing with the technical aspects and the way it is incorporated into the ALPHA model.

   First, ALPHA's approach to maintain the vehicle performance when reducing weight is to scale the BSFC maps to increase fuel consumption while downsizing an engine, reflecting the increase in heat losses due to higher cylinder surface area to volume ratio. Ricardo also used this method on their previous modeling work. Although the idea is technically sound, the limitation that we perceive with this approach is that it ignores the option of reducing the number of cylinders, which would decrease the cylinder surface area to volume ratio. The option of using an engine with fewer cylinders implies that the model would have to incorporate algorithms that can select the appropriate engine for downsizing; this implies developing additional engine maps and criteria for selecting the right one.

EPA Response: *We are aware of this type of analysis for selecting engine size, and recognize that ALPHA's engine scaling could be enhanced to cover more options. This is an area of active study at this time.*

7. Second, the documentation describes the development of a parametric analysis tool to compare the different technology approaches to find the best technology option (SAE 2016-01-0910). In this case, the ideal outcome would be to incorporate the ability to change number of cylinders, i.e., engine maps, as part of the effort.

   EPA Response: *Altering the number of cylinders and/or adjusting cylinder displacement to accomplish optimal engine scaling to maintain vehicle performance would affect the overall efficiency of the engine. The parametric analysis is an internal quality control tool (as opposed to an optimization tool) used to evaluate changes in engine efficiency after scaling has occurred. The parametric analysis is not dependent on any particular method of resizing, the end number of cylinders, or final displacement.*

8. Synergy between engines and transmissions. In the SAE paper describing ALPHAs performance, the authors correctly note that engines and transmissions have some overlap in their benefits and derive parametric estimates for the "synergy factor" (SAE 2016-01-0910). As shown in Table 7 of that paper, the synergy factor is negative for 6AT, 8AT, and future 8AT. But it is positive for the future 8DCT - which basically defies theory. EPA should evaluate why there are positive synergies between engines and future 8DCTs and, if this is not an error in the modeling, describe in the next iteration of the supporting documentation how the synergy factor was determined for future 8DCTs and why it has positive synergies.

   EPA Response: *You correctly detected an issue with that specific "synergy factor". As stated in the SAE paper, one of the key purposes of EPA's internal parametric analysis of the data matrix of 1080 unique vehicle packages in the SAE paper was to facilitate vetting of the complete dataset for quality control problems. While we did not detect this issue before the SAE paper was published, soon afterwards we determined that this positive value of the "synergy" factor was due to an improper idle fueling rate contained in an early version of one of the input engine maps used to generate results for the SAE paper. There was no error in ALPHA's calculation method or the software which uses the engine fuel consumption maps to determine the CO2 values in the paper. However, there was just a simple problem with the input data for one specific fuel consumption map. This engine map has since been corrected.*

Topic 2: The appropriateness and completeness of the contents of the overall model structure and its individual systems, such as:

a. The performance of the example component models, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.

b. The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel consumption over the given driving cycles.

Sujit Das

1. With the availability of new engine, transmission, and operational control benchmarking data, ALPHA model would be able to support the 2017-2025 light-duty GHG rule requiring a comprehensive advanced technology review, known as the mid-term evaluation for the 2022-2025 light-duty GHG emission standard. The model is flexible enough with the capability to determine the effectiveness contributions from advanced technologies not considered during the original Federal rulemaking.

   EPA Response: *Thank you for your comment.*

2. The model performance validation is a continuous process, which has been accomplished by using the newly acquired in-depth vehicle, engine, and transmission benchmarking data from more than 25 different types of conventional and hybrid vehicles 2013-2015. At any point, model appropriateness and completeness will be dictated by the extent of benchmarking data available for the model performance validation.

   EPA Response: *EPA agrees that the model is data-driven which is why we have utilized data from so many different types of test vehicles.*

3. A complete listing of model limitations (e.g., sensitivity of electric power steering losses with vehicle speed and a lack of dynamic temperature algorithm) is critical for any model validation. However, a few of these limitations have been discussed in the recent SAE publications.

   EPA Response: *The current version of the ALPHA model was not designed to be a general purpose vehicle simulation model. It was designed to accurately estimate CO2 emissions over the EPA City and Highway drive cycles from a variety of advanced technology vehicle packages. Within that context, ALPHA has no "limitations", only a lack of additional features that it does not need to estimate CO2 emissions over the city and highway cycles. ALPHA does not require the additional fidelity or flexibility that would come from adding those features.*

   To specifically address the items mentioned above, ALPHA has adequate assumptions for alternator loading to cover the electric power steering requirements. ALPHA also has an algorithm to adjust ALPHA's warm FTP results for cold start operation and has no other need to dynamically simulate an engine's temperature. Using ALPHA's existing capabilities we have successfully validated ALPHA using test data from over 20 engines and vehicles.

4. The primary gear selection routine, the ALPHAshift algorithm critical to the fuel economy and CO2 emissions, has recently been validated and updated (based on the recently published SAE

paper) to dynamically generate transmission shift logic from a set of user-defined parameters and generate more realistic vehicle performance during simulation. Since the modelling approach used is completely data driven, algorithms for new control strategies need to be developed including its validation of tunable control parameters in order for reliable vehicle performance estimation using ALPHA.

EPA Response*: The ALPHAshift parameters are determined during a simulation pre-processing calibration step. Basic shift speed limitations are provided within reasonable limits and adjustments are made based on available engine capability in order to provide reasonable performance and drivability. For example, downsized turbo engines shift at higher speeds than naturally aspirated engines. Consequently, appropriate ALPHAshift parameters are selected when simulating a vehicle with this type of engine. This pre-processing step is an input to the model and was not included as part of the peer review.*

5. A recent SAE publication (SAE 2016-01-1142) reports an excellent agreement of fuel consumption results from a comparative examination of advanced transmissions among studies conducted by National Research Council, Argonne National Laboratory, and earlier EPA lumped parameter model.

   EPA Response*: EPA thanks the reviewer for the comments on EPA publication SAE 2016-01-1142. EPA has spent considerable time and resources investigating transmission losses and behavior since transmissions are second only to engines in terms of influence on fuel economy for conventional vehicles.*

6. It is a fairly simple transparent model which allows to examine both fuel economy and CO2 emissions of alternative light-duty technology pathways. The model execution requires an expert MatLab/Simulink user since no user-friendly interface currently exists. Although the model use as indicated will be mainly by in-house EPA experts, but the model validation of its transparency particularly when pertaining to the Federal rulemaking needs to be addressed. A specific simulation runtime is significantly high, more than 10 mins. without providing any indication to the user progress made so far. A fairly more complicated model such as Autonomie available even with enhanced capabilities is significantly faster today.

   EPA Response*: We appreciate your comment that “*no user-friendly interface currently exists” *and your acknowledgement of EPA’s intent that ALPHA will be mainly used by in-house EPA experts. Indeed ALPHA was developed primarily to help EPA estimate CO2 emissions from future vehicle technology packages. As with any internal tool, EPA does not have the need for a “user-friendly interface” like one that would normally accompany a commercial product which is available for purchase and fully supported for wide external usage.*

   We recognize the need for sufficient documentation to be transparent about the model for review by the public. EPA has provided documentation necessary to observe and review the model inputs, modeling assumptions & behavior, and outputs of the model, which are sufficient for external review and use by technical experts. Through the release of the Draft Technology Assessment Report (TAR) in 2016, EPA has significantly increased transparency by providing more in-depth *modeling information than was released with the 2012 FRM. As shown in the table below, we have expanded the transparency of the ALPHA modeling functions; ALPHA inputs, results and their use to update EPA's Lumped Parameter Model (LPM); model source code; and finally benchmarking, mapping and validation through the use of peer reviewed SAE papers. We plan to further increase transparency over the next year through the release of enhanced ALPHA documentation and additional SAE papers.*

Description of ALPHA materials published with the Draft TAR
Explanation of the modeling functions
Modeling results used to calibrate EPA's Lumped Parameter Model (LPM)
Access to inputs that produced the modeling results used to calibrate LPM
Access to full model source code
SAE papers describing various benchmarking, mapping and validation (10 papers)

Your comment about the slowness of the model available to the Peer Reviewers is simply the result of the fact that a Simulink model was provided for the review process so the internal structure of the model could be examined easily. The compiled version of the model is executed at EPA and it only takes a few seconds to run a simulation.

7. Although a model run requires comparatively a fewer number of consolidated input parameter files, but a lack of proper model documentation (both as a standalone document and within the MatLab files) makes harder for a better model structure understanding including any sensitivity runs of any user-specified variables.

   EPA Response: *Since ALPHA is a modeling tool used by in-house EPA experts, its release to outside parties presents a different need to provide documentation that is sufficient to "observe and review" the model. ALPHA is not intended to be a commercial product or supported for wide external usage as a development tool. EPA has documentation necessary to observe the inputs, modeling assumptions & behavior, and outputs of the model. The model itself is largely straightforward and the MatLab Classes provide formatted documentation for most critical components.*

Shawn Midland-Mohler

1. Driver Submodel

   The driver does a good job at manipulating the brake and accelerator pedals in a smooth and natural way while matching the drive cycle for the vehicle and cycles included in the review. For different vehicles and cycles, this may or may not be true. Just checking for the error in the target and actual speed is not enough to check for this as it is possible to meet the desired speed trace with rapidly oscillating (i.e. unnatural) manipulation of the accelerator and brake signals. This can lead to poor quality results while driving the trace accurately. This is not a flaw with the approach used – just that a diagnostic needs to be added to check for this type of behavior to ensure that the data produced is accurate.

   EPA Response: *At EPA, as a pre-processing setup, the driver model setup is adapted to the test weight and performance level of the target vehicle. As a result the driver model can adapt from compact cars up to Class 8 tractor-trailers. In addition, SAE J2951 drive quality statistics are calculated in post-processing for each phase of any drive cycle to determine if the driver model is performing satisfactorily.*

2. Engine Submodel

   There are many controls and calibrations imbedded in the engine plant model. This can be problematic in some circumstances for model reuse and calibration. An example would be the decel fuel cutoff strategy and the idle speed control strategy. At a minimum, clarity could be improved by making control function and plant models visible and different.

   EPA Response: *Thank you for your comment. It might be possible in the future to update the engine submodel in this way, which might be more like the transmission submodels where the overall controls are separated from the plant.*

   For a model aimed at fuel economy predictions, there may be more fidelity then strictly necessary. For instance, use of inertia in the engine model requires additional complexity for the transmission/engine model for minimal gains in fuel economy prediction. The approach used is fine but it may be more complex than necessary for the model goals. The use of so many inertias when things like shift durations simply enforced via the initialization files seems odd – but not wrong from a technical perspective.

   EPA Response: *It may be the case that a model of lower fidelity could achieve similar results. However, reducing model fidelity can lead to modeling shortcuts that can cause as many problems as they solve. For example, it would probably be possible to eliminate the closed loop idle speed control without any effect on fuel consumption (and the model might run faster), but then unnatural behaviors may result during the transition away from idle. Generally speaking, different transmissions in different drivelines have similar shift times relative to the number of gears in the transmission, regardless of the specifics of the powertrain involved, therefore shift times are parametrized primarily by gear count and not component inertias.*

I was not able to find any type of thermal model for the engine – which is well known to have temperature effects for efficiency. Components like the 12 V battery have one – so it is inconsistent to not include one for the engine.

EPA Response: *Engine thermal behavior is handled as a fuel consumption adjustment in post-processing as discussed previously. The battery model is parameterized by temperature simply because detailed data was available. For a 12V battery, thermal response is not a critical factor, however the same battery model (with appropriate parameter data) is also used to model electric vehicle batteries and can be used to investigate their response to temperature variations.*

There are several ad-hoc factors like the 'tip-in penalty' that appears in the engine fuel-flow submodel. It is not clear on how one would calibrate this or what it is really meant to capture from a physical standpoint. Fuel enrichment on tip is not something that is done in modern engine controls – air prediction is good enough that in general there is only a minor amount of enrichment happening. Another example would be the 'acceleration_penalty_squelch_gps' factor.

EPA Response: *Perhaps the naming convention of this variable was somewhat misleading. The 'tip-in penalty' refers to extra fuel consumed after operating in decel fuel cutoff as observed during vehicle testing, it does not refer to a performance-based enrichment. These parameters are meant to represent the fuel consumption of the engine that is not captured by a steady-state fuel consumption map.*

3. Automatic Transmission Submodel

The fidelity of the transmission model and the resulting number of calibration parameters is fairly high given the goal of the model. There are many look up tables some of which have four dimensions. It is not clear how one would calibrate these parameters given the context of use.

EPA Response*: As mentioned previously, the model can adapt to different and unique input data sets. This gives the model the flexibility to use very simplified or highly specified input data.*

The shift logic appears to produce reasonable shift commands – there are no frequent shifts, inappropriate skip shifts, etc. There is a great deal of logic in the 'automatic trans control' block. Similar to previous comments, the question is how does one calibrate all of this for technology that may not exist?

EPA Response*: Conventional transmissions are relatively straightforward. The shift control has been documented in detail in the paper SAE 2015-01-1142 " Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation," and is based on observed behavior in test vehicles. The shift parameters are also adjusted in pre-processing for a particular powertrain, as discussed previously.*

There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

EPA Response: *Faster transmission warmup is accounted for as part of the fuel consumption penalties applied to the FTP results to account for cold start operation. EPA has acquired transmission thermal data during benchmarking but not all of this data is required for modeling two-cycle fuel economy. The transmission is assumed to operate under fully warmed-up conditions (true for the HWFET and the last two phases of a four-phase FTP) and an adjustment factor is applied to increase the fuel consumption for phases 1 and 2 to account for the additional fuel used to warm up both engine and transmission. This same approach is used for all transmission types.*

4. Continuously Variable Transmission Submodel

Control logic is much simpler in contrast to the automatic – this is a positive thing in terms of the intended use.

EPA Response: *Yes, the CVT has a simpler shift strategy, as documented in SAE 2016-01-1141 "Modeling of a Conventional Mid-Size Car with CVT Using ALPHA and Comparable Powertrain Technologies".*

There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

EPA Response: *The same cold temperature adjustment factor described in the previous response on this topic under automatic transmissions is used for all transmission types including CVTs.*

5. Dual Clutch Transmission Submodel

There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

EPA Response: *The same cold temperature adjustment factor described in the previous response on this topic under automatic transmissions is used for all transmission types including DCTs.*

6. 12V System Model

The 12V battery model is one of the more complex models in the model. The alternator model is some control logic and a single constant efficiency for current to torque based on speed – so quite simple. This is a large mismatch in fidelity. Having a fairly elaborate 2nd order RC model for the battery and then modeling the alternator so simply is not technically incorrect, but is something to consider.

EPA Response: *High fidelity data is used for the 12V battery model because it was available. EPA has a battery test facility and is actively benchmarking several types of conventional 12V batteries in order to provide accurate parameters to the ALPHA model. The alternator model can be* *updated to include, for example, a full 2D efficiency map. However, at this time, the alternator model remains simplified and the approach taken is consistent with the 2011 Ricardo modeling work performed for the 2017-2015 FRM.*

The electric/mechanical loads are all fairly simple map-based which matches the overall fidelity of the model. They will, of course, need to be calibrated to somehow represent future vehicle systems. How that will be done is an important item to consider for the future application of the model.

EPA Response: *At this time, future vehicles are modeled with a slightly improved alternator efficiency relative to current alternators.*

7. Vehicle Sub Model - The vehicle driver model typical of model of this class.

   EPA Response: *Thank you for your comment.*

8. Transmission Input File - The input files are appropriate given the model – it is done in a pretty typical way and should work well. As mentioned in the model sections, the input files contain a lot of parameters – particularly the automatic transmission one. The main concern here is how one would arrive at this large list of parameters given the intended use of the model.

   EPA Response: *As mentioned in a previous response, the data used for automatic transmissions was obtained through laboratory benchmarking of several transmissions.*

9. Engine Input File

   The input file contains a handful of unspecified parameters – not causing any issues but it is strange to have them there if they are unused. It is not sure how something like fuel octane number would be used in this type of model.

   EPA Response: *Fuel properties are stored in a simple database format, fuel Octane is simply one of the fields and is automatically pulled in to the fuel properties object regardless of whether it is used in the model. Extra information associated with fuel properties is important in understanding the performance level of the engine and the conditions under which it was mapped or modeled.*

   Input file is appropriate given the model – done in a very typical way.

   EPA Response: *Thank you for your comment.*

10. Other Input Files - Pretty typical of what one would expect from the accompanying model.

    EPA Response: *Thank you for your comment.*

11. Output Structures

The output used a structure of structures and included a wide range of data (time-domain, summary data, *etc.*) This could be adapted as necessary to bring in whatever data was deemed necessary.

I may have missed it because it is hard to navigate through all of a nested set of structures, but I did not see that the model input data was stored in the output structure. If not, then it should definitely be included as well as the model version (which was included.) This is so that a model result can be rerun if necessary using the same input parameters without having to track down the initialization files that created the model input.

EPA Response: *For a normal Simulink run, the input data is not saved as part of the output, it's already present the in the MatLab workspace (which can be saved in its entirety, including the outputs). However, when running the executable version of the model, a complete input data file is saved and may be reviewed or reloaded later in conjunction with the output data file for that particular simulation. In this way the initial conditions can be produced in order to replicate or troubleshoot the simulation.*

ICCT

1. ICCT checked the underlying equations for the physical models and in general they seem reasonable, although perhaps simplified (e.g. rotational dynamics simply assume an "equivalent mass" to account for rotational inertia). We also evaluated the impacts of selected changes in model inputs on the outputs and we are providing our views on overall model structure from a perspective of the final user. We also considered the types of outputs that can be relevant for the development and operation of the updated OMEGA model that is expected to be released along with the release of this ALPHA model.

   EPA Response: *Converting inertias to equivalent mass is acceptable as it maintains conservation of energy and simplifies the model.*

2. Test Runs

   ICCT conducted a series of runs by changing a parameter at a time and observing the result in terms of 2-cycle CO2 emissions. Note that our simplified parametric test did not include constant performance, due to the iterative modeling required to match performance, thus no changes were made to the model engine size.

   The results of the parametric test, summarized in Table 1, confirm the results of the parameter estimates in the SAE paper - load reduction results in a constant gCO2/mi reduction, regardless of the baseline fuel consumption when no changes are made to engine size. Note that this was true for mass, rolling resistance (RR), and aerodynamic drag (Cd) reductions – in every case the gCO2/mi reduction for the NA+AT5 vehicle, with 270.5 gCO2/mi, was almost identical to the gCO2/mi for the

EGRB24_TDS+8DCT+ALT vehicle, with 189.7 gCO2/mi.[2] This defies basic theory, as fuel consumption (and CO2) is generally proportional to vehicle load. In addition, ICCT has reduced load using both FEV's and Ricardo's simulation models, and both modeled proportional reductions in gCO2/mi, not a constant g/mi reduction. **This strongly suggests that the model has errors in the underlying equations or coding with respect to all of the load reductions.**

2-cycle ALPHA results	Emission results, gCO2/mi			Reductions, gCO2/mi		
	NA +AT5	NA + CVT+SS	EGRB24_TDS+ 8DCT+ALT	NA +AT5	NA + CVT+SS	EGRB24_TDS+ 8DCT+ALT
Baseline per model	270.5	250.1	189.7	-	-	-
Mass red 5%	265.4	244.9	184.6	5.1	5.2	5.1
Mass red 10%	260.8	239.2	179.9	9.8	10.9	9.8
Mass red 15%	256.1	234.6	174.3	14.4	15.5	15.4
RR red 10%	267.1	246.1	186.2	3.4	4.0	3.4
RR red 20%	263.1	242.6	182.2	7.4	7.4	7.4
Cd red 10%	266.3	245.3	185.4	4.3	4.8	4.3
Cd red 20%	261.9	241.5	181.1	8.6	8.6	8.6

EPA Response: *The reviewer's conclusion and analysis shown in the chart above examines the effect of applying a constant vehicle road load reduction to three different powertrains. Our understanding of this comment is that the reviewer expected to find CO2 g/mi reductions proportional (relatively equal to) to the base CO2 g/mi, rather than near constant reductions in CO2.*

Although in some circumstances the reviewer is correct that gCO2/mi reduction is a function of the baseline fuel consumption, this general principle holds best for vehicles with a range of road loads but similar powertrain technology. On the other hand, the principle does not hold for vehicles with similar vehicle road loads but a range of different powertrain technology. The text box following this response contains a more technical discussion of the reasons behind this principle. The analysis in EPA's SAE paper[3] compared vehicles with similar vehicle road loads, but different powertrain technology.

Runs similar to those referenced by the reviewer were also completed by Argonne National Laboratory using their Autonomie vehicle simulation tool.[4] We used the Autonomie results to calculate the

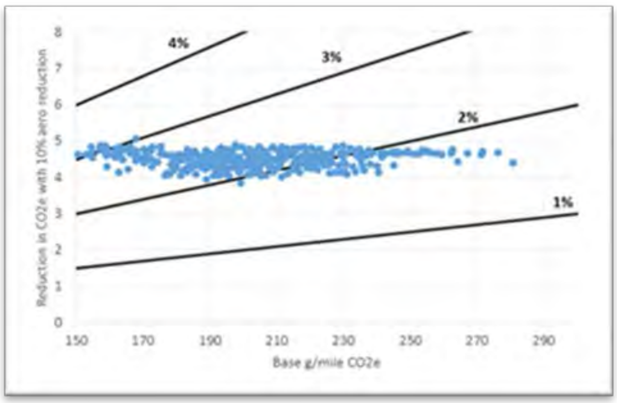
[2] The SAE paper reported mass reduction results after adjusting for performance and found CO2 reductions varied more proportionally with the baseline vehicle gCO2/mi. Perhaps correcting for constant performance shifted the CO2 reduction to more of a constant percent reduction instead of a constant g/mi reduction, but we did not see this when reducing mass without correcting for performance.

[3] EPA's SAE paper: Kargul, J., Moskalik, A., Barba, D., Newman, K. et al., *"Estimating GHG Reduction from Combinations of Current Best-Available and Future Powertrain and Vehicle Technologies for a Midsized Car Using EPA's ALPHA Model,"* SAE Technical Paper 2016-01-0910, 2016, doi:10.4271/2016-01-0910

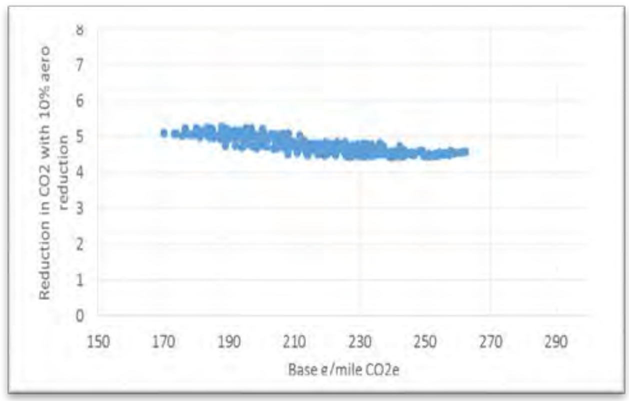
[4] The Autonomie results are publically available from the National Highway Traffic Administration, via their Midterm Evaluation website located at: http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/ld-cafe-midterm-evaluation-2022-25

incremental CO2 reduction associated with a reduction in various road loads. The same trend of approximately constant CO2 reduction was observed (for example, the effect of reducing the aero loads by 10% within both models, for a mid-sized car equipped with a range of conventional engine, transmission, and other technologies, is shown in the figures below), with numbers roughly corresponding to the ALPHA results, as well as with those in the table above in the reviewer's comment. We believe that the effect of the road load change was correctly calculated using both models, and should also be observed from any other well designed and physics-based vehicle simulation model.

<u>Results from EPA's ALPHA Model</u>



<u>Similar Results from Autonomie</u>



efficiency (shown in the figure
as higher fuel requirement for
incremental torque).

Additional Technical Discussion for Previous EPA Response:

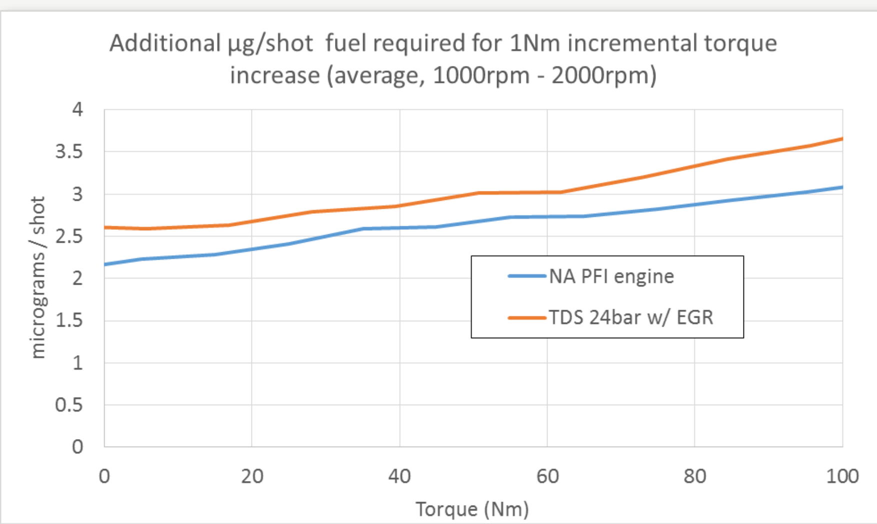
Generally in a high level analysis of a powertrain, the total fuel used at any operational point consist of some constant fuel to cover parasitic overhead losses that are independent of road load/power, plus incremental fuel to cover the power needs that are proportional to road load/power, but independent of the overhead losses. Thus, when incremental fuel needs are roughly the same for two different engines, the incremental additional fuel saved for an incremental decrease in road load remains constant (as does the incremental fuel consumed for an incremental increase in road load).

A recent SAE paper does an excellent job of describing this for the curious. *(Patrick Phlips, "Analytic Engine and Transmission Models for Vehicle Fuel Consumption Estimation," SAE International Journal of Fuels and Lubricants, 8(2):2015, doi: 10.4271/2015-01-0981)* The paper states that there is *"historically fairly wide recognition that internal combustion engine fuel use increases proportionally with output, with an offset related to engine losses **[overhead losses]** and a slope related to indicated efficiency **[marginal efficiency]**."* [bracketed words added]

Many technologies used to increase powertrain efficiency (engine or transmission friction reduction, as an obvious example) decrease *overhead losses* rather than increase *marginal efficiency*. Some engine technologies (increasing compression ratio, for example) do increase marginal efficiency; however, many of the most popular advanced technologies – those reducing pumping work in engines – reduce the *overhead losses* at the expense of decreasing *marginal efficiency*.

So, although it's not a hard and fast rule that *marginal efficiency* (and thus incremental CO2 consumption) remain the same across technology packages, it should not be surprising to find that this is indeed approximately the case. For reductions in CO2 to only be proportional to the base CO2 emissions, as suggested by the reviewer, would require advanced technologies to exclusively increase *marginal efficiency* with absolutely no effect on *overhead losses*, which is certainly not the case.

As an example, the figure below illustrates the incremental fuel usage required to produce one additional Nm of torque from the engine alone, for a NA PFI engine versus a turbo-downsized (TDS) 24 bar engine with EGR. In the area most used during the two-cycle testing, the two engines have roughly equivalent incremental fuel requirements, with the TDS engine actually requiring slightly more incremental fuel (likely due to the introduction of EGR and consequent reduction in pumping losses). As can be inferred from the figure, an identical decrease in road load for vehicles containing these two engines would lead to very similar reductions in fuel consumption.



Note:
Generally, the TDS engine is quite a bit more efficient than the naturally aspirated engine, but this higher efficiency is due to the reduction in overhead losses (not shown in the figure) which more than offsets the slight decrease in marginal efficiency (shown in the figure as higher fuel requirement for incremental torque).

3. Accessories

According to the supporting documents, "power steering, air conditioning, fan and a generic load to cover the remaining losses are observed. Each load can apply mechanical loads to the engine crankshaft and/or electrical loads to the battery. Each load can be independently correlated to model signals via dynamic lookup tables, and is calibrated to match test data."

Access to defining such losses was difficult to find and the structure of the inputs was not clearly defined in the model. Allowing accessory power consumption to be user-defined inputs could promote developments in technologies that reduce the power requirements of accessories such as the alternator, air-conditioning compressor, power steering pump, or cooling fan. There are other opportunities for engine accessories such as oil, coolant, and fuel pumps, but is not clear at this point if all those savings are going to be captured by the engine mapping process. Accurate accounting of the benefits of advanced accessories is extremely relevant to the implementation of future off-cycle credits for GHG.

EPA Response: *The quoted reference refers to the structure of the model, not necessarily what was provided, or what is used, for MTE modeling. These represent modeling flexibilities, not requirements. At this time, the MTE modeling for current and future vehicles assumes a fixed electrical load that represents the estimated expected total average load. Improvements to oil, coolant, and fuel pumps would presumably be reflected in improved steady-state engine maps since these components would be accounted for during engine dyno testing. Off-cycle credit modeling is not considered by ALPHA at this time.*

Topic 3: Use of good engineering judgment to ensure robust and expeditious program execution

Shawn Midland-Mohler

1. See comments above regarding the possible higher than necessary model fidelity.

   EPA Response: *High model fidelity is a matter of flexibility, not a requirement. See previous responses such as the one for Shawn Midland-Mohler Topic 1-Q1.*

2. The choice of a 0.01 sec step size should be validated by running a step size independence study. If that step size is unnecessary then it would be possible to decrease the model run time.

   EPA Response: *EPA has run studies as suggested by the reviewer. The model may run slightly faster, perhaps with 0.02 second steps, but larger steps may cause instability in, for example, the engine idle speed control. See response for next comment as well.*

3. To run a HWFET, the model as delivered required 175.8 seconds to run. Enabling the 'accelerator' option in Simulink took it down to 89.7 seconds including the time to build it – and only 32.9

seconds if the model did not need to be rebuilt for a run. The model developers are likely already aware of this feature in Simulink – if not then they should familiarize themselves with it.

EPA Response: *EPA staff are aware of this feature in Simulink. As mentioned previously, EPA uses a fully compiled version of the model when running batch simulations that only takes a few seconds to run.*

4. In terms of robustness, I do have some concerns regarding the amount of control logic that is imbedded at various places. The model fidelity requires some of this – but there are also a number of things that are not contributing to fuel economy greatly (some were noted in the submodel notes above.) These controls can lead to problems in certain applications if they are not adapted accordingly.

   EPA Response: *The reviewer's point is well received. Since the basic underpinnings of the ALPHA model are shared by the heavy-duty simulation model GEM and the heavy-duty GHG compliance certification tool, the model has been specifically designed to adjust to a wide variety of target vehicles from compact cars to Class 8 tractor-trailer vehicles with little or no intervention required by the user. In other words, the controls are designed to scale with the application, either in pre-processing or in the model itself.*

ICCT

1. In our opinion, the best measure of engineering judgment and proper program execution is obtaining good agreement between ALPHA simulations and actual testing data. The documentation reviewed suggests that the errors over the FTP and highway drive cycles are often within 3%, which are within the +/-3% test-to-test variability of chassis dynamometer testing.

   EPA Response: *We agree with the reviewer's input. As stated in earlier responses, EPA has spent considerable time and effort to validate the model and its inputs. These efforts are documented, for example, in a number of SAE papers that have been published in the last two years and will continue to be published.*

Topic 4: Clarity, completeness and accuracy of the output/results

Sujit Das

1. A simplified set of model outputs exists consisting of (a) Energy Audit Report; (b) SAE J2951 Drive Quality Metrics; and (3) Fuel Consumption and Economy and CO2 emissions by two specific drive cycles. Although the specific details are not intense, but appropriate enough for the overall model objective. In addition, sixty specific plots as a function of drive cycle time are available. Use of MatLab/Simulink modeling software allows us to examine variables of common interest generated in the MatLab workspace for each simulation. Unless an expert MatLab/Simulink, it is not intuitive to track down the logical flow of summary final results from its initial parameter values used in underlying equations. Complete model documentation would be helpful in this regard.

EPA Response: *The large number of plots provided allow for one element of quality control and for demonstration purposes and not a complete set of outputs. Many possibilities exist for data analysis and ALPHA applies a "data class" methodology that is consistent when examining benchmarking data as well as model outputs so that they may be directly compared, if desired, in a common and documented name space.*

As stated in our previous responses regarding documentation (Sujit Das' Topic 1-Q3), EPA has provided model documentation that can be used by outside parties to observe and review the model. We plan to continually look for ways to enhance the ALPHA documentation as opportunities arise.

2. Model simulation results for the three transmission cases provided for the review were appropriate as one would expect. Higher fuel economy and resulting lower CO2 emissions were obtained with more efficient transmission technology, maximum in the case of dual clutch transmission (DCT). For the maximum efficient DCT technology, a simple sensitivity case was run by increasing the vehicle chassis mass by 175 lbs. A 4.8% increase in vehicle chassis mass resulted in a 2.1% decrease in fuel economy.

   EPA Response: *Note that the different powertrains (AT/CVT/DCT) also represented different configurations in terms of stop/start and alternator regen. In this case the DCT included alternator regen and the CVT included stop/start. This approach was intended to demonstrate a range of ALPHA's modeling capabilities for this peer review.*

<u>Shawn Midland-Mohler</u>

1. Without having validation data, there is no way to evaluate accuracy. It was also noted in the peer review directive that we were looking mainly at model structure as it is not yet fully calibrated.

   EPA Response: *ALPHA development/validation is ongoing and the simulations provided for the peer review were for example purposes. ALPHA validation activities have utilized test data from over 25 different vehicles, engines and transmissions. EPA's model validation efforts have been documented in SAE papers and other forums. Please refer to the MTE website for additional information: https://www3.epa.gov/otaq/climate/mte.htm*

2. The energy balance that is conducted is the first step in ensuring things are working well. More would need to be done do validate the model.

   EPA Response: *We agree with the reviewers comment. Energy balance within ALPHA simulation runs is definitely one of the measures we utilize to validate the model. Again, model validation has been accomplished by using newly acquired in-depth vehicle, engine, and transmission benchmarking data from more than 25 different types of conventional and hybrid vehicles 2013-2015.*

3. The model appears to have the major vehicle system models one would expect for fuel economy prediction.

   EPA Response: *Thank you for your comment.*

ICCT

1. The report is very thorough, including a detailed energy audit and 50+ figures, which is commendable. However, we recommend that a smaller "summary" report, only with the very key parameters (fuel consumption, engine cycle efficiency, speed-trace following metrics) be produced for easy tracking of multiple runs.

   EPA Response: *Thank you for your comment, we will consider such an approach for future versions of ALPHA.*

2. The input and output structure of ALPHA was not finalized when released for peer review, however the current version of the output structure were provided to give the reviewer a flavor of the potential structure. The inclusion of performance metrics is highly commended, although we suggest spelling out some metrics in the output file to facilitate troubleshooting and give the user a better perspective.

   EPA Response: *Performance metrics are an important component of the MTE modeling effort to enable powertrains to be properly sized while moving from one technology to another. We will take your suggestion under advisement for future versions of ALPHA.*

Topic 5: Any recommendations for specific improvements to the functioning or the quality of the outputs of the model.

Sujit Das

1. A detailed model documentation including a detailed listing of model variables definition is necessary to satisfy the model objective of transparency.

   EPA Response: *Thank you for your comment. Documentation of model variables is an ongoing component of our current ALPHA work as exemplified by using MatLab classes as much as possible (instead of structures, for example) as they provide well formatted documentation sheets when used as intended. As stated in earlier responses about documentation (Sujit Das' Topic 1-Q3), we plan to release more detailed ALPHA documentation as appropriate to continue our commitment to transparency.*

2. Timely availability of the validated vehicle system data for the potential technology pathways to be considered for the EPA mid-term evaluation will be critical to achieve the model objective.

EPA Response: *EPA has publically released the modeling assumptions and benchmarking data as part of the MTE process.*

3. Any comparative analysis with the similar forward-looking, full vehicle computer simulation model such as AUTONOMIE used by U.S. Department of Energy will be useful towards the model validation.

   EPA Response: *Several comparative analyses were completed as part of the coordination efforts between EPA and NHTSA during the ongoing MTE process. ALPHA results have been compared with the original MY2017-2025 LD FRM Ricardo EASY5 results, as well as with results from AUTONOMIE. When the models are viewed as a calculators, then providing the same inputs to the calculators should provide the same outputs. In some cases there were minor differences between simulation results due to specific model behaviors or implementations, but in effect these models are very close in terms of computational results when run using the same input assumptions.*

4. It is critical that the level of accuracy of vehicle performance results obtained from a simplistic model such as ALPHA be frequently demonstrated and documented to meet the stringent requirements of any Federal regulation such as CAFÉ in this case.

   EPA Response: *We agree that it is important to document ALPHA, and for this reason EPA has spent considerable time and effort producing publicly available ALPHA documentation in publications such as the Draft Technical Assessment Report (TAR), benchmarking data, key ALPHA input file descriptions, key ALPHA result outputs, and SAE papers and presentations. However, it is also important to note that ALPHA is EPA's internal tool used to estimate future CO2 emissions, not a regulation compliance tool for either EPA's GHG or NHTSA's CAFE regulations.*

5. It'd be good to add Aftertreatment component module in order to enhance ALPHA estimation capability of several other types of pollutants beyond CO2.

   EPA Response: *We agree this would be a good enhancement to ALPHA if there ever becomes a need to estimate criteria pollutants other than CO2. Because the light-duty GHG rules does not require this, we have not included it in this version of the ALPHA model.*

6. It is recommended that to better simulate a vehicles cold-start operation, a study of bag fuel consumption reported in EPA certification data would be useful for a better understanding of the cold-temperature correction factor (currently used in ALPHA simulations) trend with new model vehicles.

   EPA Response: *EPA has performed this examination using certification data and used the results to determine the nominal correction factor used for bag one of the FTP. Further testing with four-bag FTPs and warm vs. cold UDDS cycles was used to determine the nominal correction factor used for bag two of the FTP.*

ICCT

1. It would be useful for the user have access to a list of all the relevant vehicle parameters that can be modified and the corresponding file where those parameters are input. Some parameters are intuitive, but some others may fall out of sight unless there is a set list. Moreover, EPA has invested a great deal of time and resources making sure the physical models are representing the physical elements, and a parameters list would help produce a better representation of the system being modeled.

   EPA Response: *Currently, we use MatLab Classes to help document the available parameters for the primary components. As stated in our response about documentation (Sujit Das' Topic 1-Q3), we plan to continue to enhance ALPHA documentation in the future as appropriate.*

2. The way the model handles vehicle weight, tire rolling resistance, and Cd inputs may be improved. As presented in the model, when changing vehicle mass, the user must change the vehicle mass and separately change the rolling resistance by changing the A coefficient on the road load equation. In the same way, changes in RR values have to be performed in the model by changing the A coefficient. It would be better suited and less prone to errors to input these parameters separately and program the ALPHA code to do the changes automatically. It would also be desirable to provide flexibility to input either m, A, B, and C; or m, Cd, and RRc.

   EPA Response: *ALPHA supports both ABC and coefficient-based road loads. There are benefits and liabilities to each approach. When modeling for the 2016 Draft TAR, the roadload corrections, as a function of mass, for example, are handled in the processing steps prior to model execution.*

3. We were not able to find any information on how the model handles component weight changes. Specifically, how does ALPHA handle changes in mass due to components with different mass? For example, if an AT6 is being replaced with a DCT8 and that there are mass changes associated with that. Does the delta in transmission mass change affect the vehicle overall weight or road load parameter A? The model needs to at least inform the user that it the user's responsibility to assess and incorporate any impacts of changes in components on vehicle mass.

   EPA Response: *ALPHA does not track changes to component masses individually, only the total vehicle weight is embodied in the test weight/inertia. Within ALPHA, for the draft Technology Assessment Report (TAR), mass and roadload reductions are considered separately from individual component specifications.*

4. **Extra fuel usage for other vehicle operating requirements.** The introduction of overhead functions to compensate the steady-state based model for fuel used during transient conditions is very useful. Our recommendation is to make those key adjustments available to the user on a clearer way; such as a list of functions and parameters, or maybe developing a parameter list that deals with such items.

EPA Response: *We agree, and EPA staff are working on a peer reviewed technical paper on this topic at this time. Transient operation penalties are also currently under active investigation. See previous responses regarding user documentation.*

Appendix A. Resumes and Conflict of Interest Statements

Appendix B. **Charge Letter**

May 7th, 2016

Sujit Das
Oak Ridge National Laboratory
Energy and Transportation Science Division
12305 Fort West Drive
Knoxville, TN 37934

Subject: Peer Review of EPA ALPHA Model

Dear Mr. Das,

ICF International has been contracted by EPA to facilitate a peer review. In late April we corresponded by email and you indicated your availability to participate as a paid reviewer of the EPA Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) model. You have been selected to participate on this panel. ICF will compensate you up to $4,000 for your services. This charge letter provides you with a list of directed questions for your review, the review schedule, and the materials we would like you to send to us at the conclusion of the review. In addition, attached to the email is a Zip file with a copy of the model that we would like you to review. You will need to rename the file with a zip extension to open it.

Charge Questions

The purpose of this peer review is to examine the structure, operation, and simulation results of the ALPHA tool used by EPA to determine the effectiveness of various technologies via simulation. For this review, no independent data analysis is required. EPA is looking for the reviewer's opinion of the concepts and methodologies upon which the model relies and whether or not the model can be expected to execute these algorithms correctly. This review concentrates on the implementation of conventional powertrain (non-hybrid) vehicles. Model inputs such as engine and transmission maps are not part of this review and are only included to provide the reviewer with a complete functioning model. Feedback on the technical aspects of ALPHA rather than a critique of variable names or presentation of results is preferred.

In your comments, please distinguish between recommendations for clearly defined improvements that can be readily made, based on data or literature reasonably available to EPA, and improvements that are more exploratory or dependent, which would be based on information not readily available to EPA. Comments should be clear and detailed enough to EPA readers or other parties familiar with the report to allow a thorough understanding of the comment's relevance to material provided for review.

Below are questions to define the scope of the review; we are not expecting individual responses to the questions, but would like them to help guide your response.

<u>General Questions and Issues to Consider</u>

1. EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and whether the particular attributes found in resulting model embodies that purpose.
2. The appropriateness and completeness of the contents of the overall model structure and its individual systems, such as:
    a. The performance of the example component models, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.
    b. The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel consumption over the given driving cycles.
3. Use of good engineering judgment to ensure robust and expeditious program execution;
4. Clarity, completeness and accuracy of the output/results; and
5. Any recommendations for specific improvements to the functioning or the quality of the outputs of the model.

EPA requests that the reviewers not release the peer review materials or their comments until the Agency makes its ALPHA model and supporting documentation public. EPA will notify the reviewers when this occurs.

Schedule
The schedule for this peer review is as follows:

- May 7th, 2016: Charge letter distributed to reviewers
- June 10th, 2016: Comment/review due via email to Laurence.O'Rourke@icfi.com

Materials

Upon completion of your review, you should submit your report under a cover letter that states 1) your name, 2) the name and address of your organization, and 3) a statement of any real or perceived conflict(s) of interest.

Should you have any questions or concerns, feel free to contact me via phone at 617-250-4226 or by email. In addition, the EPA project manager for this effort is Jeff Cherry and he may be reached at 734-214-4371 or cherry.jeff@epa.gov. For any questions about the review process itself, please contact Ruth Schenk in EPA's Quality Office, National Vehicle and Fuel Emissions Laboratory at 734-214-4017 or schenk.ruth@epa.gov.

Thanks for your participation!

Sincerely,

Larry O'Rourke
Manager, ICF International
Attachment: Alpha Peer Review WA 4-03.EPA

Appendix C. **Sujit Das Comments**

Sujit Das
12305 Fort West Drive, Knoxville, TN 37934
Knoxville, TN 37934, USA
(865)789-0299
dass@ornl.gov

June 9, 2016

Larry O'Rourke
Manager, ICF International

RE: Peer Review of *Draft Report on EPA ALPHA Model*

Dear Mr. O'Rourke:

Thank you for inviting me to conduct a peer review of the *Draft Report on EPA ALPHA Model.* I have completed the review.

Enclosed with this letter is a summary of my review comments and recommendations. These comments are made on the basis of the current state of science as I understand it. To the best of knowledge, I have no real or perceived conflicts of interest in conducting this review.

Please feel free to contact me should you have any questions or need additional regarding this review.

Sincerely,

Sujit Das

Enclosure: A summary of review comments and recommendations

PEER REVIEW COMMENTS

EPA ALPHA MODEL

Sujit Das
Oak Ridge National Laboratory
12305 Fort West Drive, Knoxville, TN 37934
June 10, 2016

Peer Review of EPA ALPHA Model

A. APPROACH

1. The ALPHA model approach is a fairly simple forward-looking based on underlying physics used in other similar commercial packages available today. It consists of a simplified structure of total five modules, three for vehicle, and one each for engine and transmission. It is significantly more sophisticated in terms of its capability of estimating the CO_2 and the resulting fuel consumption than the original lumped parameter model used by EPA in the original analysis of light-duty vehicle GHG emission standards. Concepts and methodologies implemented in a simplified MatLab/Simulink framework are consistent with other similar currently available models, although less complicated with the limited capability such as with the only CO_2 emissions estimates.

2. The modular nature of modeling framework provides the flexibility in using a technology specific from a list of available individually parametrized powertrain components collected by engine and chassis dynamometer testing to examine the vehicle performance of user-defined specific technology packages.

3. It is difficult to examine in detail the model approach due to a lack of detailed documentation. However, several peer review papers ~10 among which include seven recently published at the SAE 2016 Annual Congress related to benchmarking several types of engines and transmissions to generate inputs for use in ALPHA model have been published.

4. The model is completely input data driven, which need to be collected by either engine or chassis dynamometer testing by specific vehicle system technology case. The model application is thereby

limited to the extent of validated data availability. The overall model performance is dictated by calibration of numerous technology-specific parameters used to determine final vehicle fuel economy and CO2 emissions for various vehicle drive cycles.

5. A simplistic approach without any consideration of any aftertreatment is sufficient for CO_2 emissions estimation based on the actual fuel consumption.

B. APPROPRIATENESS AND COMPLETENESS

1. With the availability of new engine, transmission, and operational control benchmarking data, ALPHA model would be able to support the 2017-2025 light-duty GHG rule requiring a comprehensive advanced technology review, known as the mid-term evaluation for the 2022-2025 light-duty GHG emission standard. The model is flexible enough with the capability to determine the effectiveness contributions from advanced technologies not considered during the original Federal rulemaking.

2. The model performance validation is a continuous process, which has been accomplished by using the newly acquired in-depth vehicle, engine, and transmission benchmarking data from more than 25 different types of conventional and hybrid vehicles 2013-2015. At any point, model appropriateness and completeness will be dictated by the extent of benchmarking data available for the model performance validation.

3.. A complete listing of model limitations (e.g., sensitivity of electric power steering losses with vehicle speed and a lack of dynamic temperature algorithm) is critical for any model validation. However, a few of these limitations have been discussed in the recent SAE publications.

4. The primary gear selection routine, the ALPHAshift algorithm critical to the fuel economy and CO_2 emissions, has recently been validated and updated (based on the recently published SAE paper) to dynamically generate transmission shift logic from a set of user-defined parameters and generate more realistic vehicle performance during simulation. Since the modelling approach used is completely data driven, algorithms for new control strategies need to be developed including its validation of tunable control parameters in order for reliable vehicle performance estimation using ALPHA.

5. A recent SAE publication (SAE 2016-01-1142) reports an excellent agreement of fuel consumption results from a comparative examination of advanced transmissions among studies conducted by National Research Council, Argonne National Laboratory, and earlier EPA lumped parameter model.

C. MODEL STRCUTURE AND OUTPUTS/RESULTS

1. It is a fairly simple transparent model which allows to examine both fuel economy and CO_2 emissions of alternative light-duty technology pathways. The model execution requires an expert MatLab/Simulink user since no user-friendly interface currently exists. Although the model use as indicated will be mainly by in-house EPA experts, but the model validation of its transparency particularly when pertaining to the Federal rulemaking needs to be addressed. A specific simulation runtime is significantly high, more than 10 mins. without providing any indication to the user progress made so far. A fairly more complicated model such as Autonomie available even with enhanced capabilities is significantly faster today.

2. Although a model run requires comparatively a fewer number of consolidated input parameter files, but a lack of proper model documentation (both as a standalone document and within the MatLab files) makes harder for a better model structure understanding including any sensitivity runs of any user-specified variables.

3. A simplified set of model outputs exists consisting of (a) Energy Audit Report; (b) SAE J2951 Drive Quality Metrics; and (3) Fuel Consumption and Economy and CO_2 emissions by two specific drive cycles. Although the specific details are not intense, but appropriate enough for the overall model objective. In addition, sixty specific plots as a function of drive cycle time are available. Use of MatLab/Simulink modeling software allows to examine variables of common interest generated in the MatLab workspace for each simulation. Unless an expert MatLab/Simulink, it is not intuitive to track down the logical flow of summary final results from its initial parameter values used in underlying equations. A complete model documentation would be helpful in this regard.

4. Model simulation results for the three transmission cases provided for the review were appropriate as one would expect. Higher fuel economy and resulting lower CO_2 emissions were obtained with more efficient transmission technology, maximum in the case of dual clutch transmission (DCT). For the maximum efficient DCT technology, a simple sensitivity case was run by increasing the vehicle chassis mass by 175 lbs. A 4.8% increase in vehicle chassis mass resulted in a 2.1% decrease in fuel economy.

D. RECOMMENDATIONS

1. A detailed model documentation including a detailed listing of model variables definition is necessary to satisfy the model objective of transparency.

2. Timely availability of the validated vehicle system data for the potential technology pathways to be considered for the EPA mid-term evaluation will be critical to achieve the model objective.

3. Any comparative analysis with the similar forward-looking, full vehicle computer simulation model such as AUTONOMIE used by U.S. Department of Energy will be useful towards the model validation.

4. It is critical that the level of accuracy of vehicle performance results obtained from a simplistic model such as ALPHA be frequently demonstrated and documented to meet the stringent requirements of any Federal regulation such as CAFÉ in this case.

5. It'd be good to add Aftertreatment component module in order to enhance ALPHA estimation capability of several other types of pollutants beyond CO_2.

6. It is recommended that to better simulate a vehicle's cold-start operation, a study of bag fuel consumption reported in EPA certification data would be useful for a better understanding of the cold-temperature correction factor (currently used in ALPHA simulations) trend with new model vehicles.

Appendix D. Shawn Midlam-Mohler Comments

Shawn Midlam-Mohler
3938 Norbrook Drive
Columbus Ohio 43220

Larry O'Rourke
ICF International, LLC
9300 Lee Highway
Fairfax, VA 22031

Dear Mr. O'Rourke,

Attached you find my comments regarding my peer review of the EPA Alpha model.

I am an employed as a professor by Ohio State University and my campus address is:

OSU Center for Automotive Research
Attn.: Shawn Midlam-Mohler
930 Kinnear Road
Columbus OH 43212

This work was done outside of my normal job duties as consulting, thus, any correspondence regarding for this work should be sent to my home address:

Shawn Midlam-Mohler
3938 Norbrook Drive
Columbus OH 43212

I am not aware of any real or perceived conflicts of interest that would effect my performance on this peer review.

I appreciate the opportunity to work with ICF and would welcome additional opportunities.

Sincerely,

Shawn Midlam-Mohler

PEER REVIEW

EPA ALPHA Model

Conducted by: Shawn Midlam-Mohler

Submitted on: 6/13/2016

Overall Summary:

No technical issues were found in the model that would impact its intended use. The main concern I have is in the overall fidelity of the model. The model reviewed has a decent level of fidelity – perhaps even greater than required for the intended use. An excellent example would be the use of 4-D maps of certain parameters in the transmission. The concern is on how one calibrates these maps to be representative of future technology. If one has the component on a test bench, then it is possible to extract these parameters, however, that is not the context in which this will be applied. The components being evaluated don't yet exist in physical form in many cases. One will be left to alter relatively complex non-physical models that are black-box models of complex physical behavior. I am not sure if all of the submodels will lend themselves for that type of activity. It can be done, but the question is what will the effort be to do so and how does one verify the results. A simpler model may be more appropriate in some cases. Alternately, calibrating the existing models from models of much higher fidelity may be an option as well. To completely understand this one would need to go through a couple of test cases to understand the overall process from a workflow perspective.

Driver Submodel:

- The driver does a good job at manipulating the brake and accelerator pedals in a smooth and natural way while matching the drive cycle for the vehicle and cycles included in the review. For different vehicles and cycles, this may or may not be true. Just checking for the error in the target and actual speed is not enough to check for this as it is possible to meet the desired speed trace with rapidly oscillating (*i.e.* unnatural) manipulation of the accelerator and brake signals. This can lead to poor quality results while driving the trace accurately. This is not a flaw with the approach used – just that a diagnostic needs to be added to check for this type of behavior to ensure that the data produced is accurate.

Engine Submodel:

- There are many controls and calibrations imbedded in the engine plant model. This can be problematic in some circumstances for model reuse and calibration. An example would be the decel fuel cutoff strategy and the idle speed control strategy. At a minimum, clarity could be improved by making control function and plant models visible and different.

- For a model aimed at fuel economy predictions, there may be more fidelity then strictly necessary. For instance, use of inertia in the engine model requires additional complexity for the transmission/engine model for minimal gains in fuel economy prediction. The approach used is fine but it may be more complex then necessary for the model goals. The use of so many inertias when things like shift durations simply enforced via the initialization files seems odd – but not wrong from a technical perspective.
- I was not able to find any type of thermal model for the engine – which are well known to have temperature effects for efficiency. Components like the 12 V battery have one – so it is inconsistent to not include one for the engine.
- There are several ad-hoc factors like the 'tip-in penalty' that appears in the engine fuel-flow submodel. It is not clear on how one would calibrate this or what it is really meant to capture from a physical standpoint. Fuel enrichment on tip is not something that is done in modern engine controls – air prediction is good enough that in general there is only a minor amount of enrichment happening. Another example would be the 'acceleration_penalty_squelch_gps' factor.

Automatic Transmission Submodel:

- The fidelity of the transmission model and the resulting number of calibration parameters is fairly high given the goal of the model. There are many look up tables some of which have four dimensions. It is not clear how one would calibrate these parameters given the context of use.
- The shift logic appears to produce reasonable shift commands – there are no frequent shifts, inappropriate skip shifts, etc. There is a great deal of logic in the 'automatic trans control' block. Similar to previous comments, the question is how does one calibrate all of this for technology that may not exist?
- There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

Continuously Variable Transmission Submodel:

- Control logic is much simpler in contrast to the automatic – this is a positive thing in terms of the intended use
- There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

Dual Clutch Transmission Submodel:

- There are many thermal models present – only constant temperature is enabled. Transmission temperature is important to fuel economy predictions and likely future vehicles will involve more tightly integrated thermal systems.

12V System Model:

- The 12V battery model is one of the more complex models in the model. The alternator model is some control logic and a single constant efficiency for current to torque based on speed – so quite simple. This is a large mismatch in fidelity. Having a fairly elaborate 2^{nd} order RC model for the battery and then modeling the alternator so simply is not technically incorrect, but is something to consider.
- The electric/mechanical loads are all fairly simple map-based which matches the overall fidelity of the model. They will, of course, need to be calibrated to somehow represent future vehicle systems. How that will be done is an important item to consider for the future application of the model.

Vehicle Sub Model:

- The vehicle driver model typical of model of this class.

Transmission Input File:

- The input files are appropriate given the model – it is done in a pretty typical way and should work well.
- As mentioned in the model sections, the input files contain a lot of parameters – particularly the automatic transmission one. The main concern here is how one would arrive at this large list of parameters given the intended use of the model.

Engine Input File:

- The input file contains a handful of unspecified parameters – not causing any issues but it is strange to have them there if they are unused. It is not sure how something like fuel octane number would be used in this type of model.
- Input file is appropriate given the model – done in a very typical way.

Other Input Files:

- Pretty typical of what one would expect from the accompanying model.

Output Structures:

- The output used a structure of structures and included a wide range of data (time-domain, summary data, *etc.*) This could be adapted as necessary to bring in whatever data was deemed necessary.
- I may have missed it because it is hard to navigate through all of a nested set of structures, but I did not see that the model input data was stored in the output structure. If not, then it should definitely be included as well as the model version (which was included.) This is so that a model result can be rerun if necessary using the same input parameters without having to track down the initialization files that created the model input.

Program Execution and Robustness:

- See comments above regarding the possible higher than necessary model fidelity.
- The choice of a 0.01 sec step size should be validated by running a step size independence study. If that step size is unnecessary then it would be possible to decrease the model run time.
- To run a HWFET, the model as delivered required 175.8 seconds to run. Enabling the 'accelerator' option in Simulink took it down to 89.7 seconds including the time to build it – and only 32.9 seconds if the model did not need to be rebuilt for a run. The model developers are likely already aware of this feature in Simulink – if not then they should familiarize themselves with it.
- In terms of robustness, I do have some concerns regarding the amount of control logic that is imbedded at various places. The model fidelity requires some of this – but there are also a number of things that are not contributing to fuel economy greatly (some were noted in the submodel notes above.) These controls can lead to problems in certain applications if they are not adapted accordingly.

Accuracy, Clarity, and Completeness:

- Without having validation data, there is no way to evaluate accuracy. It was also noted in the peer review directive that we were looking mainly at model structure as it is not yet fully calibrated.
- The energy balance that is conducted is the first step in ensuring things are working well. More would need to be done do validate the model.
- The model appears to have the major vehicle system models one would expect for fuel economy prediction.

Appendix E. ICCT - John German (lead reviewer), Anup Bandivadekar, Oscar Delgado, Francisco Posada Comments

Peer Review Comments of EPA's ALPHA model

Francisco Posada, Oscar Delgado, John German
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INTRODUCTION

This document summarizes the findings of ICCT's review of the US EPA's the EPA Advanced Light-Duty Powertrain and Hybrid Analysis (ALPHA) model and supporting documentation ("Chapter 5: Technology Cost, Effectiveness, and Feasibility Assessment "). The tool will serve as one of the principal supports for EPA's midterm review phase of the Light-Duty GHG 2022-2025 emissions regulations. The agencies consider simulation modeling to be critical to assess the expected real-world performance of various vehicle, engine, and transmission technologies. The main purpose of this review is to evaluate how well the developed model can serve as a regulatory and compliance tool.

I. GENERAL IMPRESSIONS

After reviewing the MatLab/Simulink model and the accompanying report, our general impression is that the ALPHA model tool constitutes a valuable development effort by EPA and a major step forward. It is beyond the limitations of our review to determine if the ALPHA model is more accurate than the preceding model developed by Ricardo, but the ALPHA model offers two major advantages. The first is the transparency of the model. EPA intends to publicly release both the model and the data used for the modeling, which is a huge improvement over the confidential Ricardo model. The second is the flexibility to develop maps and algorithms for future technology and efficiency improvements and to model a wide variety of scenarios.

The model architecture is clear and easy to follow and has incorporated some key features that enhance its overall accuracy with respect to real world performance of technologies, and allows the model to capture fuel consumption reductions from a broad range of technologies. In our opinion, the model will be capable of performing its intended purpose of reflecting technology benefits for compliance purposes of most of the technologies that the agencies are considering.

Some features are specially welcome, namely the ability of the model to incorporate user-defined engine fueling maps and driveline parameters, the development of different transmission options (especially CVTs and DCTs), and the enhanced transmission gear-shifting strategy. We are also impressed by the testing effort that was done to validate the model and the fact that the model is capturing the incorporated technologies in close agreement with engine and chassis dynamometer testing, which is not an easy task.

The documentation available for this peer review appears to be at an early draft stage and needs to be enhanced. There is an overall lack of detail on key technical features that are new in the model. Proper documentation needs to be provided. An interested reader would like to see a better description of such features, how they were developed, and perhaps, more quantitative results.

Although we understand that most of the key technical design elements have been already peer-reviewed and published in SAE Technical papers, some claims in the report need to be appropriately quantified, and supported via appendices or any means that don't require direct access to the SAE documents. Also, the quality of the report may be enhanced with an appendix containing a table with all parameters and the respective file names (*filename.m* or equivalent) that contain each parameter. The Figures in the documentation also need to be improved. Most of the inputs and outputs simply reference "system bus" or "bus_out", instead of describing how each component is input or output to other components.

II. RESPONSE TO CHARGE QUESTIONS

1. **EPA's overall approach to the stated purpose of the model (demonstrate technology effectiveness for various fuel economy improvement technologies) and whether the particular attributes found in resulting model embodies that purpose.**

The model in its current form will be capable of performing its intended purpose of modeling technology benefits for most of the technologies that the agencies are considering. Moreover, the inclusion of CVT technologies as part of the modeling efforts shows the commitment by EPA to include all potential technology pathways to meet the targets. We do recommend that a table be added in the documentation that informs the reader of what technologies ALPHA is capable of modeling and what technologies are yet to be implemented in the model or the model is incapable to simulate.

Some specific model elements that could be improved to better reflect technologies in the future that may be impacted as well by Tier 3/LEV III emission standards:

1) Cold start operation modeling: ALPHA does not simulate or model cold-start operation, instead applying the adjustment factors derived by Ricardo for Ricardo's 2011 modeling for EPA. This approach likely works fine for current, known technology, but it is likely inadequate for future engines with fast warm-up strategies, especially considering the upcoming changes to emission standards. There is also no ability to model other drive cycles with a cold start, as the adjustment factors are specific to the FTP.

Also, specifically relating to the correction factors for Bag 1, where the fuel consumed during this period is increased by around 16-17%, how does ALPHA correct the energy audit to account for this correction? Would that 16-17% extra be reflected on energy losses, thermal or mechanical? The effect of the correction on the energy audit should be described.

2) According to the documentation review, ALPHA's stop/start modeling appears to be very simplistic. Their description says, "Alpha contains a sub-model for 12 volt electrical start-stop technology, which simulates shutting the engine off after vehicle has stopped moving for 0.1 second. During a simulation, the start-stop mode is disabled when the vehicle is assumed to be operating cold

such as during the first 100 sec of bag 1 of the FTP cycle." Potential limitations of this approach to SS technology modeling are:

- No ability to do stop/start during coasting or deceleration (sailing).
- The length of stop/start disablement after a cold start appears to be completely arbitrary. Note that actually modeling cold start operation, instead of using a simple adjustment factor, would fix this problem as well, although we recognize that this would require development of more sophisticated modeling.

3) Engine scaling to maintain vehicle performance. ICCT's comments regarding this approach have two components, dealing with the technical aspects and the way it is incorporated into the ALPHA model.

First, ALPHA's approach to maintain the vehicle performance when reducing weight is to scale the BSFC maps to increase fuel consumption while downsizing an engine, reflecting the increase in heat losses due to higher cylinder surface area to volume ratio. Ricardo also used this method on their previous modeling work. Although the idea is technically sound, the limitation that we perceive with this approach is that it ignores the option of <u>reducing the number of cylinders</u>, which would decrease the cylinder surface area to volume ratio. The option of using an engine with fewer cylinders implies that the model would have to incorporate algorithms that can select the appropriate engine for downsizing; this implies developing additional engine maps and criteria for selecting the right one.

Second, the documentation describes the development of a parametric analysis tool to compare the different technology approaches to find the best technology option (SAE 2016-01-0910). In this case, the ideal outcome would be to incorporate the ability to change number of cylinders, i.e., engine maps, as part of the effort.

4) Synergy between engines and transmissions. In the SAE paper describing ALPHAs performance, the authors correctly note that engines and transmissions have some overlap in their benefits and derive parametric estimates for the "synergy factor" (SAE 2016-01-0910). As shown in Table 7 of that paper, the synergy factor is negative for 6AT, 8AT, and future 8AT. But it is positive for the future 8DCT - which basically defies theory. EPA should evaluate why there are positive synergies between engines and future 8DCTs and, if this is not an error in the modeling, describe in the next iteration of the supporting documentation how the synergy factor was determined for future 8DCTs and why it has positive synergies.

2. The appropriateness and completeness of the contents of the overall model structure and its individual systems, such as:

   a. The performance of the example component models, including the reviewer's assessment of the underlying equations and/or physical principles coded into that component.

   b. The input and output structures and how they interface with the model to obtain the expected result, i.e., fuel consumption over the given driving cycles.

ICCT checked the underlying equations for the physical models and in general they seem reasonable, although perhaps simplified (e.g. rotational dynamics simply assume an "equivalent mass" to account for rotational inertia). We also evaluated the impacts of selected changes in model inputs on the outputs and we are providing our views on overall model structure from a perspective of the final user. We also considered the types of outputs that can be relevant for the development and operation of the updated OMEGA model that is expected to be released along with the release of this ALPHA model.

Test Runs

ICCT conducted a series of runs by changing a parameter at a time and observing the result in terms of 2-cycle CO2 emissions. Note that our simplified parametric test did not include constant performance, due to the iterative modeling required to match performance, thus no changes were made to the model engine size.

The results of the parametric test, summarized in Table 1, confirm the results of the parameter estimates in the SAE paper - load reduction results in a constant gCO2/mi reduction, regardless of the baseline fuel consumption when no changes are made to engine size. Note that this was true for mass, rolling resistance (RR), and aerodynamic drag (Cd) reductions – in every case the gCO2/mi reduction for the NA+AT5 vehicle, with 270.5 gCO2/mi, was almost identical to the gCO2/mi for the EGRB24_TDS+8DCT+ALT vehicle, with 189.7 gCO2/mi.[5] This defies basic theory, as fuel consumption (and CO2) is generally proportional to vehicle load. In addition, ICCT has reduced load using both FEV's and Ricardo's simulation models, and both modeled proportional reductions in gCO2/mi, not a constant g/mi reduction. **This strongly suggests that the model has errors in the underlying equations or coding with respect to all of the load reductions.**

2-cycle ALPHA results	Emission results, gCO2/mi			Reductions, gCO2/mi		
	NA +AT5	NA + CVT+SS	EGRB24_TDS + 8DCT+ALT	NA +AT5	NA + CVT+SS	EGRB24_TDS+ 8DCT+ALT
Baseline per model	270.5	250.1	189.7	-	-	-
Mass red 5%	265.4	244.9	184.6	5.1	5.2	5.1
Mass red 10%	260.8	239.2	179.9	9.8	10.9	9.8
Mass red 15%	256.1	234.6	174.3	14.4	15.5	15.4
RR red 10%	267.1	246.1	186.2	3.4	4.0	3.4
RR red 20%	263.1	242.6	182.2	7.4	7.4	7.4
Cd red 10%	266.3	245.3	185.4	4.3	4.8	4.3
Cd red 20%	261.9	241.5	181.1	8.6	8.6	8.6

[5] The SAE paper reported mass reduction results after adjusting for performance and found CO2 reductions varied more proportionally with the baseline vehicle gCO2/mi. Perhaps correcting for constant performance shifted the CO2 reduction to more of a constant percent reduction instead of a constant g/mi reduction, but we did not see this when reducing mass without correcting for performance.

Accessories

According to the supporting documents, "power steering, air conditioning, fan and a generic load to cover the remaining losses are observed. Each load can apply mechanical loads to the engine crankshaft and/or electrical loads to the battery. Each load can be independently correlated to model signals via dynamic lookup tables, and is calibrated to match test data."

Access to defining such losses was difficult to find and the structure of the inputs was not clearly defined in the model. Allowing accessory power consumption to be user-defined inputs could promote developments in technologies that reduce the power requirements of accessories such as the alternator, air-conditioning compressor, power steering pump, or cooling fan. There are other opportunities for engine accessories such as oil, coolant, and fuel pumps, but is not clear at this point if all those savings are going to be captured by the engine mapping process. Accurate accounting of the benefits of advanced accessories is extremely relevant to the implementation of future off-cycle credits for GHG.

3. Use of good engineering judgment to ensure robust and expeditious program execution.

In our opinion, the best measure of engineering judgment and proper program execution is obtaining good agreement between ALPHA simulations and actual testing data. The documentation reviewed suggests that the errors over the FTP and highway drive cycles are often within 3%, which are within the +/-3%, test-to-test variability of chassis dynamometer testing.

4. Clarity, completeness and accuracy of the output/results.

The report is very thorough, including a detailed energy audit and 50+ figures, which is commendable. However, we recommend that a smaller "summary" report, only with the very key parameters (fuel consumption, engine cycle efficiency, speed-trace following metrics) be produced for easy tracking of multiple runs.

The input and output structure of ALPHA was not finalized when released for peer review, however the current version of the output structure were provided to give the reviewer a flavor of the potential structure. The inclusion of performance metrics is highly commended, although we suggest spelling out some metrics in the output file to facilitate troubleshooting and give the user a better perspective.

5. Any recommendations for specific improvements to the functioning or the quality of the outputs of the model.

It would be useful for the user have access to a list of all the relevant vehicle parameters that can be modified and the corresponding file where those parameters are input. Some parameters are intuitive, but some others may fall out of sight unless there is a set list. Moreover, EPA has invested a great deal of time and resources making sure the physical models are representing the physical elements, and a parameters list would help produce a better representation of the system being modeled.

The way the model handles vehicle weight, tire rolling resistance, and Cd inputs may be improved. As presented in the model, when changing vehicle mass, the user must change the vehicle mass and separately change the rolling resistance by changing the A coefficient on the road load equation. In the same way, changes in RR values have to be performed in the model by changing the A coefficient. It would be better suited and less prone to errors to input these parameters separately and program the ALPHA code to do the changes automatically. It would also be desirable to provide flexibility to input either m, A, B, and C; or m, Cd, and RRc.

We were not able to find any information on how the model handles component weight changes. Specifically, how does ALPHA handle changes in mass due to components with different mass? For example, if an AT6 is being replaced with a DCT8 and that there are mass changes associated with that. Does the delta in transmission mass change affect the vehicle overall weight or road load parameter A? The model needs to at least inform the user that it the user’s responsibility to assess and incorporate any impacts of changes in components on vehicle mass.

Extra fuel usage for other vehicle operating requirements. The introduction of overhead functions to compensate the steady-state based model for fuel used during transient conditions is very useful. Our recommendation is to make those key adjustments available to the user on a clearer way; such as a list of functions and parameters, or maybe developing a parameter list that deals with such items.