Chapter 3: Test Procedures

Test procedures are a crucial aspect of the proposed heavy duty vehicle GHG and fuel consumption program. The proposed rulemaking is establishing several new test procedures for both engine and vehicle compliance. This chapter will describe the development process for the test procedures being proposed, including the assessment of engines, aerodynamics, rolling resistance, chassis dynamometer testing, and drive cycles.

3.1 Heavy Duty Engine Test Procedure

The agencies are proposing to control heavy duty engine fuel consumption and greenhouse gas emissions through the use of engine certification. The proposed program will mirror existing engine regulations for the control of non-GHG pollutants in many aspects. The following sections provide an overview of the proposed test procedures.

3.1.1 Existing regulation reference

Heavy duty engines currently are certified for non-GHG pollutants using test procedures developed by EPA. The Heavy Duty Federal Test Procedure is a transient test consisting of second-by-second sequences of engine speed and torque pairs with values given in normalized percent of maximum form. The cycle was computer generated from a dataset of 88 heavy duty trucks in urban operation in New York and Los Angeles. These procedures are well-defined and we believe appropriate also for the assessment of GHG emissions. EPA is concerned that we maintain a regulatory relationship between the non-GHG emissions and GHG emissions, especially for control of CO_2 and NO_x. Therefore, we are proposing to use the same test procedures.

For 2007 and later Heavy Duty engines, Parts 86 – "Control of Emissions from New and In-Use Highway Vehicles and Engines" and 1065 – "Engine Testing Procedures" detail the certification process. Part 86.007-11 defines the standard settings of Oxides of Nitrogen, Non-Methane Hydrocarbons, Carbon Monoxide, and Particulate. The duty cycles are defined in Part 86. The Federal Test Procedure engine test cycle is defined in Part 86 Appendix I. The Supplemental Emissions Test engine cycle is defined in §86.1360-2007(b). All emission measurements and calculations are defined in Part 1065, with exceptions as noted in §86.007-11. The data requirements are defined in § 86.001-23 and 1065.695.

The procedure for CO_2 measurement is presented in §1065.250. For measurement of CH_4 refer to §1065.260. For measurement of N_2O refer to §1065.275. We recommend that you use an analyzer that meets performance specifications shown in Table 1 of §1065.205. Note that your system must meet the linearity verification of §1065.307. To calculate the brake specific mass emissions for CO_2, CH_4 and N_2O refer to §1065.650. For CH_4 refer to §1065.660(a) to calculate the contamination correction.

3.1.2 Engine Dynamometer Test Procedure Modifications

3.1.2.1 Fuel Consumption Calculation

EPA and NHTSA propose to calculate fuel consumption, as defined as gallons per brake horsepower-hour, from the CO_2 measurement. The agencies are proposing that manufacturers use 8,887 gram of CO_2 per gallon of gasoline and 10,180 g CO_2 per gallon of diesel fuel.[1]

3.1.2.2 N_2O Measurement

EPA proposes that manufacturers would need to submit measurements of N_2O to be able to apply for a certificate of conformity with the N_2O standard. Engine emissions regulations do not currently require testing for N_2O, and most test facilities do not have equipment for its measurement. Manufacturers without this capability would need to acquire and install appropriate measurement equipment. EPA is proposing four N_2O measurement methods, all of which are commercially available today. EPA expects that most manufacturers would use photo-acoustic measurement equipment, which the Agency estimates would result in a one-time cost of about $50,000 for each test cell that would need to be upgraded.

3.1.2.3 CO_2 Measurement Variability

EPA and NHTSA evaluated two means to handle the CO_2 and fuel consumption variability. The first is to use an approach similar to the LD GHG and Fuel Economy program where the agencies propose a compliance factor that is applied to the measured value. The second is an approach where the standard is set as a not to exceed standard. Manufacturers set a design target set sufficiently below the standard to account for production variability and deterioration.

The agencies are proposing to take an approach where manufacturers are allowed to determine their own compliance margin, but it must be at least two percent to account for the test-to-test variation. The agencies developed the two percent threshold based on CO_2 measurement variability from several test programs. The programs include internal EPA round-robin testing, ACES[2], and the Gaseous MA program.[3] Table 3-1 summarizes the results from each of these programs.

Table 3-1: Summary of CO_2 Measurement Variability

ENGINE	AFTERTREATMENT	TEST SITE	TEST	# OF TESTS	CoV (%)
Same Engine – Same Test Cell – Different Days					
11L	DPF	EPA HD05	Hot Transient	10	0.22%
11L	DPF	EPA HD05	RMC	7	0.12%
11L	DPF	EPA HD05	Cold/Soak/Hot	3	0.02%
9L	No DPF	EPA HD05	8 Mode	7	0.44%
12L	No DPF	EPA HD01	Hot Transient	8	0.09%
12L	No DPF	EPA HD05	Hot Transient	31	1.37%
6.7L	No DPF	EPA HD02	FTP	12	0.67%

13L	DPF	EPA HD05	FTP	11	0.37%
14L	DPF	SwRI	NTE	9	0.2%
14L	DPF	SwRI	13 Mode SET	6	0.2%
14L	DPF	CE-CERT	NTE	9	0.5%
14L	DPF	CE-CERT	13 Mode SET	6	0.5%
Engine A	DPF	SwRI (ACES)	FTP	3	0.1%
Engine B	DPF	SwRI (ACES)	FTP	3	0.4%
Engine C	DPF	SwRI (ACES)	FTP	3	0.6%
Engine D	DPF	SwRI (ACES)	FTP	3	0.5%
Same Engine – Different Test Cells – Different Days					
12L	No DPF	EPA HD01 & HD05	Hot Transient	39	1.58%
14L	DPF	SwRI & CE-CERT	NTE	18	1.4%
14L	DPF	SwRI & CE-CERT	13 Mode SET	12	1.2%

3.1.2.4 Regeneration impact on CO_2

The current engine test procedures also require the development of regeneration emission rate and frequency factors to account for the emission changes during a regeneration event.[4] We are proposing to exclude the CO_2 emissions due to regeneration. Our assessment of the current non-GHG regulatory program indicates that engine manufacturers are already highly motivated to reduce the frequency of regeneration events due to the significant impact on NO_x emissions. In addition, market forces already exist to incentivize the reduction of fuel consumption during regeneration. EPA is proposing the exclusion of CO_2 emissions during regeneration; however, we consider the existing regulations, as described below, as a potential alternative.

As described in §86.001-24(i), emission results from heavy-duty engines equipped with aftertreatment systems may need to be adjusted to account for regeneration events. This is particularly true if these regenerations are expected to occur on a frequency of less than once per transient test cycle. Regeneration of exhaust aftertreatment devices commonly involves increases in fueling rate to raise exhaust temperature or lower exhaust oxygen content. While the impact of a regeneration event on criteria pollutant emissions (i.e. CO, NO_x, PM, HC) varies, regeneration is more likely to increase CO_2 emissions and therefore must be considered.

The current regulations outline a method of accounting for changes in emissions due to regeneration events (§86.001-24(i)(1)-(i)(5)). This method involves developing upward and downward adjustment factors (U/DAFs) meant to characterize emissions with and without (respectively) a regeneration event. Combined with a frequency factor (F), characterizing the frequency at which regeneration occurs, these adjustments are applied to the final emission test results. Use of this procedure to account for changes in CO_2 emissions during regeneration appears to be a practical, well accepted, and accurate method for certification. Any increases (or decreases) in CO_2 due to regeneration would be captured in the adjustment factors and final emission results could be corrected accordingly.

3.1.2.5 Fuel heating value correction

The agencies collected baseline CO_2 performance of diesel engines from testing which used fuels with similar properties. The agencies are proposing a fuel-specific correction factor for the fuel's energy content in case this changes in the future. The agencies found the average energy content of the diesel fuel used at EPA's National Vehicle Fuel and Emissions Laboratory was 21,200 BTU per pound of carbon. This value is determined by dividing the Net Heating Value (BTU per pound) by the carbon weight fraction of the fuel used in testing.

The existing regulations correct for gasoline fuel properties, as described in Part 86. The same correction can be used for the testing of complete pickup trucks and vans with gasoline fueled engines.

The agencies are not proposing fuel corrections for alcohols because the fuel chemistry is homogeneous. The agencies are proposing a fuel correction for natural gas.

3.1.2.6 Multiple fuel maps

Modern heavy-duty engines may have multiple fuel maps, commonly meant to improve performance or fuel economy under certain operating conditions. CO_2 emissions can also be different depending on which map is tested, so therefore it is important to specify a procedure to properly deal with engines with multiple fuel maps. Consistent with criteria-pollutant emissions certification, manufacturers should submit CO_2 data from all fuel maps on a given test engine. This includes fuel map information as well as the conditions under which a given fuel map is used (i.e. transmission gear, vehicle speed, etc).

3.1.3 Engine Family definition and test engine selection

3.1.3.1 Criteria for engine families

The current regulations outline the criteria for grouping engine models into engine families sharing similar emission characteristics. A few of these defining criteria include bore-center dimensions, cylinder block configuration, valve configuration, and combustion cycle; a comprehensive list can be found in §86.096-24(a)(2). While this set of criteria was developed with criteria pollutant emissions in mind, similar effects on CO_2 emissions can be expected. For this reason, this methodology should continue to be followed when considering CO_2 emissions.

3.1.3.2 Emissions test engine

Manufacturers must select at least one engine per engine family for emission testing. The methodology for selecting the test engine(s) should be consistent with §86.096-24(b)(2) (for heavy-duty Otto cycle engines) and §86.096-24(b)(3) (for heavy-duty diesel engines). An inherent characteristic of these methodologies is selecting the engine with the highest fuel feed per stroke (primarily at the speed of maximum rated torque and secondarily at rated speed) as the test engine, as this is expected to produce the worst-case criteria pollutant emissions. CO_2 emissions are expected scale well with fuel feed in a given engine family and therefore work-based CO_2 measurements are expected to be less sensitive to the specific engine model selected than criteria pollutant emissions. To be consistent however, it is recommended that the same methodology continue to be used for selecting test engines.

3.2 Aerodynamic Assessment

The aerodynamics of a combination truck is dependent on many factors, including the tractor design, trailer design, gap between the tractor and trailer, vehicle speed, wind speed, and many others. We believe to fairly assess the aerodynamics of combinations tractors that certain aspects of the truck need to be defined, including the trailer, location of payload, and tractor-trailer gap.

3.2.1 Standardized Trailer Definition

We are proposing standardized trailers for each subcategory of the Class 7/8 tractor subcategories based on roof height. High roof tractors are designed to optimally pull box trailers. The height of the roof fairing is designed to minimize the height differential between the tractor and typical trailer to reduce the air flow disruption. Low roof tractors are designed to carry flatbed or low-boy trailers. Mid roof tractors are designed to carry tanker and bulk carrier trailers. High roof tractors are designed to optimally pull box trailers. However, we recognize that during actual operation tractors sometimes pull trailers that do not provide the optimal roof height that matches the tractor. In order to assess how often truck and trailer mismatches are found in operation, EPA conducted a study based on observations of traffic across the U.S.[5] Data was gathered on over 4,000 tractor-trailer combinations using 33 live traffic cameras in 22 states across the United States. Approximately 95% of trucks were “matched” per our definition (e.g. box trailers were pulled by high roof tractors and flatbed trailers were pulled with low roof tractors). The amount of mismatch varied depending on the type of location. Over 99% of the tractors were observed to be in matched configuration in Indiana at the I-80/I-94/I-65 interchange, which is representative of long-haul operation. On the other hand, only about 90% of the tractors were matched with the appropriate trailer in metro New York City, where all mismatches consisted of a day cab and a tall container trailer. The study also found that approximately 3% of the tractors were traveling without a trailer or with an empty flatbed.

Section 1037.510 prescribes the standardized trailer for each tractor subcategory (low, mid, and high roof) including trailer dimensions and tractor-trailer gap.

3.2.2 Aerodynamic Assessment

The aerodynamic drag of a vehicle is determined by the vehicle’s coefficient of drag (Cd), frontal area, air density and speed. The agencies are proposing to define the input parameters to [TEST] which represent the frontal area and air density, while the speed of the vehicle would be determined in [TEST] through the proposed drive cycles. The agencies are proposing that the manufacturer would determine a truck’s Cd, a dimensionless measure of a vehicle's aerodynamics, through testing which then would be input into the [TEST] model. Quantifying truck aerodynamics as an input to the [TEST] presents technical challenges because of the proliferation of truck configurations and the lack of a common industry-standard test method. Class 7/8 tractor aerodynamics are currently developed by manufacturers using coastdown testing, wind tunnel testing and computational fluid dynamics. The agencies are proposing to allow all three aerodynamic evaluation methods.

3.2.2.1 Coastdown Testing

For several decades, light-duty vehicle manufacturers have performed coastdown tests prior to vehicle certification. However, this practice is less common with heavy-duty vehicles, since the current heavy-duty certification process focuses on engine and not vehicle exhaust emissions, i.e., NOx, PM, NMHC, CO. In recent years, growing concerns over energy security, fuel efficiency and carbon footprint have prompted efforts to develop and improve design features or technologies related to the aerodynamic and mechanical components of heavy-duty (HD) vehicles. Lowering tire rolling resistance, aerodynamic drag, and driveline parasitic losses on HD vehicles could translate into significant long-term fuel savings as well as HD greenhouse gas emissions reductions, since vehicles with enhanced aerodynamic or mechanical features encounter lower road load force during transport, and thereby consume less fuel. The road load force can be captured by coasting a vehicle along a flat straightaway under a set of prescribed conditions. Such coastdown tests produce vehicle specific coastdown coefficients describing the road load as a function of vehicle speed.

The coefficients obtained are essential parameters for conducting chassis dynamometer tests as well as for assessing today's truck GHG potential *via* modeling. Because the existing coastdown test protocols, i.e., SAE J1263and SAE J2263, were established primarily from the light-duty perspective, the agencies realize that some aspects of this methodology might not be applicable or directly transferable to heavy-duty applications. [6,7] Therefore, some modifications to existing light-duty-focused coastdown protocols are necessary. Sections 3.2.4 and 3.2.5 describe the existing protocols and our proposed modifications to the protocols, respectively.

3.2.2.1.1 Overview of SAE J2263

The Society of Automotive Engineers (SAE) publishes voluntary reports to advance the technical and engineering sciences. The SAE Technical Standards Board, in the J2263 DEC2008 Surface Vehicle Recommended Practice publication, established a procedure for determination of vehicle road load force using onboard anemometry and coastdown techniques.[7]

The coastdown runs need to be conducted on a dry and level road, under no rain or fog conditions, at an ambient temperature between 5 to 35°C (41 to 95°F), and average wind speed less than 35 km/h (21.7 mi/h) with wind gusts less than 15 km/h (31.3 mi/h) and average cross winds less than 15 km/h (9.3 mi/h).

The vehicle and tires should have a preferable break-in of 6500 km (4039 mi) prior to testing, and a minimum of 3500 km (2175 mi). The tire pressure must be set and recorded before moving the vehicle. The vehicle and tires require preconditioning for a minimum of 30 minutes running at 80 km/h (49.7 mi/h). Calibration of the instrumentation can be done during preconditioning.

The vehicle's windows and vents must be closed and the use of any accessory that can affect the engine speed shall be noted and duplicated during any subsequent dynamometer adjustments.

The recommended relative wind speed and direction measurement location is at the approximate mid-point of the vehicle's frontal cross section and about 2 meters in front of it.

A minimum of 10 valid runs, 5 in each alternating direction, must be made. For each run the vehicle is accelerated to a speed of 125 km/h (77.7 mi/h) for heavy duty vehicles, the transmission is shift into neutral gear, and measurements are taken until the vehicle speed reaches 15 km/h (9.3 mi/h). Engage the transmission and accelerate for the next run; try to minimize the time between runs to avoid vehicle and ambient variations.

Lane changes should be avoided, and the run should be voided if a passing vehicle in the same direction comes within 200 meters from the leading or trailing end of the vehicle. Traffic moving in the adjacent lane in opposite direction is fine. For tracks that are too short, "split" coastdown runs are allowed to form a complete run.

Data from the "split" runs should be knitted by taking the information recorded for the coastdown from the 100 km/h (62.2 mi/h) speed to speed X, and the information recorded from speed X to the 15 km/h (9.3 mi/h) speed.

The mass of the vehicle is recorded at the end of the test; including instrumentation, driver and any passengers.

The road load force model is a function of vehicle speed, relative wind speed and yaw angle. The model will calculate road force for vehicle speeds between of 100 km/h (62.2 mi/h) and 15 km/h (9.3 mi/h).

The mechanical drag is modeled as a three-term polynomial with respect to speed (V):

$$D_{mech} = A + B*V + C*V^2$$

Where A, B, and C coefficients are determined by fitting the data into the polynomial curve.

The aerodynamic drag is modeled as a five-term polynomial with respect to the yaw angle (Y) in degrees:

$$D_{aero} = ½ * \rho * A * V_r^2 * (a + b*Y + c*Y^2 + d*Y^3 + e*Y^4)$$

Where ρ is the air density (kg/m^3), A is the vehicle's frontal area (m^2), V_r is the relative wind velocity (km/h), and a, b, c, d, and e coefficients are determined by fitting the data into the polynomial curve.

The test asks for a level surface, but if the track is not level, the force contribution due to gravity is:

$$D_{grav} = \pm M*g*(dh/ds)$$

Where the plus sign is up and minus is down, M is the mass of the vehicle, g is gravity, and (dh/ds) is the change in elevation per distance along the track.

The equation of motion is:

$$-M_e*(dV/dt) = D_{mech} + D_{aero} + D_{grav}$$

Where M_e is the effective vehicle mass, and (dV/dt) is the vehicle velocity as a function of time.

The road load force equation used by EPA is:

$$\text{Road Load Force} = A_{mech} + B_{mech}*V + C_{totl}*V^2$$

Where A_{mech}, B_{mech} and C_{totl} are values obtained from the analysis of the data done by SAE program and V is the vehicle speed

3.2.2.1.2 Proposed Modifications to SAE J2263

The agencies have assessed the feasibility of performing coastdown testing on heavy-duty trucks. EPA, through its contractor Southwest Research Institute, conducted coastdown tests using SAE test methods J1263[6] and J2263[7] on three SmartWay-certified Class 8 tractor-trailers equipped with sleeper cabs during the period October 2008 through November 2009. Also, other contractors, Transportation Research Center in Ohio and Automotive Testing and Development Inc. in California performed coastdown testing for the agencies on up to two dozen Class 2b-8 trucks in 2009-2010. EPA also gained firsthand experience of such testing by performing its own coastdown testing on one Class 6 and multiple Class 8 truck configurations at nearby locations using both SAE test methods. Details regarding these tests can be found in Docket #XX “Coastdown Testing Procedure Development” by Sze, C. and Kopin, A.[8]

Based on our ongoing experiences with heavy-duty coastdown testing and our consultation with light-duty coastdown expert Peter Janosi, we propose the following for a heavy-duty coastdown test procedure; details on how we reached our determination through coastdown data analysis are presented below.

- Vehicle testing
  - Conduct SAE J2263 with more runs. EPA recommends that 10 pairs be run for a total of 20 tests. Since heavy-duty coastdowns involve more uncertainty, more tests are required to achieve and acceptable certainty in the mean of the resulting coefficients. Abide all road and weather restrictions given in the SAE J2263 standard.

- For safety reasons, because EPA was conducting its coastdown on roadways, EPA modified the high speed procedure running at vehicle speeds between 100 km/h (62.2 mi/h) and 15 km/h (9.3 mi/h).
- Calibration runs can be conducted at constant 50mph in each road direction, immediately back-to-back so as to minimize changes in weather/average wind speed
- Whole runs recommended. Split runs can be used, but treated as separate runs in the analysis.
- J2263 states that consecutive runs shall be made in opposite directions, however, to reduce our presence on state and county roads and run more tests during core testing hours, EPA ran two to four consecutive tests (depending on the vehicle class) in the same direction and accounted for this in the analysis; we are proposing this modification to J2263.

- Data analysis
  - Use Equation 2 for yaw angle correction
  - Use Equation 1 for wind speed correction
  - Use MM5 for road load mean and uncertainty determination. If *E* is not statistically significant, then use MM6.
  - Correct regression coefficients for ambient temperature and ambient pressure as per SAE J2263
  - Use Equation 12 to determine rolling resistance coefficient

3.2.2.1.3 Mixed Model analysis with SAS

As already mentioned, the agencies conducted several coastdown testing programs to evaluate the feasibility of heavy truck coastdown testing. This section details the process which we undertook upon generating or receiving coastdown data files. First, we determined which runs were valid, based on instrument readings, weather, and other criteria. During travel, air will "pile up" near the front of the tractor. This causes our anemometer wind speed readings to be offset from actual wind speed. To correct for this, we calculated the ratio between the vehicle speed and measured wind speed at each time interval. We then averaged the ratio by run direction. We then averaged each run direction's ratio for each date and applied this ratio back to the measured wind speed to estimate actual wind speed.

Equation 1

$$V_{r,i} = \frac{1}{2} V_{r,meas,dir,i} \sum_{dir} \left[\frac{1}{n_{i,dir}} \sum_{i} \left(\frac{V_{dir,i}}{V_{r,meas,dir,i}} \right) \right]$$

We observed an offset to the anemometer's wind direction measurements. We corrected this by assuming that at high speeds, wind direction is head-on (zero degrees). For each date, we averaged the first five seconds (25 measurements for 5-hz data) of wind direction for each run direction. We then averaged the two directions' average. We then subtracted the resulting value from all of the measured wind direction values to get our correct wind direction.

Equation 2

$$Y_i = Y_{meas,i} - \frac{1}{2}\sum_{dir}\left[\frac{1}{n_{i,dir}}\sum_{i=1}^{25} Y_{meas,dir,i}\right]$$

In general, the J2263 analysis method and equations were used as a foundation for this analysis:

Equation 3

$$-M_e \frac{dV}{dt} = A_m + B_m V + C_m V^2 + D V_r^2 (a_0 + a_1 Y + a_2 Y^2 + a_3 Y^3 + a_4 Y^4) \pm Mg \frac{dh}{ds}$$

We used a mixed model (through SAS® software) to describe our 5-hz data with the above equation. A mixed model allows us to accurately predict the mean coefficients for each vehicle, while accounting for the scatter within each run and also the run-to-run variability when determining the standard error of the coefficient estimates. This takes into account that measurements are not independent within each run, but each run is independent from all other runs.

The equations below represent the versions of Equation 3 we modeled to determine means and significances of each of the variables. As an initial simplification, a_1, a_3, and a_4 were eliminated in all iterations since we determined that yaw angle did not vary enough during testing to warrant such a complex polynomial characterization. We also set $a_0=1$ so that the drag coefficient could be characterized by the *D* term. Since our elevation change was negligible in the stretch of road on which we conducted coastdowns, the grade term was also eliminated for all runs. The following mixed models were run:

Equation 4

$$-M_e \frac{dV}{dt} = A_m + B_m V + C_m V^2 + DV_r^2(1 + a_2 Y^2) \text{, rewritten as}$$

MM1

Equation 5

$$-M_e \frac{dV}{dt} = A_m + B_m V + C_m V^2 + DV_r^2 + EV_r^2 Y^2 \text{, where } a_2 = E/D$$

Equation 6

$$-M_e \frac{dV}{dt} = A_m + B_m V + C_m V^2 + DV_r^2 \qquad \text{MM2}$$

Equation 7

$$-M_e \frac{dV}{dt} = A_m + B_m V + DV_r^2 + EV_r^2 Y^2 \qquad \text{MM3}$$

Equation 8

$$-M_e \frac{dV}{dt} = A_m + B_m V + DV_r^2 \qquad \text{MM4}$$

Equation 9

$$-M_e \frac{dV}{dt} = A_m + DV_r^2 + EV_r^2 Y^2 \qquad \text{MM5}$$

Equation 10

$$-M_e \frac{dV}{dt} = A_m + DV_r^2 \qquad \text{MM6}$$

Based on statistical significance of the various effects, one of the mixed models was chosen as the model to appropriately determine the road load coefficients. For heavy duty trucks, this was usually MM6.

3.2.2.1.4 Use of the Data for Modeling

In each mixed model (MM1-MM6), we found that the B_m, C_m, and E were not consistently significant from zero. As examples, models MM4 and MM6 are described below.

In MM4, the results consistently show that B_m is not significant from zero. Table 3-2 summarizes these results. The inclusion of B_m often causes the estimates and uncertainties of the other terms to vary.

Table 3-2 – Mixed model MM4 shows no significant road load linear with vehicle speed.

Date	Truck configuration (tractor_trailer_payload)	A_m [lb]	% Std err	Sig from zero?	B_m [lb/mph]	Std err	Sig from zero?	D [lb/mph^2]	% Std err
5-Aug-09	FL60_N/A_full	153.8	7.75%	Yes	0.165	497.00%	No	0.143	9.64%

6-Aug-09	**FL60_N/A_full**	**137.7**	**5.24%**	**Yes**	**1.105**	**41.42%**	**Yes**	**0.127**	**5.86%**
1-Sep-09	**Int'l_flatbed_full**	**490.5**	**10.94%**	**Yes**	**-2.070**	**-177.70%**	**No**	**0.233**	**25.87%**
2-Sep-09	**Int'l_flatbed_full**	**483.3**	**7.69%**	**Yes**	**-2.065**	**-122.70%**	**No**	**0.237**	**17.99%**
3-Sep-09	**Int'l_flatbed_full**	**551.5**	**7.76%**	**Yes**	**-6.123**	**-47.40%**	**No**	**0.291**	**16.55%**
18-Sep-09	**Int'l_flatbed_half**	**372.2**	**9.72%**	**Yes**	**-1.979**	**-127.80%**	**No**	**0.244**	**17.38%**
23-Sep-09	**Int'l_flatbed_empty**	**226.3**	**9.38%**	**Yes**	**1.153**	**119.90%**	**No**	**0.174**	**12.27%**
24-Sep-09	**Int'l_box_full**	**521.5**	**6.51%**	**Yes**	**-3.480**	**-63.15%**	**No**	**0.248**	**14.11%**
25-Sep-09	**Int'l_box_full**	**495.7**	**8.47%**	**Yes**	**-1.149**	**-238.00%**	**No**	**0.208**	**21.04%**

In MM6, the elimination of B_m shows confident and stable estimates of A_m and D, with lower relative standard errors. This indicates that the road load curve is best described by just A_m and D.

Table 3-3 – Mixed model MM6 shows the most confident estimates of A and D.

Date	Truck configuration	A_m [N]	A_m [lb]	% Std error	D [N/(m/s)^2]	D [lb/mph^2]	% Std error
5-Aug-09	**FL60_N/A_full**	693.9	**156.0**	**3.81%**	3.24	**0.145**	**2.05%**
6-Aug-09	**FL60_N/A_full**	676.8	**152.2**	**2.63%**	3.23	**0.145**	**1.13%**
1-Sep-09	**Int'l_flatbed_full**	2060.3	**463.2**	**4.85%**	4.45	**0.200**	**6.08%**
2-Sep-09	**Int'l_flatbed_full**	2030.6	**456.5**	**3.71%**	4.51	**0.203**	**4.59%**
3-Sep-09	**Int'l_flatbed_full**	2093.6	**470.7**	**3.89%**	4.25	**0.191**	**5.55%**
18-Sep-09	**Int'l_flatbed_half**	1539.8	**346.2**	**3.92%**	4.71	**0.212**	**4.09%**
23-Sep-09	**Int'l_flatbed_empty**	1076.2	**242.0**	**4.53%**	4.27	**0.192**	**2.39%**
24-Sep-09	**Int'l_box_full**	2119.1	**476.4**	**3.87%**	4.32	**0.194**	**4.06%**
25-Sep-09	**Int'l_box_full**	2136.5	**480.3**	**4.12%**	4.23	**0.190**	**4.88%**

Compared to the MM4, MM6 produces more confident mean coefficient values. Also, for the same configurations, the MM6 shows better day-to-day variability, confirming that the coastdown procedure is repeatable from one day to the next. Often, the MM6 model is used to simplify the road load versus speed curve through rolling resistance and aerodynamic drag coefficients. The EPA MOVES heavy-duty inventory model and the CRC E-55/59 chassis dynamometer emissions test program are two examples of this. In general, the equation implemented during a coastdown is:

Equation 11 $$-M_e \frac{dV}{dt} = \mu M g + \frac{1}{2}\rho A c_D V^2$$

Therefore,

Equation 12 $$\mu = \frac{A_m}{Mg} \quad \text{and} \quad c_D = \frac{D}{2\rho A}$$ **Equation 13**

Equation 11 and Equation 12 assume that the rolling resistance coefficient μ is wholly contained in the A_m coefficient and the drag coefficient c_d is wholly contained in the D coefficient. The equations also imply that any values of B_m and C_m that would be used in the other mixed models are mechanical drag forces, other than rolling resistance, that are dependent on vehicle speed. To check the reasonability of our results and feasibility of using our coefficients to accurately determine μ and C_d, we can compare our results to realistic values of rolling resistance and drag coefficients.

Rolling resistance coefficient

For the International truck, we recorded the tire model and obtained different laboratory results of tire rolling resistance coefficients. These values were determined through the SAE J1269 standard. This standard does not contain a provision that lets a laboratory result be corrected against a reference laboratory result. As a result, each laboratory has its own bias for any given tire. When we weighed the truck, we recorded the weight measured over each axle: steer, drive, and trailer. Since we had no more than one tire model on any one axle, we can weight-average the laboratory rolling resistance coefficients to estimate the truck's overall rolling resistance coefficient.

Equation 14 $$\mu = \frac{1}{M}\left(\mu_{steer} M_{steer} + \mu_{drive} M_{drive} + \mu_{trailer} M_{trailer}\right)$$

Figure 3-1 below compares our coastdown rolling resistance results with those from three different tire labs. We are not naming the tire models or the laboratories to protect confidential business information. The dimensionless rolling resistance coefficient is multiplied by 1000 for convenience (resulting "unit" is often referred to as kg/metric ton).

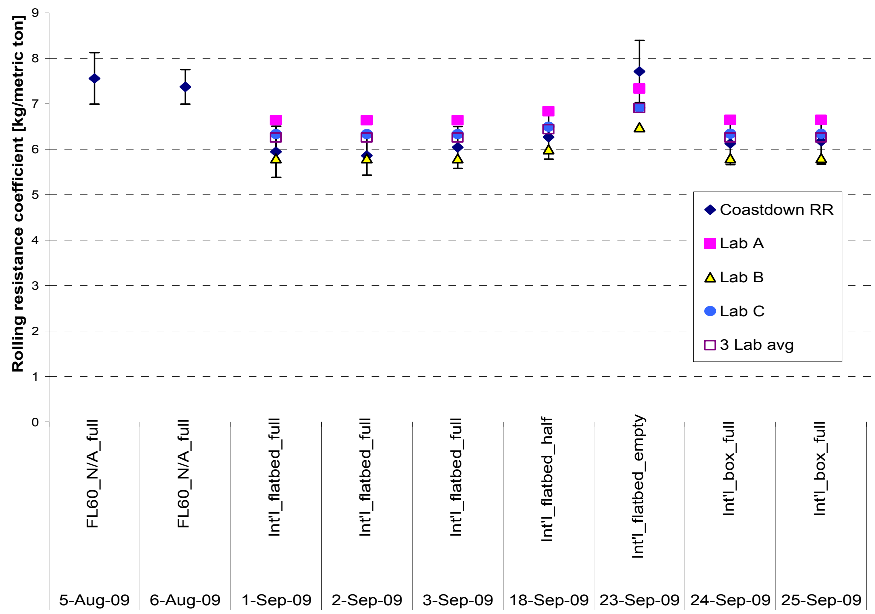


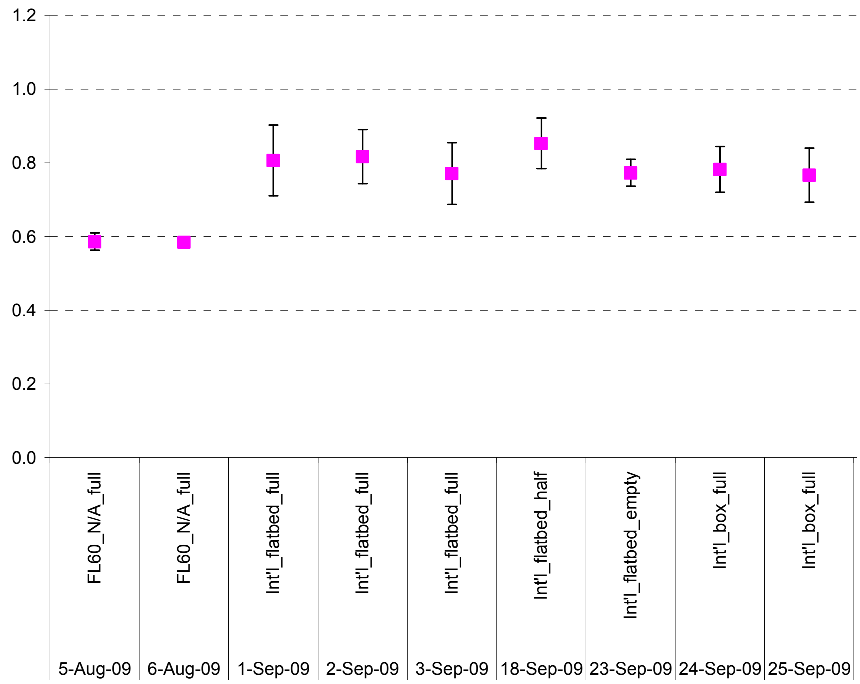
Figure 3-1 – Coastdown-determined and independent lab rolling resistance coefficients match reasonably well.

There are only three different labs, with four unique weightings (flatbed full, flatbed half, flatbed empty, and box full) for each lab. Lab results were only available for the tires used on the International truck. Our coastdown results show reliable day-to-day repeatability for the same truck configuration (Sep 1-3, Sep 24-25). Also, when we reduced the weight on the flatbed trailer, we found that our coastdowns produced a higher theoretical tire rolling resistance. This is most likely due to the fact that reducing weight from full payload increases the relative weight over the drive axle. Since the tires on the drive axle have a higher rolling resistance coefficient (inverse relation with grip for a given tire material and surface), the overall rolling resistance coefficient increased. This is confirmed by the lab tests, which showed higher rolling resistance coefficients for the drive and steer axles tire models. Our coastdown results do, however, show a larger increase in coefficient due to complete payload removal compared to the lab results.

Drag coefficient

We estimated frontal area of the International truck to be 99 ft^2 (9.2 m^2) by measuring the various dimensions of the tractor cab and other equipment such as exterior mirrors and tires. We used this value as a placeholder estimate for the FL60 vehicle also. Using these frontal area estimates and Equation 13, Figure 3-2 shows our coastdown-estimated drag coefficients for each date and truck configuration.

Figure 3-2 – Drag coefficient calculated from D from mixed model



Unlike rolling resistance, we do not expect our drag coefficient to change with payload removal because the physical configuration of the tractor-trailer is not significantly altered, which is reflected in Figure 3-2. Also, while we are using a frontal area of 9.2 m^2 specific to the International tractor, a uniform frontal area, such as an average box trailer frontal area or typical tractor frontal area, may be used for all trucks of a certain class when determining drag coefficient as an input to the compliance model.

3.2.2.2 Wind Tunnel Testing

A wind tunnel provides a stable environment yielding a more repeatable test than coastdown. This allows the manufacturer to run multiple baseline vehicle tests and explore configuration modifications for nearly the same effort (e.g., time and cost) as conducting the coastdown procedure. In addition, wind tunnels provide testers with the ability to yaw the vehicle at positive and negative angles relative to the original centerline of the vehicle to accurately capture the influence of non-uniform wind direction on the Cd (e.g., wind averaged Cd).

However, there are challenges with the use of wind tunnels in a regulatory program that would need to be addressed in order for manufacturers to use this method. There are several different configurations and types of wind tunnels. There are wind tunnels that use forced air (fan upstream pushing air through the wind tunnel) versus suction (fan downstream and pulling air through the wind tunnel). There are wind tunnels with open or semi-open jet, closed jet, and slotted or adaptive wall test sections. There are wind tunnels with static floors versus moving floors or suction that compensate for the boundary layer of air that builds up at the ground level. Finally, there are full scale wind tunnels (e.g., dimensions as large as 80 feet times 120 feet in the test section) that can accommodate a full-size vehicle or clay model versus reduced scale wind tunnels (e.g., dimensions as small as 3 feet by 4.5 feet) that require the vehicle to be scaled down in model form. In addition, regardless of wind tunnel type there are several factors that would need to be minimized or addressed by applying correction factors to maintain flow quality including but not limited to ground boundary layer thickness and location; flow uniformity, angularity and fluctuation; turbulence and wall interference, and environmental conditions (e.g., temperature, humidity, air/fluid density) in the tunnel.

As a result of the wind tunnel testing issues and configuration complexities, it would be difficult to develop a new, uniform wind tunnel testing standard for this rulemaking. Therefore, the agencies propose to use the established SAE standards (such as SAE J1252) and recommended practices, with some modifications and exceptions, for aerodynamic assessment.

3.2.2.3 Computational Fluid Dynamics

Computational Fluid Dynamics, or CFD, capitalizes on today's computing power by modeling a full size vehicle and simulating the flows around this model to examine the fluid dynamic properties, in a virtual environment. CFD tools are used to solve the Navier-Stokes equations that follow physical law of conservation of momentum and govern fluid dynamics and flow relationship around a body in motion or a static body with fluid in motion around it. CFD analysis involves several steps: defining the model structure or geometry based on provided specifications to define the basic model shape, applying a closed surface around the structure to define the external model shape (wrapping or surface meshing), dividing the control volume, including the model and the surrounding environment, up into smaller, discreet shapes (gridding), defining the flow conditions in and out of the control volume and the flow relationships within the grid (including eddies and turbulence), and solving the flow equations based on the prescribed flow conditions and relationships.

This approach can be beneficial to manufacturers since they can rapidly prototype (e.g., design, research, and model) an entire vehicle without investing in material costs; they can modify and investigate changes easily; and the data files can be re-used and shared within the company or with corporate partners.

As with the two aerodynamic assessment methods mentioned above, CFD has challenges that must be addressed. Although it can save on material cost, it can be time consuming (manpower cost) and requires significant computing power depending on the model detail (information technology costs). As described above, a considerable amount of time goes into defining the shape, meshing or gridding the shape and the environment, and solving all of the associated flow equations. Meshes/grids in CFD can contain anywhere from 1 million to 100 million individual cells depending on the modeler's criteria. Consequently, run times needed to solve all of the flow relationships can be extremely long.

The accuracy of the outputs from CFD analysis is highly dependent on the inputs. The CFD modeler decides what method to use for wrapping, how fine the mesh cell and grid size should be, and the physical and flow relationships within the environment. A balance must be achieved between the number of cells, which defines how fine the mesh is, and the computational times for a result (i.e., solution-time-efficiency). All of these decisions affect the results of the CFD aerodynamic assessment.

In addition, CFD software tools have difficulty solving for complex turbulent flows and the spatial interaction that occurs in real-world aerodynamics. This source can lead to large errors between the actual and predicted aerodynamic characteristics. Therefore, care must be taken to ensure that the various turbulent flows and ground/wall interference affects are accounted for.

As with any software tool, the CFD software marketplace is vast and ever-evolving at an astonishing pace. There are commercially-available CFD software tools and publicly-available customized CFD software tools used by academia and government agencies. Any attempt to require one particular CFD software tool in a rulemaking would nearly guarantee its obsolescence by the time the rule was published. In addition, no two CFD software tools are alike and there are currently no established SAE standards or recommended practices, that we are aware of, governing the use of CFD. As a result, it is difficult propose a particular CFD software tool or approach in a regulatory arena.

Much of the recent research has examined the correlation of CFD to experimental results and to determine the sensitivity of the results to certain aspects of CFD (e.g., varying cell size and shape, grid size and meshing technique). This research can aid in defining boundaries for the use of CFD in aerodynamic assessment. In addition, the available research has demonstrated correlation of CFD predictions within one to five percent of experimental results. [9] Thus, CFD does have some ability to accurately model aerodynamic assessments, if conditions for performing the analysis are appropriately defined.

To address these considerations, the agencies propose a minimum set of criteria applicable to using CFD for aerodynamic assessment. Further, we are proposing a requirement to correlate CFD aerodynamic assessments with experimental results from either or both the coastdown procedure and wind tunnel testing, within a certain tolerance level. This will allow the use of CFD and the design freedom that it offers while ensuring that, regardless of the decisions made during the process, the CFD aerodynamic assessment accurately simulates real-world aerodynamics.

3.2.2.4 Aerodynamic Assessment Proposal

The agencies are proposing that the coefficient of drag assessment be a product of test data and modeling using good engineering judgment. This is a similar approach that EPA has provided as an option in testing light duty vehicles where the manufacturers supply representative road load forces for the vehicle.[10]

The agencies are also interested in developing an acceptance demonstration process for aerodynamic testing in the final rulemaking. As part of the process, the manufacturer would have to demonstrate that the methodology used for aerodynamic assessment is acceptable prior to using it for aerodynamic assessment. In addition to the acceptance demonstration, alternative methods would also require correlation testing to the coastdown procedure using a reference vehicle. This process would provide confidence in the use of the alternative method once this rule is implemented. We are requesting comment on the proposed requirements for each allowed method, standards and practices that should be used and any unique criteria that we are proposing.

In addition, EPA and NHTSA recognize that wind conditions have a greater impact on real world CO_2 emissions and fuel consumption of heavy duty trucks than occur with light duty vehicles. As stated in the NAS report[11], the wind average drag coefficient is about 15 percent higher than the zero degree coefficient of drag (Cd). The large ratio of the side area of a combination tractor and trailer to the frontal area illustrates that winds will have a significant impact on the drag. One disadvantage of the agencies' proposed approach to aerodynamic assessment is that the test methods have varying degrees of ability to assess wind conditions. Wind tunnels are currently the only demonstrated tool to accurately assess the influence of wind speed and direction on a truck's aerodynamic performance. Both the coastdown tests and computational fluid dynamics modeling have limited ability in assessing yaw conditions. To address this issue, the agencies are proposing to use coefficient of drag values which represent zero yaw (i.e., representing wind from directly in front of the vehicle, not from the side). The agencies recognize that the results of using the zero yaw approach will produce fuel consumption results in the regulatory program which are slightly lower than in-use but we believe this approach is appropriate since not all manufacturers will use wind tunnels for the aerodynamic assessment.

NHTSA and EPA are proposing that manufacturers take the aerodynamic test result from a truck and determine the appropriate bin (e.g., Classic, Conventional, SmartWay, etc.), as defined in Table 3-4. The agencies are proposing aerodynamic technology categories which divide the wide spectrum of tractor aerodynamics into five categories. The first category, "Classic," represents tractor bodies which prioritize appearance or special duty capabilities over aerodynamics. The Classic trucks incorporate few, if any, aerodynamic features and may have several which detract from aerodynamics, such as bug deflectors, custom sunshades, b-pillar exhaust stacks, and others. The second category for aerodynamics is the "Conventional" tractor body. The agencies consider Conventional tractors to be the average new tractor today which capitalizes on a generally aerodynamic shape and avoids classic features which increase drag. Tractors within the "SmartWay" category build on Conventional tractors with added components to reduce drag in the most significant areas on the tractor, such as fully enclosed roof fairings, side extending gap reducers, fuel tank fairings, and streamlined grill/hood/mirrors/bumpers. The "Advanced SmartWay" aerodynamic category builds upon the SmartWay tractor body with additional aerodynamic treatments such as underbody airflow treatment, down exhaust, and lowered ride height. "Advanced SmartWay II" tractors incorporate advanced technologies which are currently in the prototype stage of development, such as advanced gap reduction, rearview cameras to replace mirrors, wheel system streamlining, and advanced body designs.

Under this proposal, the manufacturer would then input into [TEST] the Cd value specified for each bin as also defined in Table 3-4. For example, if a manufacturer tests a Class 8 sleeper cab high roof tractor with features which are similar to a SmartWay tractor and the test produces a Cd value of 0.59, then the manufacturer would assign this tractor to the Class 8 Sleeper Cab High Roof SmartWay bin. The manufacturer would then use the Cd value of 0.60 as the input to [TEST]. The agencies are proposing the aerodynamic bin approach to address the variability in the proposed testing methods.

Table 3-4: Aerodynamic Input Definitions to [TEST]

	Class 7		Class 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low Roof	High Roof	Low Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics Test Results (Cd)							
Classic	>0.83	>0.73	>0.83	>0.73	>0.83	>0.77	>0.73
Conventional	0.78-0.82	0.63-0.67	0.78-0.82	0.63-0.67	0.78-0.82	0.68-0.72	0.63-0.67
SmartWay	0.73-0.77	0.58-0.62	0.73-0.77	0.58-0.62	0.73-0.77	0.63-0.67	0.58-0.62
Advanced SmartWay	0.68-0.72	0.53-0.57	0.68-0.72	0.53-0.57	0.68-0.72	0.58-0.62	0.53-0.57
Advanced SmartWay II	<0.68	<0.53	<0.68	<0.53	<0.68	<0.58	<0.53
Aerodynamic Input to [TEST] (Cd)							
Frontal Area (m^2)	6.0	9.8	6.0	9.8	6.0	6.6	9.8
Classic	0.85	0.75	0.85	0.75	0.85	0.80	0.75
Conventional	0.80	0.65	0.80	0.65	0.80	0.75	0.65
SmartWay	0.75	0.60	0.75	0.60	0.75	0.70	0.60
Advanced SmartWay	0.70	0.55	0.70	0.55	0.70	0.65	0.55
Advanced SmartWay II	0.65	0.50	0.65	0.50	0.65	0.60	0.50

Coefficient of drag (C_d) and frontal area of the tractor-trailer combination go hand-in-hand to determine the force required to overcome aerodynamic drag. As explained above, the agencies are proposing that the Cd value is one of the [TEST] inputs which will be derived by the manufacturer. However, the agencies are proposing to specify the truck's frontal area for each regulatory class (i.e. each of the seven subcategories which are proposed). The frontal area of a high roof tractor pulling a box trailer will be determined primarily by the box trailer's dimensions and the ground clearance of the tractor. The frontal area of low and mid roof tractors will be determined by the tractor itself. An alternate approach to the proposed frontal area specification is to create the aerodynamic input table (as discussed in Table 3-4) with values that represent the C_d multiplied by the frontal area. This approach will provide the same aerodynamic load, but it will not allow the comparison of aerodynamic efficiency across regulatory classes that can be done with the C_d values alone.

EPA recognizes that wind conditions have a greater impact on real world GHG emissions from heavy duty trucks than occur with light duty vehicles. The ratio of the side area of a combination tractor and trailer to the frontal area illustrates that winds will have a significant impact on the drag. A disadvantage of EPA's proposed approach to aerodynamic assessment is that the test methods have varying degrees of ability to assess wind conditions. Wind tunnels are currently the only tool which has demonstrated the ability to accurately assess the influence of wind speed and direction on a truck's aerodynamic performance. Therefore, we are proposing to use coefficient of drag values which represent zero yaw.

3.3 Tire Rolling Resistance

EPA is proposing that the ISO 28580 test method be used to determine rolling resistance and the coefficient of rolling resistance. A copy of the test method can be obtained through the American National Standards Institute (http://webstore.ansi.org/RecordDetail.aspx?sku=ISO+28580%3a2009).

3.3.1 Reason for Using ISO 28580

The EPA SmartWay Partnership Program started to identify equipment and feature requirements for SmartWay-designated Class 8 over-the-road tractors and trailers in 2006. In order to develop a tire rolling resistance specification for SmartWay-designated commercial trucks, EPA researched different test methods used to evaluate tire rolling resistance, reviewing data and information from tire manufacturers, testing laboratories, the State of California, the Department of Transportation, truck manufacturers, and various technical organizations. After assessing this information, EPA determined that its SmartWay program would use the SAE J1269[12] tire rolling resistance method until the ISO 28580[13] method (at that time under development) was finalized, at which time the Agency would consider moving to this method for its SmartWay program.

During this same time period, the National Highway Traffic Safety Administration (NHTSA) conducted an evaluation of passenger vehicle tire rolling resistance test methods and their variability[14]. Five different laboratory test methods at two separate labs were evaluated. The NHTSA study focused on passenger tires; however, three of the four test methods evaluated can be used for medium duty and heavy duty truck tires. The methods evaluated were SAE J1269, SAE J2452[15] (not applicable for medium duty or heavy duty truck tires), ISO 18164[16] and ISO 28580. The NHTSA study showed significant lab to lab variability between the labs used. The variability was not consistent between tests or types of tire within the same test. The study concluded that a method to account for this variability is necessary if the rolling resistance value of tires is to be compared (NHTSA, 2009). Because of laboratory variability, NHTSA recommended that the use of ISO 28580 is preferred over the other test methods referenced.

The reason that ISO 28580 is preferred is that the test involves a laboratory alignment is between a “reference laboratory” and a “candidate laboratory.” The ISO technical committee involved in developing this test method also has the responsibility for determining the laboratory that will serve as the reference laboratory. The reference laboratory will make available an alignment tire that can be purchased by candidate laboratories. The candidate laboratory shall identify its reference machine. However, at this time, the reference laboratory and alignment tires have not been identified.

3.3.2 Measurement Method and Results

The ISO 28580 test method includes a specific methodology for “light truck, commercial truck and bus” tires, and it has 4 measurement methods, force, torque, deceleration, and power, all of which appear to be suitable for use.

The results of the ISO 28580 test are intended for use in vehicle simulation modeling, such as the model used to assess the effects of various technology options for national greenhouse gas and fuel economy requirements for commercial trucks (see chapter 4). The results are usually expressed as a rolling resistance coefficient and measured as kilogram per metric ton (kg/metric ton) or as dimensionless units. (1 kg/metric ton is the same as the dimensionless unit 0.001) The results are corrected for ambient temperature drum surface and drum diameter as specified in the test method.

3.3.3 Sample Size

The rolling resistance of tires within the same model and construction are expected to be relatively uniform. In the study conducted by NHTSA, only one individual tire had a rolling resistance value that was significantly different from the other tires of the same model. This means that only one tire within a model needs to be tested to obtain a representative value of rolling resistance for the model. The effect of test-to-test variability can be further reduced by conducting three replicate tests and using the average as the value for the rolling resistance coefficient. Tire models available in multiple diameters may have different values of rolling resistance for each diameter because larger diameter tires produce lower rolling resistance than smaller diameters under the same load and inflation conditions. If the size range within a tire model becomes large enough that a given tire size is no longer "substantially similar" in rolling resistance performance to all other tire sizes of that model, then good engineering judgment should be exercised as to whether the differently-sized tire shall be treated, for testing and vehicle simulation purposes, as a distinct tire model. For Class 8 tractors that typically use tires that fit on 22.5" or 24.5" wheels, this situation might occur with 17.5" tires, more commonly used on moving vans and other applications that require a low floor.

3.4 Drive cycle

Drive cycles have a significant impact on the GHG emissions from a truck and how technologies are assessed. Every truck has a different drive cycle in-use. Therefore, it is very challenging to develop a uniform drive cycle which accurately assesses GHG improvements from technologies relative to their performance in the real world.

The drive cycle attributes that impact a vehicle's performance include average speed, maximum speed, acceleration rates, deceleration rates, number of stops, road grade, and idling time. Average and maximum speeds are the attributes which have the greatest impact on aerodynamic technologies. Vehicle speed also impacts the effect of low rolling resistance tires. The effectiveness of extended idle reduction measures is determined by the amount of time spent idling. Lastly, hybrid technologies demonstrate the greatest improvement on cycles which include a significant amount of stop-and-go driving due to the opportunities to recover braking energy. In addition, the amount of power take-off operation will impact the effectiveness of some vocational hybrid applications.

The ideal drive cycle for a line-haul truck would account for significant amount of time spent cruising at high speeds. A pickup and delivery truck would contain a combination of urban driving, some number of stops, and limited highway driving. If EPA proposes an ill-suited drive cycle for a regulatory class, it may drive technologies where they may not see the in-use benefits.

For example, requiring all trucks to use a constant speed highway drive cycle will drive significant aerodynamic improvements. However, in the real world a pickup and delivery truck may spend too little time on the highway to realize the benefits of aerodynamic enhancements. In addition, the extra weight of the aerodynamic fairings will actually penalize the GHG performance of that truck in urban driving and may reduce its freight carrying capability.

3.4.1 Drive Cycles Considered

EPA considered several drive cycles in the development of the proposal including EPA's MOVES model; the Light Duty FTP75 and HWFEC; Heavy Duty UDDS; World Wide Transient Vehicle Cycle (WTVC); Highway Line Haul; Hybrid Truck User Forum (HTUF) cycles; and California ARB's Heavy Heavy Duty Truck 5 Mode Cycle.

MOVES Medium-Duty and Heavy-Duty schedules were developed based on three studies. Eastern Research Group (ERG) instrumented 150 medium and heavy-duty vehicles, Battelle instrumented 120 vehicles instrumented with GPS, and Faucett instrumented 30 trucks to characterize their in-use operation.[17] ERG then segregated the driving into freeway and non-freeway driving for medium and heavy-duty vehicles, and then further stratified vehicles trips according the predefined ranges of average speed covering the range of vehicle operation. Driving schedules were then developed for each speed bin by creating combinations of idle-to-idle "microtrips" until the representative target metrics were achieved. The schedules developed by ERG are not contiguous schedules which would be run on a chassis dynamometer, but are made up of non-continguous "snippets" of driving meant to represent target distributions. This gives MOVES the versatility to handle smaller scale inventories, such as intersections or sections of interstate highway, independently.

The FTP75 and HWFEC drive cycles are used extensively for Light Duty emissions and CAFE programs. Our assessment is that these cycles are not appropriate for HD trucks for two primary reasons. First, the FTP has 24 accelerations during the cycle which are too steep for a Cl. 8 truck to follow. Second, the maximum speed is 60 mph during the HWFEC, while the national average truck highway speed is 65 mph.

The Heavy Duty Urban Dynamometer Driving Cycle was developed to determine the Heavy Duty Engine FTP cycle. The cycle was developed from CAPE-21 survey data which included information from 44 trucks and 3 buses in Los Angeles and 44 trucks and 4 buses in New York in 1977. The cycle was computer generated and weighted to represent New York non-freeway (254 sec), Los Angeles non-freeway (285 sec), Los Angeles freeway (267 sec), New York non-freeway (254 sec) to produce a nearly 50/50 weighting of highway cruise and urban transient. We believe this cycle is not appropriate for our program for several reasons. The maximum speed on the UDDS is 58 mph which is low relative to the truck speed limits in effect today. The 50/50 weighting of cruise to transient is too low for line-haul trucks and too high for vocational trucks and the single cycle does not provide flexibility to change the weightings. Lastly, the acceleration rates are low for today's higher power trucks.

The World Harmonized WTVC was developed by the UN ECE GRPE group. It represents urban, rural, and motorway operation. The cycle was developed based on data from 20 straight trucks, 18 combination trucks, and 11 buses total from Australia, Europe, Japan, and US. EPA has a desire to harmonize internationally, however, we believe this single cycle does not optimally cover the different types of truck operation in the United States and does not provide the flexibility to vary the weightings of a single cycle.

The Highway Line Haul schedule was created by Southwest Research Institute, using input from a group of stakeholders, including EPA, Northeastern States for Coordinated Air Use Management (NESCAUM), several truck and engine manufacturers, state organizations, and others, for a NESCAUM heavy truck fuel efficiency modeling and simulation project. The cycle is 103 miles long and incorporates grade and altitude. This cycle is a good representation of line haul operation. However, the grade and altitude changes cannot be incorporated into a chassis dynamometer or track test. The cycle is also too long for a typical chassis dynamometer test.

The Calstart-Weststart Hybrid Truck Users Forum is developing cycles to match the characteristics of trucks applications which are expected to be first to market for hybrids. The cycles include the Manhattan Bus Cycle, Orange County Bus Cycle, Class 4 Parcel Delivery, Class 6 Parcel Delivery, Combined International Local and Commuter Cycle (CILCC), Neighborhood Refuse, Utility Service, and Intermodal Drayage cycles. The cycles are very application-specific and appropriately evaluate each vocation. However, the use of these type of application specific cycles in a regulatory scheme will lead to a proliferation of cycles for every application, an outcome that is not desirable.

The ARB 5 Mode cycle was developed from data gathered by the University of California Riverside in collaboration with California ARB from 270 1993 through 2001 MY trucks and over 1 million miles of activity. The cycles were developed to reflect typical in-use behavior as demonstrated from the data collected. The four modes (idle, creep, transient, and cruise) were determined as distinct operating patterns, which then led to the four drive schedules. The cycle is well accepted in the heavy duty industry. It was used in the CRC E55/59 Study which is the largest HD chassis dynomometer study to date and used in MOVES and EMFAC to determine emission rate inputs; the EPA biodiesel study which used engine dynomometer schedules created from ARB cruise cycle; the HEI ACES Study: WVU developed engine cycles from ARB 4-mode chassis cycles; CE/CERT test; and by WVU to predict fuel efficiency performance on any drive cycle from ARB 5 mode results. The modal approach to the cycles provides flexibility in cycle weightings to accommodate a variety of truck applications. A downside of the cycle is that it was developed from truck activity in California only.

3.4.2 Proposed Drive Cycles

The drive cycle we are proposing is a modified version of the California Air Resource Board (CARB) Heavy Heavy Duty Truck 5 Mode Cycle. We are proposing the use of the Transient mode, as defined by CARB. We are also proposing to alter the High Speed Cruise and Low Speed Cruise modes to reflect only constant speed cycles at 65 mph and 55 mph respectively. Based on input from trucking fleets and truck manufacturers, we believe the latter is representative of in-use operation, wherein truck drivers use cruise control whenever the possible during periods of sustained higher speed driving.

3.4.3 Weightings of each cycle per regulatory class

As mentioned above, the advantage of using a modal approach to drive cycles is that the standardized modes can be weighted differently to reflect the difference in operating conditions of various truck applications.

The development of the Class 8 sleeper cab cycle weightings is based on studies developed to characterize the operation of line haul trucks. The EPA MOVES model, a study conducted by University of California Riverside, an estimation of commercial truck idling conducted by Argonne National Lab, and a tire test on line haul trucks conducted by Oak Ridge National Lab were used in the weighting analysis.

The distribution of vehicle miles travelled (VMT) among different speed bins was developed for the EPA MOVES model from analysis of the Federal Highway Administration data. The data is based on highway vehicle monitoring data from FHWA used to develop the distribution of VMT among road types from 1999. The information on speed distributions on the different type of roads at different times of day came from traffic modeling of urban locations and chase car data in rural California. This data was used to characterize the fraction of VMT spent in high speed cruise versus transient operation.

The University of California Riverside and California Air Resource Board evaluated engine control module data from 270 trucks which travelled over one million miles to develop the heavy duty diesel truck activity report in 2006.[18] The study found that line haul trucks spend approximately 50% of the time cruising at speeds greater than 45 mph, 10% of time in transient stop-and-go driving, and 40% in extended idle operation. After removing the idle portion to establish weightings of only the motive operation, the breakdown looks like 82% of the time cruising at speeds greater than 45 mph and 18% in transient operation.

Argonne National Lab estimated the percentage of fuel consumed while idling for various combinations of trucks, such as sleeper cabs.[19] The estimation is based on FHWA's Highway Statistics and the Census Bureau's Vehicle In-Use Survey (VIUS). The study found that Class 8 sleeper cabs use an average of 6.8% of their fuel idling.

Oak Ridge National Laboratory evaluated the fuel efficiency effect of tires on Class 8 heavy trucks.[20] The study collected fleet data related to real-world highway environments over a period of two years. The fleet consisted of six trucks which operate widely across the United States. In the Transportation Energy Data Book (2009)[21] Table 5.11 was analyzed and found on average that the line haul trucks spent 5% of the miles at speeds less than 50 mph, 17% between 50 and 60 mph, and 78% of the time at speeds greater than 60 mph.

Table 3-5: Combination Truck Drive Cycle Weighting and Table 3-6: Vocational Vehicle Drive Cycle Weighting summarize the studies and the agencies' proposal for drive cycle weightings.

Table 3-5: Combination Truck Drive Cycle Weighting

	MOVES		UCR		Proposal	
	All	Restricted Access	Short Haul	Long Haul	Sleeper Cab Proposal	Day Cab Proposal
> 60 mph	64%	86%	47% > 45 mph	81% > 45 mph	86% 65 mph Cruise	64% 65 mph Cruise
50-60 mph	17%	9%			9% 55 mph Cruise	17% 55 mph Cruise
< 50 mph	19%	5%	53%	5%	5% Transient	19% Transient

Table 3-6: Vocational Vehicle Drive Cycle Weighting

	MOVES Single Unit	UCR Medium Duty	Proposal
> 60 mph	37%	16% > 45 mph	37% 65 mph Cruise
50-60 mph	21%		21% 55 mph Cruise
< 50 mph	42%	84%	42% Transient

The proposed drive cycle weightings for each regulatory class are included in Table 3-7: Drive Cycle Mode Weightings.

Table 3-7: Drive Cycle Mode Weightings

	VOCATIONAL TRUCKS	DAY CABS	SLEEPER CABS
Transient	42%	19%	5%
55 mph Cruise	21%	17%	9%
65 mph Cruise	37%	64%	86%

3.5 Tare Weights and Payload

The total weight of a truck is the combination of the truck's tare weight, a trailer's tare weight (if applicable), and the payload. The total weight of a truck is important because it in part determines the impact of technologies, such as rolling resistance, on GHG emissions and fuel consumptions. As the HD program is proposed, it is important that the agencies define weights which are representative of the fleet while recognizing that the proposed weights are not representative of a specific vehicle. The sections below describe the agencies' approach to defining each of these weights.

3.5.1 Truck Tare Weights

The tare weight of a truck will vary depending on many factors, including the choices made by the manufacturer in designing the truck (such as the use of lightweight materials, the cab configuration (such as day or sleeper cab), whether it has aerodynamic fairing (such as a roof fairing), and the specific options on the truck.

The proposed Class 8 combination tractor tare weights were developed based on the weights of actual tractors tested in the EPA coastdown program. The empty weight of the Class 8 sleeper cabs with a high roof tested ranged between 19,000 and 20,260 pounds. The empty weight of the Class 8 day cab with a high roof tested was 17,840 pounds. The agencies derived the tare weight of the Class 7 day cabs based on the guidance of truck manufacturer. The agencies then assumed that a roof fairing weighs approximately 500 pounds. Based on this, the agencies are proposing the tractor tare weights as shown in Table 3-8.

Table 3-8: Tractor Tare Weights

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7
Regulatory Class	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,000	11,500	11,000

The agencies developed the empty tare weights of the vocational trucks based on the EDF report[22] on GHG management for Medium-Duty Fleets. The EDF report found that the average tare weight of a Class 4 truck is 10,343 pounds, of a Class 6 trucks is 13,942 pounds, and a Class 8 as 28,979 pounds. The agencies are proposing the following tare weights:

- Light Heavy (Class 2b-5) = 10,300 pounds
- Medium Heavy (Class 6-7) = 13,950 pounds
- Heavy Heavy (Class 8) = 29,000 pounds

3.5.2 Trailer Tare Weights

The proposed trailer tare weights are based on measurements conducted during EPA's coastdown testing and information gathered by ICF in the cost report to EPA.[23]

A typical 53 foot box (or van) trailer has an empty weight ranging between 13,500 and 14,000 pounds per ICF's findings. The box trailer tested by EPA in the coastdown testing weighed 13,660 pounds. Therefore, the agencies are proposing to define the empty box trailer weight as 13,500 pounds.

A typical flatbed trailer weighs between 9,760 and 10,760 per the survey conducted by ICF. EPA's coastdown work utilized a flatbed trailer which weighed 10,480 pounds. Based on this, the agencies are proposing a defined flatbed trailer weight of 10,500 pounds.

Lastly, a tanker trailer weight typically ranges between 9,010 and 10,500 pounds based on ICF findings. The tanker trailer used in the coastdown testing weighed 9,840 pounds. The agencies are proposing an empty tanker trailer weight of 10,000 pounds.

3.5.3 Payload

The amount of payload by weight that a tractor can carry depends on the class (or GVWR) of the vehicle. For example, a typical Class 7 tractor can carry fewer tons of payload than a Class 8 tractor. Payload impacts both the overall test weight of the truck and is used to assess the "per ton-mile" fuel consumption and GHG emissions. The "tons" represent the payload measured in tons.

M.J. Bradley analyzed the Truck Inventory and Use Survey and found that approximately 9 percent of combination truck miles travelled empty, 61 percent are "cubed-out" (the trailer is full before the weight limit is reached), and 30 percent are "weighed out" (operating weight equal 80,000 pounds which is the gross vehicle weight limit on the Federal Interstate Highway System or greater than 80,000 pounds for vehicles traveling on roads outside of the interstate system).[24] The Federal Highway Administration developed Truck Payload Equivalent Factors to inform the development of highway system strategies using Vehicle Inventory and Use Survey (VIUS) and Vehicle Travel Information System (VTRIS) data. Their results, as shown in Table 3-9, found that the average payload of a Class 8 truck ranged from 29,628 to 40,243 pounds, depending on the average distance travelled per day.[25] The same results found that Class 7 trucks carried between 18,674 and 34,210 pounds of payload also depending on average distance travelled per day.

Table 3-9: National Average Payload (lbs.) per Distance Travelled and Gross Vehicle Weight Group (VIUS)[26]

	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	CLASS 8
< 50 miles	3,706	4,550	8,023	10,310	18,674	29,628
51 to100 miles	3,585	4,913	6,436	10,628	23,270	36,247
101 to 200 miles	4,189	6,628	8,491	12,747	30,180	39,743
201 to 500 miles	4,273	7,029	6,360	10,301	25,379	40,243
> 500 mile	3,216	8,052	6,545	12,031	34,210	40,089
Average	3,794	6,234	7,171	11,203	26,343	37,190

The agencies are proposing to prescribe a fixed payload of 25,000 pounds for Class 7 tractors and 38,000 pounds for Class 8 tractors for their respective test procedures. These payload values represent a heavily loaded trailer, but not maximum GVWR, since as described above the majority of tractors "cube-out" rather than "weigh-out."

NHTSA and EPA are also proposing payload requirements for each regulatory class in the vocational truck category. The payloads were developed from Federal Highway statistics based on the averaging the payloads for the weight classes of represented within each vehicle category.[27] The proposed payload requirement is 5,700 pounds for the Light Heavy trucks based on the average payload of Class 3, 4, and 5 trucks from Table 3-9. The proposed payload for Medium Heavy trucks is 11,200 pounds per the average payload of Class 6 trucks as shown in Table 3-9. Lastly the agencies are proposing 38,000 pounds payload for the Heavy Heavy trucks based on the average Class 8 payload in Table 3-9.

3.5.4 Total Weight

In summary, the total weights of the combination tractors are shown in Table 3-10.

Table 3-10: Combination Tractor Total weight

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7
Regulatory Class	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,000	11,500	11,000
Trailer Weight (lbs)	13,500	10,000	10,500	13,500	10,500	13,500	10,500
Payload (lbs)	38,000	38,000	38,000	38,000	38,000	25,000	25,000
Total Weight (lbs)	70,500	66,750	67,000	69,000	65,500	50,000	46,500

The proposed total weights of the vocational trucks are as shown in Table 3-11.

Table 3-11: Vocational Truck Total Weights

REGULATORY CLASS	LIGHT HEAVY	MEDIUM HEAVY	HEAVY HEAVY
Truck Tare Weight (lbs)	10,300	13,950	29,000
Payload (lbs)	5,700	11,200	38,000
Total Weight (lbs)	16,000	25,150	67,000

3.6 Heavy Duty Chassis Test Procedure

EPA is proposing a chassis test procedure adapted from the optional complete federal vehicle emissions certification for light heavy duty vehicles (i.e., those with a GVWR of 8,500-14,000 pounds). Details of the procedure are found in the Code of Federal Regulations (CFR), title 40, part 86.1816-05 through part 86.1816-07. Additional test procedures are described in 40 CFR §86.1863. The test method is further described in the draft SmartWay test protocol[28], which includes a description of the procedures for determining the state of charge and net energy change for hybrid vehicles. These are based on SAE test method 2711[29].

EPA, under the SmartWay program, conducted feasibility testing for the proposed test method. The testing evaluated track tests against chassis dynamometer tests, and measurement of CO_2 emissions by use of a standard test cell, a portable emissions monitoring system (PEMS), and calculation from gravimetric measurement of fuel consumption. Testing issues involving highly variable ambient conditions (i.e. wind speed, temperature, etc.) suggested that chassis dynamometer tests were preferable for obtaining consistent test results. Replicate results of the chassis dynamometer procedure demonstrate that the test precision is typically less than 5%, which is comparable to that of the similar light-duty chassis dynamometer test procedure. (Table 3-12).

Table 3-12 Coefficients of variation reported for chassis dynamometer tests conducted using the SmartWay test procedure.

METHOD OF EMISSIONS MEASUREMENT	TEST CELL			PEMS			GRAVIMETRIC		
Truck number	29	555	598	29	555	598	29	555	598
UCT	12.70%	6.16%	1.64%	1.77%	0.84%	2.16%	3.91%	2.21%	2.04%

LSC	2.04%	3.89%	1.38%	1.18%	0.26%	0.65%	2.12%	3.73%	0.68%
HSC	1.31%	4.54%	0.99%	0.63%	0.47%	0.54%	1.66%	0.62%	1.19%
Coefficient of variation is the standard deviation of the test replicates divided by the mean of the test replicates. UCT – Urban Creep and Transient duty cycle LSC -- Low Speed Cruise duty cycle HSC -- High Speed Cruise duty cycle									

The number of heavy duty chassis dynamometers in the United States is limited. EPA's investigation found 11 chassis dynamometer sites in North America, including the following:

- Air Resources Board Heavy-Duty Emissions Testing Laboratory in Los Angeles, California
- California Truck Testing Services in Richmond, California
- Colorado School of Mines, Colorado Institute for Fuels and Research in Golden, Colorado
- Environment Canada in Ottawa, Ontario, Canada
- Southwest Research Institute in San Antonio, Texas
- West Virginia University Transportable Heavy Duty Vehicle Emissions Testing Laboratory
- National Renewable Energy Lab in Golden, Colorado
- University of Houston in Houston, Texas
- US EPA in Research Triangle Park (not in operation yet)
- Argonne National Lab (up to 14,000 lb.)
- National Vehicle Fuel and Emissions Lab in Ann Arbor, Michigan (up to 14,000 lb.)

3.7 Hybrid Powertrain Test Procedures

As discussed in Section II, the agencies see an opportunity to incorporate hybrid powertrains in this proposal, to help drive technology advancement. EPA and NHTSA are proposing two methods to demonstrate benefits of a hybrid powertrain – chassis and engine testing, and thereby generate credits through the use of such technology. The reduction in CO_2 emissions and fuel consumption demonstrated will be available to use as credits in any vehicle or engine class. That is, unlike ABT credits, credits generated by use of this technology are available for use anywhere in the heavy duty vehicle and engine sector. We are proposing the greater portability for these credits in order to create incentives to use this promising technology and thereby further its acceptance in the heavy duty sector, with attendant GHG and fuel consumption reduction benefits.

The purpose of this testing provision is to allow for evaluation of greenhouse gas reducing technologies that are available, but may lack broad market penetration beyond niche sectors. To effectively incentivize the introduction of this technology, as well as to accurately characterize its effectiveness, it is important to develop a standardized protocol as a basis for comparison. As described in the preamble for this rulemaking, the benefit of the hybridized version of the will be assessed based on a comparison to the conventional version. The basic methods considered for evaluation include full vehicle chassis testing of the hybrid system and powertrain evaluation in a configuration that does not include the full vehicle. The powertrain or "powerpack" testing may be undertaken in one of two ways. A powertrain test cell capable of accommodating the engine, complete hybrid system (including motor, power electronics, battery(ies), electronic control system, etc.), and the transmission may be used to evaluate post-transmission power pack systems. Engine dynamometer test cells may be used to assess the performance the engine and hybrid power system with the control volume extending to just prior to the transmission. The distinction largely being the type of operation the engine – hybrid system can accommodate. When considering performance of any hybrid system, the durability of various emissions related system components will need to be included over the full regulatory useful life. While the industry and component manufacturers may be in the process of addressing battery technology and lifetime performance, any benefit associated with the hybrid system will be based on how this performance changes over the life of the hybrid system and vehicle.

Vehicle Chassis Dynamometer Testing

As a straightforward basis for addressing performance of hybrid systems for greenhouse gas emissions / fuel consumption reduction potential, the vehicle chassis dynamometer involves exercising the complete powertrain system within the vehicle for both conventional and hybrid systems. In this way, actual vehicle performance may be measured using prescribed duty cycles that have a real-world basis. The certification duty cycles considered for conventional heavy-duty vehicle certification may be applied to the hybrid vehicle system based on established chassis testing protocols. The A to B testing would be conducted as described in Figure 3-3 Example of A to B Testing for Chassis or Powertrain Dynamometers below.

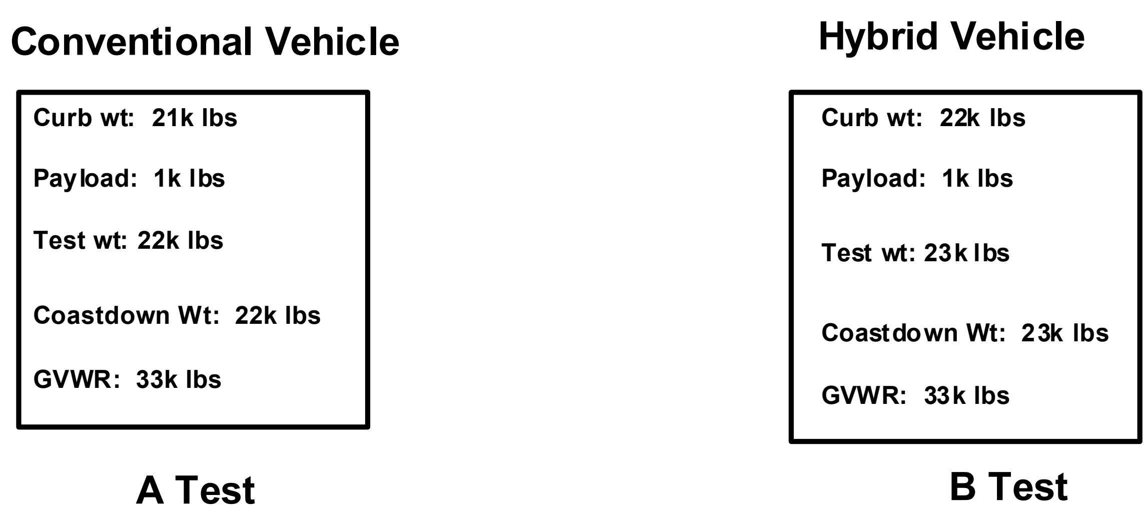


Figure 3-3 Example of A to B Testing for Chassis or Powertrain Dynamometers

This approach is meant to account for the differences in vehicle weight expected for vehicles equipped with hybrid power systems. In so doing, the capability (e.g. payload, etc.) is not diminished for testing purposes. The expectation is that the benefit associated with the use of hybrid system may be characterized by the tractive operation duty cycles and / or the Power-Take Off duty cycle meant to better reflect the idle work and emissions saved through the use of a hybrid energy system. Chassis dynamometer testing for hybrid vehicles will be conducted using standard test protocols as described in SAE J1711 and 2711. To address the use of the power-take off and the GHG emissions related improvements associated with hybrid power systems, a separate duty as described in Figure x_1 is provided. To address improvements for the purposes of credit generation, a weighted composite emission level will be used.

Powertrain / Powerpack Evaluation

To address hybrid power system performance for pre-vehicle testing configurations, this may be accomplished in a powertrain test cell or converted engine dynamometer test cell. There are various hardware-in-the-loop simulations being contemplated and implemented today, however the focus of this discussion will be on basic powertrain / powerpack evaluation. Any pre-vehicle testing provision that incorporates the benefits of hybrid power systems, would need to address several factors including durability of those components, kinetic energy recovery, design variety that could be captured using a chassis dynamometer test, and the drive cycle to appropriately characterize the vehicle activity. The testing methodologies for pre-vehicle hybrid evaluation currently consist of two equally viable strategies with different implications with respect to how emissions improvements are characterized. The first system to be discussed is the pre-transmission powerpack evaluation which incorporates all of the hybrid system components that exist prior to the transmission in the vehicle. The control volume is drawn so as to include the battery, battery support and control systems, power electronics, the engine, and xxx. The performance of this system is largely an engine based evaluation in which emission rates are determined on a brake-specific work basis. As such, the duty cycles being considered to assess this system performance are engine speed and torque command cycles. The emissions results associated with the system performance for GHG pollutants may be measured on brake-specific basis as an absolute test result. This differs from the approach used for post-transmission testing methods which may be conducted in a powertrain test cell or using a chassis dynamometer. As this rulemaking does not contemplate changes to criteria pollutant standards, the duty cycles and measurement methods may be similar to the criteria pollutants, however the emission results for GHG may be based on this full system consideration, which is not the case for criteria pollutants. Engine certification for criteria pollutant standards remain unchanged. It is expected that pre-transmission, parallel hybrids would be the most likely choice for engine-based hybrid certification.

For powertrain testing to determine hybrid benefit, the components mentioned for powerpack testing would be included for powertrain testing, as well as the transmission integrated with the hybrid power system. It is expected that testing could be conducted in a powertrain test cell which would differ from the traditional engine test cell in that it would need to accommodate the additional rotational inertia and speeds associated with inclusion of the vehicle / hybrid transmission with an electric, alternating current dynamometer. Additionally, test cell control systems will need to address all relevant control factors including ways to integrate vehicle command data into the control strategy for the engine and hybrid transmission system. This could eventually include the need for vehicle and driver model inclusions into the control schema for test cell and test article.

Emissions testing for vehicles and hybrid powertrains will require A to B testing to determine the improvement factor as described in Preamble Section IV using the T.E.S.T. result for the base vehicle model as the basis for assessing the CO2 performance improvement versus the appropriate vocational vehicle standard. Engine performance which includes the pre-transmission approach for hybrid certification will generate grams per brake-horsepower hour emissions result that should demonstrate improvement versus the base standard.

3.7.1 Chassis Dynamometer Evaluation

We are proposing that heavy-duty hybrid vehicles be certified using an A to B test method using a chassis dynamometer for testing vehicles. This concept allows the hybrid manufacturer to directly quantify the benefit associated with use of their hybrid system on an application specific basis. The concept would entail exercising the conventional vehicle, identified as "A", tested over the defined cycles. The "B" vehicle would be the hybrid version of vehicle "A". To be considered an appropriate "B" vehicle it must be the same exact vehicle model as the "A" vehicle. As an alternative, if no specific "A" vehicle exists for the hybrid vehicle that is the exact vehicle model, the most similar vehicle model must be used for certification. The most similar vehicle is defined as a vehicle with the same footprint, same payload, same intended service class, and the same coefficient of drag.

To determine the benefit associated with the hybrid system for greenhouse gas (GHG) performance, the weighted CO_2 emissions results from the chassis test of each vehicle would define the benefit as described below:

1. $(CO_{2\_A} – CO_{2\_B})/ (CO_{2\_A})$ = ______ (Improvement Factor)
2. Improvement Factor x Applicable Standard = ___ (g/ton mile benefit)

Similarly, the benefit associated with the hybrid system for fuel consumption would be determined from the weighted fuel consumption results from the chassis tests of each vehicle as described below:

3. (Fuel $Consumption_A$ – Fuel $Consumption_B$)/ (Fuel $Consumption_A$)= ______ (Improvement Factor)
4. Improvement Factor x Fuel Consumption Standard = ___ (gallon/ton mile benefit)

3.7.1.1 Chassis Dynamometer Drive Cycles

The agencies are proposing two sets of duty cycles to evaluate the benefit depending on the vehicle application (such as delivery truck, bucket truck, or refuse truck). The key difference between these two sets of vehicles is that one does not operate a power take-off (PTO) unit while the other does.

A power take off (PTO) is a system on a vehicle that allows energy to be drawn from the vehicle's drive system and used to power an attachment or a separate machine. Typically in a heavy duty truck, a shaft runs from the transmission of the truck and operates a hydraulic pump. The operator of the truck can select to engage the PTO shaft in order for it to do work, or disengage the PTO shaft when the PTO is not required to do work. The pressure and flow from this hydraulic fluid can be used to do work in implements attached to the truck. Common examples of this are utility trucks that have a lift boom on them, refuse trucks that pick up and compact trash, and cement trucks that have a rotating barrel. In each case the auxiliary implement is typically powered by a PTO that uses energy from the truck's primary drive engine.

In most PTO equipped trucks, it is necessary to run the primary drive engine at all times when the PTO might be needed. This is less efficient than an optimal system. Typical PTO systems require no more than 19 kW at any time, which is far below the optimal operation range of the primary drive engine of most trucks. Furthermore, in intermittent operations, the primary drive engine is kept running at all times in order to ensure that the PTO can operate instantaneously. This results in excess GHG emissions and fuel consumption due to idle time. Additionally, idling a truck engine for prolonged periods while operating auxiliary equipment like a PTO could cause the engine to cycle into a higher idle speed, wasting even more fuel. It would be possible to hybridize or change the operation of a conventional PTO equipped truck to lower the GHG emissions and fuel consumption in the real world. However, there is currently no method for an equipment manufacturer to demonstrate fuel consumption and GHG emissions reductions due to the application of advanced PTO technology. The proposed drive cycles do not allow for PTO operation to be included in the test protocol. We are proposing to add a new optional PTO test to the standard set of test cycles in order for manufacturers of advanced PTO systems to demonstrate in the laboratory environment fuel consumption and GHG reductions that would be realized from their systems in the real world. For this reason, the EPA contracted Southwest Research Institute (SwRI) to study PTO systems on heavy-duty trucks with a goal of determining an appropriate test cycle.

We worked with SwRI to review the heavy-duty truck market to determine what types of trucks used PTO's and if the manufacturers thought that there was any possibility of commercial hybrid PTO applications. In some segments, manufacturers did not think a hybrid PTO was feasible. On the other hand, there are already utility and refuse trucks in existence that feature hybrid PTO units. We chose to study the behavior of conventional versions of these trucks in order to understand their typical operation.

We categorized the trucks based on the PTO opportunity. Trucks where limited PTO operation makes them infeasible due to low rates of return include dump trucks. Trucks where PTO operation is infeasible due to high power requirements include blower trucks, fire/emergency trucks, and concrete mixer trucks. Trucks where there is the possibility of PTO operation but there was no commercial interest include tow trucks, grapple trucks, and snowplow trucks.

We selected one utility truck that was in a rental fleet. Over the course of several weeks this truck was rented to two different customers and used in two different environments. The first time the truck was rented it was used in a rural setting outside of San Antonio, Texas. The following week the truck was used in a more urban setting in Fort Worth, Texas. Data was taken from the truck as follows: - Engine Speed, Engine Fuel Rate, Vehicle Speed, PTO Pressure, and PTO Flow Rate.

From this data we were able to determine how often the truck's engine was running, how often the PTO was engaged, and how often the boom of the utility truck was being manipulated by the user. The field data showed that when the truck was operated in the rural setting it had a much lower rate of utilization that when it was operated in the urban setting. Table 3-13 shows a breakdown of the operation of the truck in each setting.

Table 3-13 Utility Truck PTO Operation

	Rural Setting	Urban Setting
% Time PTO at "Idle"	90%	50%
% Time PTO working	10%	50%

In order to better understand the field operation of refuse trucks, EPA commissioned SwRI to study the operation of a refuse hauling truck. SwRI worked with Waste Management in Conroe Texas to instrument a typical PTO equipped neighborhood pickup refuse hauler. The truck that we instrumented was equipped with a side-load-arm (SLA). Southwest's research revealed that approximately 20 percent of the trucks in the industry include an SLA, and the percentage of trucks with an SLA is increasing. Also, a truck with an SLA is able to service more homes per day than a standard truck, so as more SLA equipped trucks are added to the fleet, the total number of trucks will decrease.

The refuse truck was driven on its various routes over the course of a week and the data recorded. Though the truck operated on different streets and areas within the city of Conroe each day, the operation characteristics of the truck were uniform day-to-day.

Once the data was collected, definitions of power take-off (PTO) operations were identified as (1) pump "on" and idle (utility truck), and (2) compactor only, loader only, both compactor and loader, and idle (refuse truck). Steady-state pressure modes were identified by a statistical disjoint cluster analysis. Statistical frequency analyses of the in-field data were used to determine the relative proportion of time allocated to each steady-state mode. The loader and compactor pressure data from the refuse truck demonstrated cyclical behavior, therefore, a discrete Fourier transform using the fast Fourier transform (FFT) algorithm was performed on the loader and compactor data independently. The results of the FFT were used to determine the frequency of the modes in the test cycle. Information collected on population usage was used to weight different portions of the composite duty cycle (utility and refuse truck cycles) to reflect actual field PTO operations.

Based upon the results of the data collection, we decided that a representative duty cycle for PTO operation would not begin until the engine was fully warmed up. In all cases the trucks were warmed up before driving, then driven some distance to a location where the PTO was engaged. Thus, the traction engine was always fully warm before PTO operation commenced.

Based upon the data collection we believe that a representative PTO cycle should test a PTO that is at operating temperature. In the case of the utility truck, most of the operation is in an urban environment and about one-half of the operation time is loaded. Thus, the PTO would only operate in a "cold" state for less than 2% of a typical day. The refuse truck showed similar operation, the PTO was run continuously throughout the eight hour work day resulting in cold operation of the PTO for less than 2% of the typical day.

EPA and NHTSA are proposing that truck manufacturers be able to test their PTO system and compare it to a baseline system to generate GHG emissions and fuel consumption credits. The manufacturer will need to test their system in an emissions cell capable of measuring GHG emissions. The PTO would be exercised by an auxiliary test bench and commanded to follow a prescribed cycle. The cycle will be determined by the type of PTO system that is under consideration. At this time, PTO cycles have been developed for utility trucks and refuse hauling trucks.

The agencies are proposing a composite PTO cycle to allow PTO manufacturers to earn credits for GHG emissions. The cycle we are proposing has been weighted based on the utility truck and refuse truck data in the SwRI report. It was determined that utility truck usage was approximately 20 percent rural and 80 percent urban. Furthermore, based on the field data obtained from the test trucks, the utility trucks are expected to use the PTO when performing boom operations 10 percent of the time in rural settings and 50 percent of the time in urban settings. The data from the refuse truck in the SwRI report was used to complete the refuse portion of the cycle. Because the refuse truck used in the data collection had two hydraulic circuits, one for the load arm and one for the compactor, there are two pressure traces, one for each circuit. Thus, the PTO test cycle in Figure 3-4: Proposed PTO Duty Cycle reflects this.

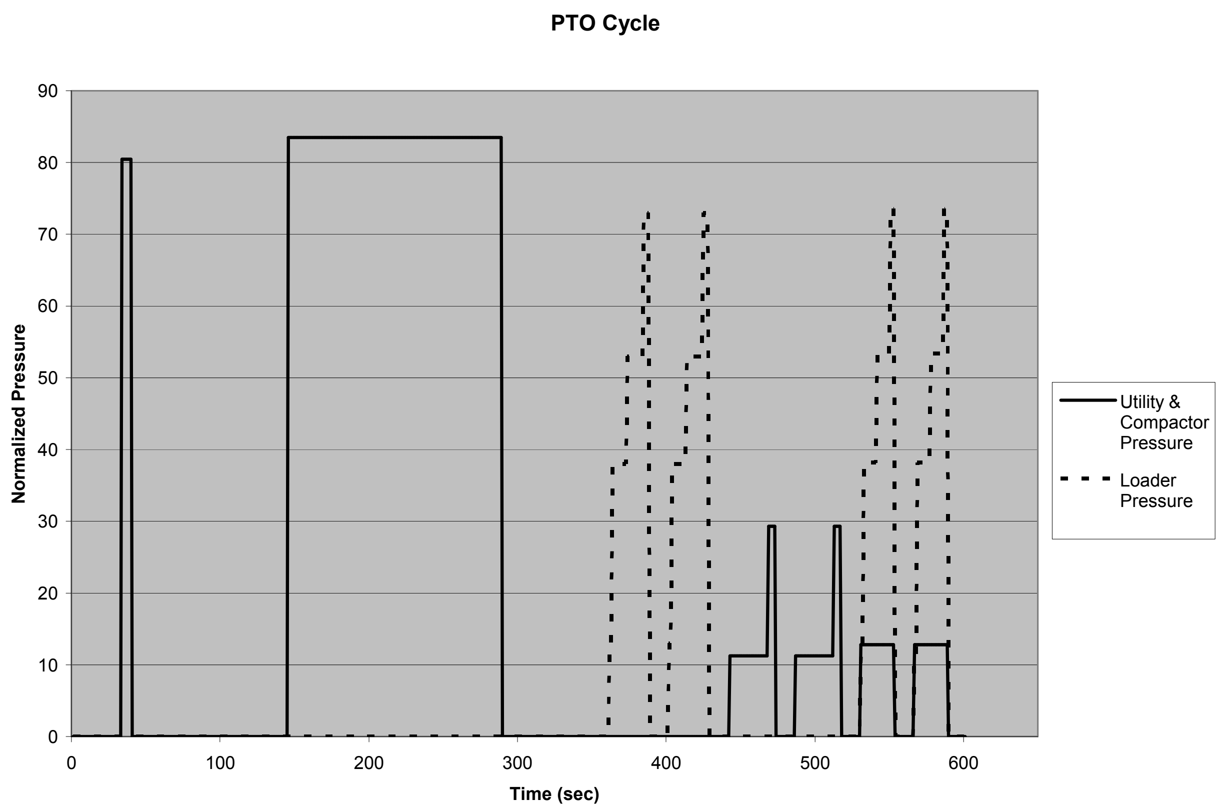


Figure 3-4: Proposed PTO Duty Cycle

The protocol for testing the PTO system will be similar to chassis testing. The vehicle will be positioned such that the exhaust system can be attached to exhaust emission analyzers. This can be done using, but does not necessarily require, a chassis dynamometer. The PTO system will be disconnected from the truck's work absorbing apparatus and connected to a bench that will provide energy absorption to the PTO system. For trucks with one hydraulic circuit in the PTO system, they will be hooked up to the utility/compactor side of the PTO bench. Trucks with two hydraulic circuits will be hooked up to both circuits on the PTO bench. A schematic of this bench can be seen in Appendix I. The vehicle will be pre-conditioned at ambient conditions and then the engine will be run until it is at operating temperature. The PTO will then be exercised until the working fluid and or driving mechanism of the PTO is up to operating temperature. The fully warmed up operating temperature may be defined by the manufacturer or may be assumed to be 150°C. The test will then commence. We believe that a "hot-start" test is appropriate because our data analysis found that trucks equipped with PTO's are nearly always warmed up before the PTO is used, and that cold PTO operation makes up less than 2% of a PTO's typical daily usage.

The PTO would be manipulated by the operator to the prescribed duty cycle. GHG emissions and fuel consumption will be measured as well as criteria pollutants. GHG emissions and fuel consumption would be reported to determine credits; criteria pollutants will simply be reported.

In order to gain credits the manufacturer would have to demonstrate how a truck with a conventional PTO system would perform over the same duty cycle. Both sets of data will need to be measured and reported to EPA and NHTSA in order to claim GHG emission and fuel consumption credits.

The first set of proposed duty cycles would apply to the hybrid powertrains used to improve the motive performance of the vehicle (such as pickup and delivery trucks). The typical operation of these vehicles is very similar to the proposed drive cycles. Therefore, the agencies are proposing to use the vocational vehicle weightings for these vehicles, as shown in Table 3-12. We are using the proposed regulatory vocational vehicle classifications for the ABT vocational vehicle classification. Hybrid vehicles used in applications such as utility and refuse trucks tend to have additional benefit associated with use of stored energy, which avoids main engine operation and related CO_2 emissions and fuel consumption. To appropriately address these alternative sources for benefits, exercising the conventional and hybrid vehicles using their PTO would help to quantify the benefit to GHG emissions and fuel consumption reductions. The duty cycle proposed to quantify the hybrid CO_2 and fuel consumption impact over this broader set of operation would be the three primary cycles plus a PTO duty cycle. The proposed weighting for the cycle is based on data gathered during the SwRI study. Based on fleet owner information, the agencies estimate that the utility trucks are used 20 percent of the time in rural operations and 80 percent of the time in urban operations. The SwRI study found that utility trucks spent 5.5 percent of the time operating the PTO in rural settings and 34.4 percent of the time on in urban settings. This produces an overall percent PTO on time for utility trucks of 28.6 percent. The study found that the refuse trucks have the PTO on 26.7 percent of the time. The agencies weighted each truck type's percent on time based on 40 percent refuse trucks and 60 percent utility trucks to establish an overall 28 percent on-time. Therefore, the agencies are proposing that the PTO cycle be weighted at 28 percent and weight the other three cycles for the remaining 72 percent. The proposed weightings for the hybrids with and without PTO are included in Table 3-14.

Table 3-14: Proposed Drive Cycle Weightings for Hybrid Vehicles

	Transient	55 mph	65 mph	PTO
Vocational Vehicles without PTO	42%	21%	37%	0%
Vocational Vehicles with PTO	30%	15%	27%	28%

3.7.2 Engine Dynamometer Evaluation

The engine test procedure we are proposing for hybrid evaluation involves exercising the conventional engine and hybrid-engine system based on an engine testing strategy. The basis for the system control volume, which serves to determine the valid test article, will need to be the most accurate representation of real world functionality. An engine test methodology would be considered valid to the extent the test is performed on a test article that does not mischaracterize criteria pollutant performance or actual system performance. Energy inputs should not be based on simulation data which is not an accurate reflection of actual real world operation. It is clearly important to be sure credits are generated based on known physical systems. This includes testing using recovered vehicle kinetic energy. Additionally, the duty cycle over which this engine-hybrid system will be exercised must reflect the use of the application, while not promoting a proliferation of duty cycles which prevent a standardized basis for comparing hybrid system performance. The agencies are proposing the use of the Heavy Duty Engine FTP cycle for evaluation of hybrid vehicles, which is the same test cycle proposed for engines used in vocational vehicles. It is important that introduction of clean technology be incentivized without compromising the program intent of real world improvements in GHG and fuel consumption performance.

3.8 Light Heavy Duty Chassis Test Procedure

For each test vehicle from a family required to comply with GHG requirements, the manufacturer shall supply representative road load forces for the vehicle at speeds between 15 km/hr (9.3 mph) and 115 km/hr (71.5 mph). The road load force shall represent vehicle operation on a smooth level road, during calm winds, with no precipitation, at an ambient temperature of 20 [deg]C (68 [deg]F), and atmospheric pressure of 98.21 kPa. Road load force for low speed may be extrapolated.

The dynamometer's power absorption shall be set for each vehicle's emission test sequence such that the force imposed during dynamometer operation matches actual road load force at all speeds.

Required test dynamometer inertia weight class selections are determined by the test vehicle test weight basis and corresponding equivalent weight (insert appropriate HD terminology)

3.8.1 LHD UDDS and HWFE Testing

The UDDS dynamometer run consists of two tests, a “cold” start test after a minimum 12-hour and a maximum 36-hour soak according to the provisions of Sec. Sec. 86.132 and 86.133, and a “hot” start test following the “cold” start by 10 minutes. Engine startup (with all accessories turned off), operation over the UDDS, and engine shutdown constitutes a complete cold start test. Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test. The driving schedule for the EPA Urban Dynamometer Driving Schedule is contained in Appendix I of 40 CFR part 86. The driving schedule is defined by a smooth trace drawn through the specified speed vs. time relationship. The schedule consists of a distinct non-repetitive series of idle, acceleration, cruise, and deceleration modes of various time sequences and rates.

The Highway Fuel Economy Dynamometer Procedure (HFET) consists of preconditioning highway driving sequence and a measured highway driving sequence. The HFET is designated to simulate non-metropolitan driving with an average speed of 48.6 mph and a maximum speed of 60 mph. The cycle is 10.2 miles long with 0.2 stop per mile and consists of warmed-up vehicle operation on a chassis dynamometer through a specified driving cycle. The Highway Fuel Economy Driving Schedule is set forth in Appendix I of 40 CFR Part 600. The driving schedule is defined by a smooth trace drawn through the specified speed versus time relationships.

Practice runs over the prescribed driving schedules may be performed at test point, provided an emission sample is not taken, for the purpose of finding the appropriate throttle action to maintain the proper speed-time relationship, or to permit sampling system adjustment. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided. The driver should attempt to follow the target schedule as closely as possible. The speed tolerance at any given time on the dynamometer driving schedules specified in Appendix I of parts 40 and 600 is defined by upper and lower limits. The upper limit is 2 mph higher than the highest point on trace within 1 second of the given time. The lower limit is 2 mph lower than the lowest point on the trace within 1 second of the given time. Speed variations greater than the tolerances (such as may occur during gear changes) are acceptable provided they occur for less than 2 seconds on any occasion. Speeds lower than those prescribed are acceptable provided the vehicle is operated at maximum available power during such occurrences.

3.8.2 LHD UDDS and HWFE Hybrid Testing

Since LHD chassis certified vehicles share test schedules and test equipment with much of Light Duty Vehicle testing, EPA believes it is appropriate to reference SAEJ1711 “Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles” instead of SAEJ2711 “Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy Duty Vehicles”.

3.8.2.1 Charge Depleting Operation – FTP or "City" Test and HFET or "Highway" Test

The EPA would like comment on incorporating by reference SAEJ1711 chapters 3 and 4, as published June 2010, testing procedures for Light Heavy Duty chassis certified vehicles with the following exceptions and clarifications

Test cycles will continue until the end of the phase in which charge sustain operation is confirmed. Charge sustain operation is confirmed when one or more phases or cycles satisfy the Net Energy Change requirements below. Optionally, a manufacturer may terminate charge deplete testing before charge sustain operation is confirmed provided that the Rechargeable Energy Storage System (RESS) has a higher State of Charge (SOC) at charge deplete testing termination than in charge sustain operation. In the case of Plug In Hybrid Electric Vehicles (PHEV) with an all electric range, engine start time will be recorded but the test does not necessarily terminate with engine start. PHEVs with all electric operation follow the same test termination criteria as blended mode PHEVs. Testing can only be terminated at the end of a test cycle. The Administrator may approve alternate end of test criteria.

For the purposes of charge depleting CO_2 and fuel economy testing, manufacturers may elect to report one measurement per phase (one bag per UDDS). Exhaust emissions need not be reported or measured in phases the engine does not operate.

End of test recharging procedure is intended to return the RESS to a full charge equivalent to pre test conditions. The recharge AC watt hours must be recorded throughout the charge time and soak time. Vehicle soak conditions must not be violated. The AC watt hours must include the charger efficiency. The measured AC watt hours are intended to reflect all applicable electricity consumption including charger losses, battery and vehicle conditioning during the recharge and soak, and the electricity consumption during the drive cycles.

Net Energy Change Tolerance (NEC), is to be applied to the RESS to confirm charge sustaining operation. The EPA intends to adopt the 1% of fuel energy NEC state of charge criteria as expressed in SAEJ1711. The Administrator may approve alternate NEC tolerances and state of charge correction factors.

3.8.2.2 Hybrid Charge Sustaining Operation – FTP or "City" Test and HFET or "Highway" Test

The EPA intends to incorporate by reference SAEJ1711 chapters 3 and 4 for definitions and test procedures, respectively, where appropriate, with the following exceptions and clarifications.

The EPA intends to adopt the 1% of fuel energy NEC state of charge criteria as expressed in SAEJ1711. The Administrator may approve alternate NEC tolerances and state of charge correction factors.

Preconditioning special procedures are optional for traditional "warm" test cycles that are now required to test starting at full RESS charge due to charge depleting range testing. If the vehicle is equipped with a charge sustain switch, the preconditioning cycle may be conducted per 600.111 provided that the RESS is not charged. Exhaust emissions are not taken in preconditioning drives. Alternate vehicle warm up strategies may be approved by the Administrator.

State of Charge tolerance correction factors may be approved by the Administrator. RESS state of charge tolerances beyond the 1% of fuel energy may be approved by the Administrator.

The EPA is seeking comment on modifying the minimum and maximum allowable test vehicle accumulated mileage for both EVs and PHEVs. Due to the nature of PHEV and EV operation, testing may require many more vehicle miles than conventional vehicles. Furthermore, EVs and PHEVs either do not have engines or may use the engine for only a fraction of the miles driven.

Electric Vehicles and PHEVs are to be recharged using the supplied manufacturer method provided that the methods are available to consumers. This method could include the electricity service requirements such as service amperage, voltage, and phase. Manufacturers may employ the use of voltage regulators in order to reduce test to test variability with prior Administrator approval.

References

[1] Need CO2 g/gallon citations from Rob French
[2] Coordinating Research Council, Inc. Phase 1 of the Advanced Colloborative Emissions Study. June 2009.
[3] Gaseous MA Program. Table 122 and 123.. Need citation from Chris Laroo.
[4] § 86.004-28
[5] Kopin, Amy, Docket #XX, Truck and Trailer Roof Height Match Analysis
[6] SAE Recommended Practice 1263, Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques, Jan 1, 2009
[7] SAE Recommended Practice J2263. *Road Load Measurement Using Onboard Anemometry and Coastdown Techniques*. Jan , 2009.
[8] Sze, C. and Kopin, A., Docket #XX, EPA/NHTSA Coastdown Testing Procedure Development by September 2010.
[9] NEED CITATION
[10] For more information, see CFR Title 40, Part 86.129-00 (e)(1).
[11] NAS Report. Finding 2-4 on page 2-40..
[12] SAE International, 2006, Rolling Resistance measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires, SAE J1269, 2006-09
[13] ISO, 2009, Passenger Car, Truck, and Bus Tyres – Methods of Measuring Rolling Resistance – Single Point Test and Correlation of Measurment Results: ISO 28580:2009(E), First Edition, 2009-07-01
[14] NHTSA, 2009. "NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 1 – Evaluation of Laboratory Test Protocols." DOT HS 811 119. June. (www.regulations.gov, Docket ID: NHTSA-2008-0121-0019).
[15] SAE International, 1999, Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance,. SAE J2452, 1999-06
[16] ISO, 2005, Passenger Car, Truck, Bus, and Motorcycle Tyres – Methods of Measuring Rolling Resistance, ISO 18164:2005(E)
[17] Need MOVES drive cycle study citation.
[18] University of California Riverside. Analysis of Heavy Duty Diesel Truck Activity and Emissions Data. 2006.
[19] Gaines, L. "Estimation of Fuel Use by Idling Commerical Trucks", Paper 06-2567. 2006.
[20] Franzese, O., H. Knee, L. Slezak. Effect of Tires on Class-8 Heavy Truck Fuel Efficiency. July 2009. Last viewed on May 1, 2010 at http://info.ornl.gov/sites/publications/files/Pub20686.pdf
[21] U.S. Department of Energy. "Transporation Energy Data Book. Edition 28 – 2009. Table 5.11. Last viewed on Mary 1, 2010 at http://cta.ornl.gov/data/tedb28/Edition28_Chapter05.pdf
[22] Environmental Defense Fund. "Greenhouse Gas Management for Medium-Duty Truck Fleets." Viewed at http://edf.org/documents/10860_fleets-med-ghg-management.pdf. Page 6.
[23] ICF International. Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles. August 2010. Pages 4-16.
[24] M.J. Bradley & Associates. Setting the Stage for Regulation of Heavy-Duty Vehicle Fuel Economy and GHG Emissions: Issues and Opportunities. February 2009. Page 35. Analysis based on 1992 Truck Inventory and Use Survey data, where the survey data allowed developing the distribution of loads instead of merely the average loads.
[25] The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm
[26] Excerpted from The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm
[27] The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm
[28] U.S. Environmental Protection Agency, SmartWay Fuel Efficiency Test Protocol for Medium and Heavy Duty Vehicles – Working Draft, EPA420-P-07-003, November 2007, http://www.epa.gov/smartway/transport/documents/tech/420p07003.pdf, site accessed September 16, 2009.

[29] SAE Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid Electric and Heavy-Duty Vehicles, September 1, 2002