SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Drive Quality Evaluation for Chassis Dynamometer and On-Road Testing

RATIONALE

As vehicle emissions and energy consumption testing expands to include driving on road courses where no “target” speed trace exists, there is motivation to identify metrics which can allow for comparison of results obtained with potentially very different drive traces. This document is revised to accommodate some examples of such metrics that have come into use recently to this end. This version also incorporates necessary changes to include impacts of regen braking on the metrics.

FOREWORD

It is generally recognized that the manner in which a vehicle is driven during a chassis dynamometer test can impact emissions and fuel economy results. The speed versus time tolerances used to validate a test do limit this impact, but even within these constraints, drive-related effects can be significant contributors to test variability. This document provides drive-quality metrics intended to enable improved monitoring and characterization of driver-related variability.

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1. SCOPE

This SAE Recommended Practice establishes uniform procedures for evaluating conformity between the actual and target drive speeds for chassis dynamometer and on-road testing utilizing standard fuel economy/energy consumption and emissions drive schedules.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1634 Battery Electric Vehicle Energy Consumption and Range Test Procedure

2.1.2 Code of Federal Regulations (CFR) Publications

Copies of these documents are available online at https://www.ecfr.gov.

40 CFR Part 86 Control of Emissions from New and In-Use Highway Vehicles and Engines

https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-86

40 CFR Part 600 Fuel Economy and Greenhouse Gas Exhaust Emissions of Motor Vehicles

https://www.ecfr.gov/current/title-40/chapter-I/subchapter-Q/part-600

40 CFR Part 1066 Vehicle-Testing Procedures

https://www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1066

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1711 Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles

SAE J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques

SAE J2264 Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques

2.2.2 Other Publications

United States Environmental Protection Agency. (1991). Specifications for Electric Chassis Dynamometers, Attachment A, RFP C100081T1.

3. DEFINITIONS

3.1 ETW CLASS (EQUIVALENT TEST WEIGHT)

Test mass dictated by U.S. Code of Federal Regulations that is assigned to represent a class of test vehicles (refer to 40 CFR § 1066.805). ETW is a weight class and is not necessarily equal to the as-tested weight of a vehicle.

3.2 DYNAMOMETER SET INERTIA (M_{SET})

The setting that specifies the inertia that is to be simulated by the dynamometer. The M_{SET} equals ETW for regulatory testing using 2WD chassis dynamometers. For testing on a 4WD chassis dynamometer, M_{SET} equals 98.5% of ETW.

3.3 EFFECTIVE TEST MASS (M_E)

Effective test mass (M_E) is the sum of (1) the dynamometer-simulated inertia (M_{SET}), and (2) the effective inertia of the vehicle components (e.g., wheels, axles) that are rotated on the dynamometer. This value describes the total inertial load acting on the vehicle system and is required to calculate the inertial component of cycle energy.

For light-duty vehicles, the effective inertia of the rotating components, per axle, may be estimated by taking 1.5% of the ETW. However, vehicles with other than single, normal-sized wheels, such as dual-wheel trucks, may require specific estimation or determination of the effective mass of the rotating drivetrain components. Using 1.5% of ETW per axle, and the definition of M_{SET} above, gives the following equation for determining the effective test mass for both 2WD and 4WD dynamometer testing:

$$M_E = 1.015 \cdot ETW \quad \text{(Eq. 1)}$$

3.4 DYNAMOMETER TARGET COEFFICIENTS F_x (F_0, F_1, and F_2)

Dynamometer target coefficients describe the total force (tire, drivetrain, and aerodynamic drag) acting on a vehicle during an on-road coastdown which need to be emulated on a vehicle dynamometer. These coefficients are developed from track data (and/or equivalent analytical methodology), corrected to standard conditions, and possibly adjusted to account for differences between vehicle weight as tested on the track and weight represented by an ETW class assigned for dynamometer testing.

3.5 SIMULATION MODE

The operating mode where the dynamometer simulates the vehicle inertia and road load commanded by the dynamometer set inertia (M_{SET}) and dynamometer set coefficients (D_x), respectively, so that a vehicle driven on the dynamometer operates as it would on the road.

3.6 VEHICLE SPEED (V)

3.6.1 ROLL SPEED (V_{ROLL})

The inferred vehicle speed as measured by the dynamometer. Roll encoder speed sampled at 10 Hz shall be used as the roll speed and shall be the same or equivalent speed signal that is used to determine conformance with the speed versus time tolerance in 40 CFR § 1066.235.

3.6.2 SCHEDULED SPEED (V_{SCHED})

The target vehicle speed as specified by the speed versus time requirements for a drive schedule. Scheduled speed is defined by a smooth trace drawn through the specified speed versus time relationship. A linear interpolation between the 1 Hz speed points given in the CFR shall be used to produce the 10 Hz scheduled speed trace (V_{SCHED}).

3.6.3 VEHICLE SPEED - DRIVEN (V_D)

The vehicle speed derived from the roll speed data (V_{ROLL}) for the purposes of calculating the drive metrics described in this document. The driven vehicle speed is used for the calculation of driven cycle energy and is calculated by taking a 0.5 second, double moving average of the 10 Hz roll speed signal. After performing the double moving average, all values less than or equal to 0.03 m/s are set to zero. This is done to reduce the impact of noise in the roll speed signal on the results. A moving average was chosen over other filter types as it provides the best compromise between smoothing the time series and preserving the response time of the signal.

The subscript "D" will be used to refer to quantities calculated from the driven vehicle speed.

3.6.4 VEHICLE SPEED - TARGET (V_T)

The target vehicle speed, calculated in the same manner as V_D but using the scheduled speed (V_{SCHED}) instead of the roll speed (V_{ROLL}). The target vehicle speed is used for the calculation of target cycle energy.

The subscript "T" will be used to refer to quantities calculated from the target vehicle speed.

3.7 SAMPLING PERIOD (Δt)

The time between successive samples of V_{ROLL} and V_{SCHED}. The calculations in this document require a sampling frequency of 10 Hz, which corresponds to a sampling period of 0.1 second. Higher sampling frequencies may be used if 10 Hz is not possible; however, the data must first be downsampled to 10 Hz, using good engineering judgement to ensure representative results, in order to maintain compatibility with the finite-difference calculations defined in 5.1.

3.8 VEHICLE ACCELERATION (a)

The acceleration of the vehicle calculated as the time-rate-of-change of the vehicle speed (V). The specifics of this calculation are detailed in 5.1.2.

3.9 ROAD LOAD FORCE (F_{RL})

The combination of intrinsic and dynamometer-simulated forces opposing the vehicle's motion on the dynamometer that are intended to duplicate the internal and external vehicle parasitic forces the engine must work against while driving on the road. These forces are primarily comprised of aerodynamic drag, driveline parasitic losses, and tire rolling resistance. The road load force is calculated using vehicle speed (V) and the dynamometer target coefficients.

$$F_{RL} = F_0 + F_1 \cdot V + F_2 \cdot V^2 \qquad \text{(Eq. 2)}$$

For testing performed at 20 °F (-7 °C), follow the procedures in 40 CFR § 1066.305(b) to adjust road load coefficients for the different operating environment.

3.10 INERTIAL FORCE (F_I)

The combination of intrinsic and dynamometer-simulated forces opposing the vehicle's motion on the dynamometer that represents the effect of its mass and the rotational inertia of its driveline components while driving on the road. Inertial force is calculated using the effective test mass (M_E) and vehicle acceleration (a).

$$F_I = M_E \cdot a \qquad \text{(Eq. 3)}$$

Substituting Equation 1 (see 3.3) for M_E gives:

$$F_I = 1.015 \cdot ETW \cdot a \qquad \text{(Eq. 4)}$$

3.11 ENGINE FORCE (F_{ENG})

The sum of the inertial force (F_I) and the road load force (F_{RL}). The engine force represents the sum of all the forces that oppose the vehicle's motion while driving on the dynamometer. It is equal to the sum of the road load force and inertial force when this sum is positive, and zero when this sum is negative. (A negative sum of F_{RL} and F_I is interpreted as braking and not considered "engine" force.)

$$F_{ENG} = \left[F_{RL} + F_I\right]^+ \quad \text{(Eq. 5)}$$

The term "engine" is a general reference to the power-generating system of the vehicle, and its use is not restricted to systems that use an internal combustion engine. In hybrid electric or battery-electric vehicles, F_{ENG} may represent, in part or in whole, work that is done by an electric motor.

3.12 ACTIVE BRAKING FORCE (F_{AB}) AB)

The application of a decelerative force on the vehicle other than road load. Active braking is any braking force greater than the road load at a given moment in time and may be the result of regenerative braking, engine braking, friction braking, or any other actively implemented device. This value represents the maximum force that could be recaptured by a regenerative braking system, providing an upper limit on calculation of recoverable energy, and provides a method to compare cycle intensity with regard to effects on different powertrains.

3.13 DISTANCE INCREMENT (d)

The incremental distance traveled by the vehicle during each sampled data point, calculated from the 10 Hz vehicle speed (V) and the sampling period (Δt).

3.14 ACCUMULATED DISTANCE (D)

The total distance traveled by the vehicle, calculated by summing the distance increments (d) over the test cycle.

3.15 ENGINE WORK INCREMENT (w)

The incremental work done by the vehicle during each sampled data point, calculated by multiplying the engine force (F_{ENG}) by the distance increment (d) for each 10 Hz sampled data point. The term "engine" is a general reference to the power-generating system of the vehicle, and its use is not restricted to systems that use an internal combustion engine. In hybrid electric or battery-electric vehicles, F_{ENG} may represent, in part or in whole, work that is done by an electric motor.

3.16 CYCLE ENERGY (CE)

The net energy a vehicle must provide in order to accelerate the vehicle over a test cycle on a chassis dynamometer. It includes only positive acceleration to represent the energy necessary to move the vehicle. Separate metrics are provided for evaluating the potential of regenerated energy and braking style if a vehicle is so equipped.

Cycle energy is calculated by summing the engine work increments (w) over the test cycle. By definition, the engine work increments are always positive (since $F_{ENG} \geq 0$), so negative work is excluded from the cycle energy summation. The exclusion of negative work is appropriate, since it is associated primarily with braking events and represents energy that is not recovered unless the vehicle is equipped with a regenerative braking system. To calculate the energy available for braking energy, the concept of Active Braking has been included in many calculations. See 3.12.

Note that the engine work increment (w) may still be positive even during decelerations. This is because even though the inertial force is negative during decelerations, engine force (F_{ENG}) will still be positive if the magnitude of the road load force is greater than the magnitude of the inertial force. In this case, the engine is still doing work, but the output from the engine is insufficient to maintain the vehicle's speed.

The term "engine" is a general reference to the power-generating system of the vehicle, and its use is not restricted to systems that use an internal combustion engine. In hybrid electric or battery-electric vehicles, F_{ENG} may represent, in part or in whole, work that is done by an electric motor.

4. DRIVING SCHEDULES

There are five driving schedules referenced in this document which are required by the EPA and the California Air Resources Board during emissions and fuel economy certification of vehicles with internal combustion engines. They are the Urban Dynamometer Driving Schedule (UDDS), the “Cold” UDDS, the Highway Fuel Economy Driving Schedule (HFEDS), the US06 Driving Schedule (US06), and the SC03 Driving Schedule (SC03).

4.1 UDDS

The Urban Dynamometer Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 22 minutes, 52 seconds. It is used to represent vehicle city driving.

4.2 HFEDS

The Highway Fuel Economy Driving Schedule is defined in 40 CFR Part 600, Appendix 1. It has a duration of 12 minutes, 45 seconds. It is used to represent vehicle highway driving. The Highway Fuel Economy Test (HFET) consists of two HFEDS cycles.

4.3 US06

The US06 Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 10 minutes. It is used to represent vehicles driving at high speeds and with aggressive accelerations. The US06 cycle is subdivided into a “city” test (0 to 130 seconds and 495 to 600 seconds) and a “highway” test (130 to 495 seconds) for the purposes of five-cycle fuel economy labeling (refer to 40 CFR § 86.159-08).

4.4 SC03

The SC03 Driving Schedule is defined in 40 CFR Part 86, Appendix 1. It has a duration of 10 minutes. It is used to represent vehicle operation with air conditioning.

4.5 “Cold” UDDS

Same as UDDS Schedule. The test is performed in cold ambient conditions as defined in 40 CFR Part 86, Subpart C.

4.6 Speed Tolerance

The speed tolerance at any given time on these driving schedules is defined by the upper and lower limits, as described in 40 CFR (refer to 40 CFR § 1066.235).

The diagrams in Figure 1 show the EPA range of acceptable speed tolerances for typical points, per 40 CFR § 86.115-78. The curve on the left is typical of portions of the speed curve that are increasing or decreasing throughout the 2-second time interval. The curve on the right is typical of portions of the speed curve that include a maximum or minimum value.

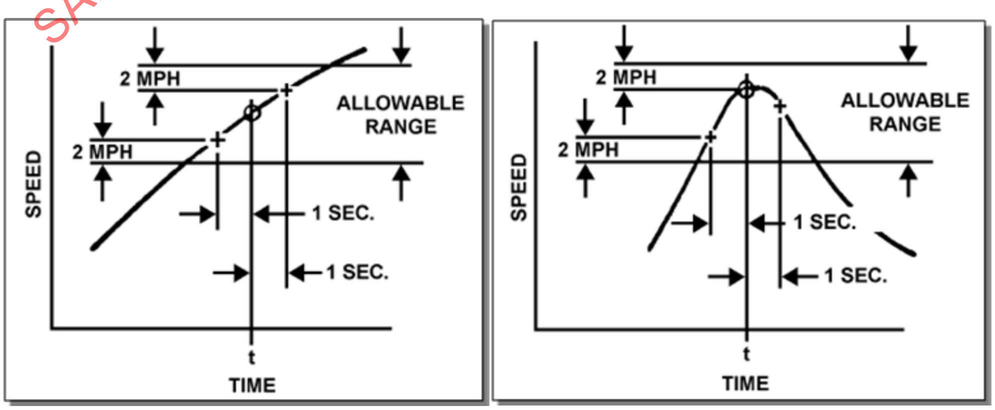


Figure 1 - Speed tolerance definitions

EPA provides additional guidance per § 86.128-00 (d): The vehicle shall be driven with appropriate accelerator pedal movement necessary to achieve the speed versus time relationship prescribed by the driving schedule. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided.

5. ENERGY-BASED DRIVE METRICS (EBDM)

Energy based drive metrics may be calculated for two speed-based traces:

1. The vehicle speed – target (V_T) of a prescribed test cycle, typically signified with the letter “T” in the variable name

2. The vehicle speed – driven (V_D) of a recorded test cycle, typically signified with the letter “D” in the variable name

Target traces are typically not considered during on-road drive cycles.

Driven traces are possible on the dynamometer or on-road.

The metrics are often separated into positive force being applied to the vehicle, indicated with the subscript “ENG” to reflect the historical use of this document to have only engine derived energy, and negative force being applied, indicated with the subscript “AB” for active braking.

5.1 Finite Difference Calculations

Throughout this section, quantities that represent 10 Hz data (time series data) are subscripted with an index, i or j. This index may assume a value from one to N, where one represents the first data point in the series, two represents the next, and so on. Summations over the range from one to N represent summation over the entire test cycle.

5.1.1 Driven and Target Speeds (V_D, V_T)

The driven and target vehicle speeds are calculated by taking a 0.5 second, double moving average of the 10 Hz roll speed and scheduled speed signals, respectively. The 0.5 second double moving average of the roll speed is calculated as follows:

Step 1: Take a 0.5 second moving average of the 10 Hz roll speed (V_{ROLL}).

$$V_{ROLL\_AVG\_1_i} = \frac{1}{5}\sum_{j=i-2}^{j=i+2} V_{ROLL\,j} \qquad \text{(Eq. 6)}$$

$V_{ROLL\_AVG\_1i}$ is set to zero if i < 3 or i > N-2, in order to avoid a condition where j < 1 or j > N.

Step 2: Take a 0.5 second moving average of $V_{ROLL\_AVG\_1}$. The result is the driven vehicle speed (V_D), and the intermediate quantity, $V_{ROLL\_AVG\_1}$, is not used for any further calculations.

$$V_{D_i} = V_{ROLL\_AVG\_2_i} = \frac{1}{5}\sum_{j=i-2}^{j=i+2} V_{ROLL\_AVG\_1_j} \qquad \text{(Eq. 7)}$$

Again, V_{D_i} is set to zero if i < 3 or i > N-2.

Step 3: After performing the double moving average, all values for V_{D_i} less than or equal to 0.03 m/s are set to zero. This is done to reduce the impact of noise in the roll speed signal on the results.

The target vehicle speed (V_T) is calculated in the same manner, using the 10 Hz scheduled speed (V_{SCHED}) instead of the roll speed (V_{ROLL}).

$$V_{SCHED\_AVG\_1_i} = \frac{1}{5}\sum_{j=i-2}^{j=i+2} V_{SCHED\,j} \quad \text{(Eq. 8)}$$

$$V_{T_i} = V_{SCHED\_AVG\_2_i} = \frac{1}{5}\sum_{j=i-2}^{j=i+2} V_{SCHED\_AVG\_1_j} \quad \text{(Eq. 9)}$$

Both V_D and V_T have units of meters per second (m/s).

5.1.2 Driven and Target Vehicle Acceleration (a_D, a_T)

The driven and target acceleration of the vehicle are calculated from the 10 Hz driven and target vehicle speeds using a central-difference approximation. The sampling period, Δt, should be expressed in seconds so that the acceleration will have units of meters per second per second (m/s^2). a_{Di} and a_{Ti} are set to zero if i = 1 or N.

$$a_{Di} = \frac{V_{Di+1} - V_{Di-1}}{t_{i+1} - t_{i-1}} = \frac{V_{Di+1} - V_{Di-1}}{2\Delta t} \quad \text{(Eq. 10)}$$

$$a_{Ti} = \frac{V_{Ti+1} - V_{Ti-1}}{t_{i+1} - t_{i-1}} = \frac{V_{Ti+1} - V_{Ti-1}}{2\Delta t} \quad \text{(Eq. 11)}$$

$$2\Delta t = 0.2 \text{ second @ 10 Hz}$$

5.1.3 Driven and Target Distance Increment (d_D, d_T)

The driven and target distance increments are calculated by multiplying the 10 Hz driven and target vehicle speeds by the sampling period. The distance increment will have units of meters (m).

$$d_{D_i} = V_{D_i} \cdot \Delta t \quad \text{(Eq. 12)}$$

$$d_{T_i} = V_{T_i} \cdot \Delta t \quad \text{(Eq. 13)}$$

$$\Delta t = 0.1 \text{ second @ 10 Hz}$$

5.1.4 Driven and Target Accumulated Distance (D_D, D_T)

The driven and target accumulated distances are calculated by summing the distance increments over the test cycle. The accumulated distance will have units of meters (m).

$$D_D = \sum_{i=1}^{N} d_{Di} \quad \text{(Eq. 14)}$$

$$D_T = \sum_{i=1}^{N} d_{Ti} \quad \text{(Eq. 15)}$$

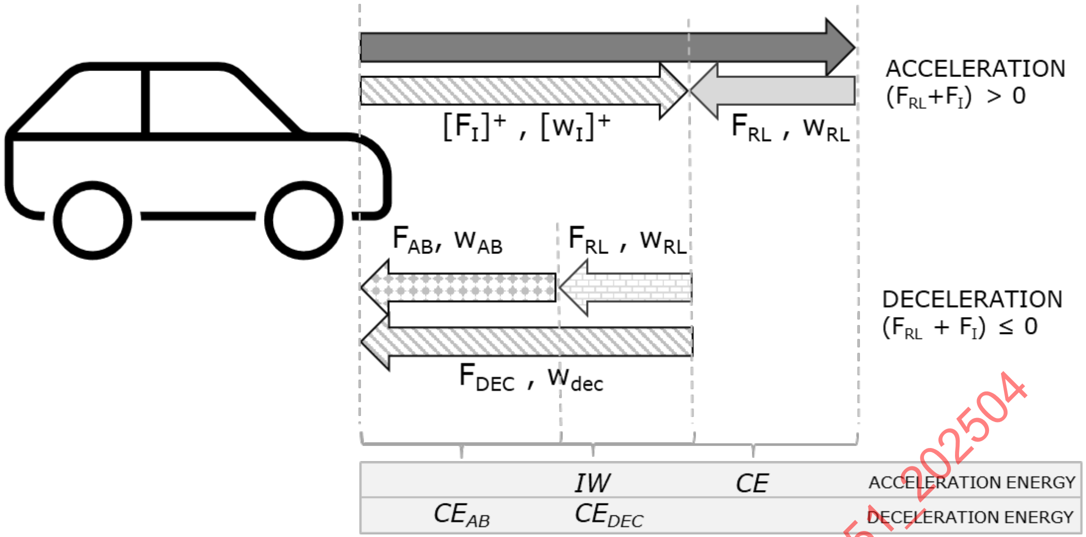


Figure 2 - Diagram of forces, work, and corresponding energy values detailed in the following sections

5.1.5 Driven and Target Road Load Forces ($F_{RL\text{-}D}$, $F_{RL\text{-}T}$)

The driven and target road load forces are calculated by using the 10 Hz driven and target vehicle speeds and dynamometer target coefficients as shown below. The dynamometer target coefficients should be expressed in units of Newtons, meters, and seconds (N, m, and s) so that the road load force will have units of Newtons (N).

$$F_{RL\text{-}D_i} = F_0 + F_1 \cdot V_{Di} + F_2 \cdot V_{Di}^2 \quad \text{(Eq. 16)}$$

$$F_{RL\text{-}Ti} = F_0 + F_1 \cdot V_{Ti} + F_2 \cdot V_{Ti}^2 \quad \text{(Eq. 17)}$$

NOTE: Dynamometer target coefficients are typically reported in units of lbf, lbf/mph, and lbf/mph². In this case, multiplying F_0, F_1, and F_2 by 4.448, 9.9504, and 22.25839, respectively, will convert these terms to the appropriate units for the calculations specified in this document (N, N/[m/s], and N/[m/s]²).

5.1.6 Driven and Target Inertial Forces ($F_{I\text{-}D}$, $F_{I\text{-}T}$)

The driven and target inertial forces are calculated by multiplying the driven and target vehicle accelerations by the effective test mass. The effective test mass should be expressed in kilograms (kg) so that the inertial force will have units of Newtons (N).

$$F_{I\text{-}Di} = M_E \cdot a_{Di} = 1.015 \cdot ETW \cdot a_{Di} \quad \text{(Eq. 18)}$$

$$F_{I\text{-}Ti} = M_E \cdot a_{Ti} = 1.015 \cdot ETW \cdot a_{Ti} \quad \text{(Eq. 19)}$$

NOTE: ETW is typically reported in units of lbm. In this case, multiplying ETW by 0.4536 will convert this value to the appropriate units for the calculations specified in this document (kilograms [kg]).

5.1.7 Driven and Target Engine Force (F_{ENG-D}, F_{ENG-T})

The driven and target engine forces are calculated by summing the driven and target road load and inertial forces. Where this sum is negative, the driven and target engine forces are set to zero. The engine force will have units of Newtons (N).

$$F_{ENG\text{-}D_i} = \begin{cases} F_{RL\text{-}Di} + F_{I\text{-}Di} & \text{for } F_{RL\text{-}Di} + F_{I\text{-}Di} > 0 \\ 0 & \text{for } F_{RL\text{-}Di} + F_{I\text{-}Di} \le 0 \end{cases} \quad \text{(Eq. 20)}$$

$$F_{ENG\text{-}T_i} = \begin{cases} F_{RL\text{-}Ti} + F_{I\text{-}Ti} & \text{for } F_{RL\text{-}Ti} + F_{I\text{-}Ti} > 0 \\ 0 & \text{for } F_{RL\text{-}Ti} + F_{I\text{-}Ti} \le 0 \end{cases} \quad \text{(Eq. 21)}$$

5.1.8 Driven and Target Deceleration Force (F_{DEC-D}, F_{DEC-T})

The driven and target deceleration forces are calculated by summing the driven and target road load and inertial forces required to reduce the speed of the vehicle. Where this sum is positive, the driven and target engine forces are set to zero. The active braking force will have units of Newtons (N), and the sign will be positive for deceleration.

$$F_{DEC-D_i} = \begin{cases} 0 & \text{for } F_{I-Di} > 0 \\ -F_{I-Di} & \text{for } F_{I-Di} \le 0 \end{cases} \quad \text{(Eq. 22)}$$

$$F_{DEC-T_i} = \begin{cases} 0 & \text{for } F_{I-Ti} > 0 \\ -F_{I-Ti} & \text{for } F_{I-Ti} \le 0 \end{cases} \quad \text{(Eq. 23)}$$

5.1.9 Driven and Target Active Braking Force (F_{AB-D}, F_{AB-T})

The driven and target active braking forces are calculated by summing the driven and target road load and deceleration forces beyond the road load required to reduce the speed of the vehicle. Where this sum is positive, the driven and target engine forces are set to zero. The active braking force will have units of Newtons (N), and the sign will be positive for deceleration.

$$F_{AB-D_i} = \begin{cases} 0 & \text{for } F_{RL-Di} + F_{DEC-Di} > 0 \\ -(F_{RL-Di} + F_{DEC-Di}) & \text{for } F_{RL-Di} + F_{DEC-Di} \le 0 \end{cases} \quad \text{(Eq. 24)}$$

$$F_{AB-T_i} = \begin{cases} 0 & \text{for } F_{RL-Ti} + F_{DEC-Ti} > 0 \\ -(F_{RL-Ti} + F_{DEC-Ti}) & \text{for } F_{RL-Ti} + F_{DEC-Ti} \le 0 \end{cases} \quad \text{(Eq. 25)}$$

Note, as F_{DEC} is equivalent to F_I for negative forces, the values of F_{I-Ti} and F_{I-Di} can be substituted.

5.1.10 Driven and Target Road Load Work Increment (w_{RL-D}, w_{RL-T})

The target incremental work that must be done by the vehicle at each sampled data point due to the road load force (F_{RL-T}). The road load work increment has units of joules (J).

$$w_{RL\text{-}Di} = F_{RL\text{-}Di} \cdot d_{Di} \quad \text{(Eq. 26)}$$

$$w_{RL\text{-}Ti} = F_{RL\text{-}Ti} \cdot d_{Ti} \quad \text{(Eq. 27)}$$

5.1.11 Driven and Target Inertial Work Increment (w_{I-D}, w_{I-T})

The target incremental work that must be done by the vehicle at each sampled data point due to the inertial force (F_{I-T}). The inertial work increment has units of joules (J).

$$w_{I\text{-}Di} = F_{I\text{-}Di} \cdot d_{Di} \quad \text{(Eq. 28)}$$

$$w_{I\text{-}Ti} = F_{I\text{-}Ti} \cdot d_{Ti} \quad \text{(Eq. 29)}$$

5.1.12 Driven and Target Engine Work Increment (w_D, w_T)

The driven and target work increments for vehicle acceleration only are calculated by multiplying the driven and target engine forces by the driven and target distance increments, respectively. The work increment will have units of joules (J). Note that incremental engine work is always positive (or zero), since it is calculated using F_{ENG}.

$$w_{Di} = F_{ENG-Di} \cdot d_{Di} \quad \text{(Eq. 30)}$$

$$w_{Ti} = F_{ENG-Ti} \cdot d_{Ti} \quad \text{(Eq. 31)}$$

5.1.13 Driven and Target Deceleration Work Increment (w_{AB-D},w_{AB-T})

The driven and target work increments required for deceleration are calculated by multiplying the driven and target deceleration forces by the driven and target distance increments, respectively. The work increment will have units of joules (J). Note that incremental deceleration work will be always positive or zero since it is using the F_{DEC} which was defined as positive being a deceleration force.

$$w_{DEC-Di} = F_{DEC-Di} \cdot d_{Di} \quad \text{(Eq. 32)}$$

$$w_{DEC-Ti} = F_{DEC-Ti} \cdot d_{Ti} \quad \text{(Eq. 33)}$$

The driven and target deceleration work includes work done by road load forces.

5.1.14 Driven and Target Active Braking Work Increment (w_{AB-D},w_{AB-T})

The driven and target work increments required for active braking are calculated by multiplying the driven and target active braking forces by the driven and target distance increments, respectively. The work increment will have units of joules (J). Note that incremental braking work will be always positive or zero since it is using the F_{AB} which was defined as positive being a deceleration force.

$$w_{AB-Di} = F_{AB-Di} \cdot d_{Di} \quad \text{(Eq. 34)}$$

$$w_{AB-Ti} = F_{AB-Ti} \cdot d_{Ti} \quad \text{(Eq. 35)}$$

The driven and target active braking work does not include work done by road load forces.

5.1.15 Driven and Target Cycle Energy (CE_D, CE_T)

The driven and target cycle energy are calculated by summing the driven and target engine work increments over the test cycle. The cycle energy will have units of joules (J).

$$CE_D = \sum_{i=1}^{N} w_{Di} \quad \text{(Eq. 36)}$$

$$CE_T = \sum_{i=1}^{N} w_{Ti} \quad \text{(Eq. 37)}$$

Alternatively, the equations for cycle energy may be equivalently represented using the sum of inertia and road load forces. Substituting equations from 5.1.6, 5.1.9, and 5.1.10, gives:

$$CE_D = \sum_{i=1}^{N} \left[\left(1.015 \cdot ETW \cdot a_{Di} + F_0 + F_1 V_{Di} + F_2 V_{Di}^2\right) \cdot d_{Di}\right]^+ \quad \text{(Eq. 38)}$$

$$CE_T = \sum_{i=1}^{N} \left[\left(1.015 \cdot ETW \cdot a_{Ti} + F_0 + F_1 V_{Ti} + F_2 V_{Ti}^2\right) \cdot d_{Ti}\right]^+ \quad \text{(Eq. 39)}$$

NOTE: Only positive values of the force-distance products in Equations 30 and 31 are included in the summation.

5.1.16 Driven and Target Deceleration Cycle Energy (CE_{DEC-D}, CE_{DEC-T})

The driven and target deceleration cycle energy values are calculated by summing the driven and target deceleration work increments over the test cycle. The cycle energy will have units of joules (J).

$$CE_{DEC-D} = \sum_{i=1}^{N} w_{DEC-Di} \quad \text{(Eq. 40)}$$

$$CE_{DEC-T} = \sum_{i=1}^{N} w_{DEC-Ti} \quad \text{(Eq. 41)}$$

The driven and target deceleration cycle energy represent the sum of all inertial energy that is available for recovery regardless of drive cycle. It is the inertial energy that must be dissipated to bring the vehicle to rest; therefore, it is equivalent to the driven and target inertial work (IW_D and IW_T) and is included as an individual calculation only to maintain nomenclature similarities. Cycles with less aggressive braking provide more opportunity for road load to dissipate the energy and therefore have a lower potential for recoverable energy.

5.1.17 Driven and Target Cycle Active Braking Energy (CE_{AB-D}, CE_{AB-T})

The driven and target active braking cycle energy are calculated by summing the driven and target active braking work increments over the test cycle. The cycle energy will have units of joules (J).

$$CE_{AB-D} = \sum_{i=1}^{N} w_{AB-Di} \quad \text{(Eq. 42)}$$

$$CE_{AB-T} = \sum_{i=1}^{N} w_{AB-Ti} \quad \text{(Eq. 43)}$$

The driven and target active braking cycle energy values represent the maximum energy that can be recovered by active systems after accounting for all road load losses associated with the drive cycle.

5.1.18 Driven and Target Absolute Speed Change Summation (ASC_D, ASC_T)

The ASC is the discrete approximation for the integral of the absolute magnitude of acceleration. It indicates the extent of velocity variation that is exhibited over the driven and scheduled cycles. Multiplication by the sampling period, Δt, provides the correct "weight" for each data point in the approximation of the integral. ASC has units of meters per second (m/s), although it should not be interpreted as a velocity.

$$ASC_D = \Delta t \sum_{i=1}^{N} |a_{Di}| \quad \text{(Eq. 44)}$$

$$ASC_T = \Delta t \sum_{i=1}^{N} |a_{Ti}| \quad \text{(Eq. 45)}$$

$\Delta t = 0.1$ second @ 10 Hz

5.1.19 Driven and Target Inertial Work (IW_D, IW_T)

The total work done by the powertrain against inertial loading. Only positive values of the inertial work increment ($w_{I\text{-}T}$) are considered. To account for negative, i.e., braking forces, the active braking work is calculated separately. Negative inertial work is taken to represent either: (1) energy dissipated by braking and thus not recovered by the vehicle or (2) energy that serves to reduce the road load work required of the engine during non-braking decelerations or (3) calculated separately in the category of "active braking" to represent energy that is, at least partially, available for recovery in some vehicle powertrains

$$IW_D = \sum_{i=1}^{N} [w_{I\text{-}Di}]^+ \quad \text{(Eq. 46)}$$

$$IW_T = \sum_{i=1}^{N} [w_{I\text{-}Ti}]^+ \quad \text{(Eq. 47)}$$

5.1.20 Energy Rating (ER)

The energy rating for a test is defined as the percent difference between the total driven and target cycle energy as defined in 5.1.15.

$$ER = \frac{CE_D - CE_T}{CE_T} \cdot 100 \quad \text{(Eq. 48)}$$

5.1.21 Energy Rating during Active Braking (ER_{AB})

The energy rating for a test is defined as the percent difference between the total driven and target cycle active braking energy as defined in 5.1.17.

$$ER_{AB} = \frac{CE_{AB-D} - CE_{AB-T}}{CE_{AB-T}} \cdot 100 \quad \text{(Eq. 49)}$$

5.2 Distance Rating (DR)

The distance rating for a test is defined as the percent difference between the total driven and scheduled distance as defined in 5.1.4.

$$DR = \frac{D_D - D_T}{D_T} \cdot 100 \quad \text{(Eq. 50)}$$

5.3 Energy Economy Rating (EER)

The EER is defined as the percentage difference between the distance per unit cycle energy for the driven and target traces. Since fuel economy is a measure of the distance traveled per unit of fuel consumed, the effect of distance driven must also be considered in an assessment of a drive quality that is intended to correlate with fuel economy.

$$EER = -\frac{\left(\frac{D_D}{CE_D}\right) - \left(\frac{D_T}{CE_T}\right)}{\left(\frac{D_T}{CE_T}\right)} \cdot 100 \quad \text{(Eq. 51)}$$

The negative sign in front of the right-hand side of Equation 51 associates lower values of fuel economy with higher values of EER, similar to the expected relationship for ER and DR.

The EER may be expressed as a combination of the energy rating (ER) and distance rating (DR) as follows:

$$EER = \left[1 - \frac{DR/100 + 1}{ER/100 + 1}\right] \cdot 100 \quad \text{(Eq. 52)}$$

5.4 Energy Economy Rating (EER_{AB})

The percentage difference between the distance per unit cycle energy of active braking energy for the driven and target traces.

$$EER_{AB} = -\frac{\left(\frac{D_D}{CE_{AB-D}}\right) - \left(\frac{D_T}{CE_{AB-T}}\right)}{\left(\frac{D_T}{CE_{AB-T}}\right)} \cdot 100 \quad \text{(Eq. 53)}$$

The negative sign in front of the right-hand side of Equation 53 associates lower values of fuel economy with higher values of EER, similar to the expected relationship for ER and DR.

The EER_{AB} may be expressed as a combination of the energy rating (ER_{AB}) and distance rating (DR) as follows:

$$EER_{AB} = \left[1 - \frac{DR/100+1}{ER_{AB}/100+1}\right] \cdot 100 \quad \text{(Eq. 54)}$$

5.5 Absolute Speed Change Rating (ASCR)

The ASCR is defined as the percentage difference between the ASC for the driven and target traces. It provides an indicator of the “smoothness” of the driven trace relative to the scheduled trace. A driven trace that is “smoother” will have a lower ASC than the scheduled trace and so will result in a negative ASCR.

$$ASCR = \frac{ASC_D - ASC_T}{ASC_T} \cdot 100 \quad \text{(Eq. 55)}$$

The ASCR is particularly well-suited to quantifying small speed changes that might come about from throttle perturbations. It should be noted that these perturbations ONLY affect the ASC when they are sufficient to change the speed of the vehicle. It is possible for a driver to intentionally produce small, high-frequency throttle movements that do not result in dynamometer roll speed changes. Such movements would not be captured by a speed-based metric. While such throttle movements can be intentionally produced, they are considered unlikely to occur in practice, since they do not contribute toward making a vehicle follow a target trace.

5.6 Inertial Work Rating (IWR)

The IWR is defined as the percentage difference between the inertial work for the driven and target traces. It can indicate when the drive style might substantially impact the overall efficiency of the engine, such that a metric based strictly on cycle energy might not fully characterize observed deviations from expected emission rates.

$$IWR = \frac{IW_D - IW_T}{IW_T} \cdot 100 \quad \text{(Eq. 56)}$$

5.7 Inertial Work Rating Active Braking (IWR_{AB})

Percentage difference between the work required to reduce the inertia between the driven and target traces through active braking. It can indicate when the braking style might substantially impact the overall efficiency of the vehicle.

$$IWR_{AB} = \frac{CE_{AB-D} - CE_{AB-T}}{CE_{AB-T}} \cdot 100 \quad \text{(Eq. 57)}$$

5.8 Root Mean Squared Speed Error (RMSSE)

The RMSSE metric provides the driver's performance in meeting the schedule speed trace throughout the test cycle in terms of the root mean squared (RMS) speed error. The value is always a positive number with lower values (closer to zero) indicating better performance. RMS speed error has units of miles per hour (mph).

$$RMSSE = 2.237 \cdot \sqrt{\frac{\sum_{i=1}^{N} (V_{Di} - V_{Ti})^2}{N}} \quad \text{(Eq. 58)}$$

The multiplier (2.237) is included in Equation 58 to convert the output to mph, assuming that V_D and V_T are in units of meters per second (m/s), as specified in 5.1.1.

5.9 Recommended EBDM Phase Ratings for U.S. Test Cycles

5.9.1 FTP and FTP4 Reporting

The drive ratings specified in 5.1 to 5.7 should be calculated individually for each phase of the FTP (“three-bag”) and FTP4 (“four-bag”) tests. Additionally, weighted city ratings should be calculated from these. For EER, ASCR, and IWR, this is done by using weighted values of the relevant quantities being compared: The weighted distance-per-cycle-energy values are used to calculate the weighted EER, the weighted ASC values are used to calculate the weighted ASCR, and the weighted positive inertial work values are used to calculate the weighted IWR, as defined by Equations 59 to 72 in this section:

FTP-Weighted EER

$$\left(\frac{D}{CE}\right)_{\text{Weighted FTP}} = \frac{1}{0.43\left(\frac{CE_{\text{phase1}}+CE_{\text{phase2}}}{D_{\text{phase1}}+D_{\text{phase2}}}\right)+0.57\left(\frac{CE_{\text{phase2}}+CE_{\text{phase3}}}{D_{\text{phase2}}+D_{\text{phase3}}}\right)} \quad \text{(Eq. 59)}$$

$$EER_{\text{Weighted FTP}} = -\frac{(D/CE)_{\text{Weighted FTP\_D}} - (D/CE)_{\text{Weighted FTP\_T}}}{(D/CE)_{\text{Weighted FTP\_T}}} \cdot 100 \quad \text{(Eq. 60)}$$

FTP4-Weighted EER

$$\left(\frac{D}{CE}\right)_{\text{Weighted FTP4}} = \frac{1}{0.43\left(\frac{CE_{\text{phase1}}+CE_{\text{phase2}}}{D_{\text{phase1}}+D_{\text{phase2}}}\right)+0.57\left(\frac{CE_{\text{phase3}}+CE_{\text{phase4}}}{D_{\text{phase3}}+D_{\text{phase4}}}\right)} \quad \text{(Eq. 61)}$$

$$EER_{\text{Weighted FTP4}} = -\frac{(D/CE)_{\text{Weighted FTP4\_D}} - (D/CE)_{\text{Weighted FTP4\_T}}}{(D/CE)_{\text{Weighted FTP4\_T}}} \cdot 100 \quad \text{(Eq. 62)}$$

FTP-Weighted ASCR

$$ASC_{\text{Weighted FTP}} = 0.43\left(ASC_{\text{phase1}} + ASC_{\text{phase2}}\right) + 0.57\left(ASC_{\text{phase2}} + ASC_{\text{phase3}}\right) \quad \text{(Eq. 63)}$$

$$ASCR_{\text{Weighted FTP}} = \frac{ASC_{\text{Weighted FTP\_D}} - ASC_{\text{Weighted FTP\_T}}}{ASC_{\text{Weighted FTP\_T}}} \cdot 100 \quad \text{(Eq. 64)}$$

FTP4-Weighted ASCR

$$ASC_{\text{Weighted FTP4}} = 0.43\left(ASC_{\text{phase1}} + ASC_{\text{phase2}}\right) + 0.57\left(ASC_{\text{phase3}} + ASC_{\text{phase4}}\right) \quad \text{(Eq. 65)}$$

$$ASCR_{\text{Weighted FTP4}} = \frac{ASC_{\text{Weighted FTP4\_D}} - ASC_{\text{Weighted FTP4\_T}}}{ASC_{\text{Weighted FTP4\_T}}} \cdot 100 \quad \text{(Eq. 66)}$$

FTP-Weighted IWR

$$IW_{\text{Weighted FTP}} = 0.43\left(IW_{\text{phase1}} + IW_{\text{phase2}}\right) + 0.57\left(IW_{\text{phase2}} + IW_{\text{phase3}}\right) \quad \text{(Eq. 67)}$$

$$IWR_{Weighted\ FTP} = \frac{IW_{Weighted\ FTP\_D} - IW_{Weighted\ FTP\_T}}{IW_{Weighted\ FTP\_T}} \cdot 100 \quad \text{(Eq. 68)}$$

FTP4-Weighted IWR

$$IW_{Weighted\ FTP4} = 0.43(IW_{phase1} + IW_{phase2}) + 0.57(IW_{phase3} + IW_{phase4}) \quad \text{(Eq. 69)}$$

$$IWR_{Weighted\ FTP4} = \frac{IW_{Weighted\ FTP4\_D} - IW_{Weighted\ FTP4\_T}}{IW_{Weighted\ FTP4\_T}} \cdot 100 \quad \text{(Eq. 70)}$$

FTP-Weighted RMSSE

$$0.5*(0.43*RMSSEphase1+RMSSEphase2+0.57*RMSSEphase3) \quad \text{(Eq. 71)}$$

FTP4-Weighted RMSSE

$$0.5*(0.43*(RMSSEphase1+RMSSEphase2)+0.57*(RMSSEphase3+RMSSEphase4)) \quad \text{(Eq. 72)}$$

These weighted calculations produce a drive rating that reflects the individual phase contributions with the same weighting that is applied for calculating the weighted fuel consumption for the city test. The weighted equations in this section also apply to the cold FTP.

5.9.2 Highway (HFET) and SC03 Reporting

Highway and SC03 drive metrics are reported for the sampled HFEDS or SC03 phase. Warm-up phases do not require a drive rating.

5.9.3 US06 Reporting

Drive ratings for the US06 test are calculated for the sampled phase of the US06. Warm-up phases do not require a drive rating. The rating must be calculated separately for the “city” and “highway" portions (see 4.3) in addition to calculating an overall test cycle result. Data from the two regions of the test that make up the “city” portion of the cycle are treated as a single phase for the drive rating calculations.

6. DRIVE SCHEDULE INTENSITY METRICS

The aforementioned metrics rely on comparison of a driven trace against a specific target trace over the course of a test and can serve as proxies (or direct indicators in the case of RMSSE) for how well the trace was followed.

The intent of this section is to establish different ways of characterizing arbitrary drive traces in order to assist in such comparisons. Several quantities that may be used in the future to quantify the “intensity” of a particular drive schedule. As new schedules are developed, it is expected that one or more of these intensity metrics may provide an indication of the expected fuel economy that would be exhibited by a vehicle driving the schedule, relative to its fuel economy when driving other schedules.

Further, as vehicle emissions and energy consumption testing increasingly encompasses driving in “real-world” situations where no specific targeted trace exists, this section also serves to evaluate the on-road trace as driven to assist comparing between to other drives or established known traces. When using on-road data where a target trace does not exist, assume that the $V_T = V_D$ to enable use of all equations without modification of subscripts or their meanings.

6.1 Cycle Energy Intensity (CE_{DIST})

Cycle energy intensity is the energy that is required to drive the cycle (CE_T), normalized by the total distance of the cycle (D_T). CE_{DIST} has units of joules per meter (J/m).

$$CE_{DIST} = \frac{CE_T}{D_T} \quad \text{(Eq. 73)}$$

6.2 Cycle Energy Active Braking Intensity ($CE_{AB-DIST}$)

Cycle deceleration intensity is the energy in addition to the road load that is required to decelerate the drive cycle using active braking normalized by the distance of the cycle. $CE_{AB-DIST}$ has units of joules per meter (J/m).

$$CE_{AB-DIST} = \frac{CE_{AB-T}}{D_T} \quad \text{(Eq. 74)}$$

6.3 Road Load and Inertial Work Contributions

6.3.1 Inertial Work Fraction (IWF)

The fraction of the total target cycle energy that the engine must provide that is due to inertial loading. The IWF is a unitless quantity.

$$IWF = \frac{IW_T}{CE_T} \quad \text{(Eq. 75)}$$

6.3.2 Inertial Work Fraction Active Braking (IWF_{AB})

The fraction of the total target cycle energy that the active braking must absorb to reduce the vehicle speed. The IWF_{AB} is a unitless quantity. The IWF_{AB} can be used to identify on-road net changes in grade or evaluate the overall drive cycle in comparison to others with higher or lower vehicle speeds.

$$IWF_{AB} = \frac{CE_{AB-T}}{CE_T} \quad \text{(Eq. 76)}$$

6.3.3 Active Braking Fraction (IWF_{ab_dec})

The fraction of the total deceleration energy that the active braking must absorb to follow the trace. It is the portion of deceleration that cannot be met with the road load alone. It can be used to compare the aggressiveness of braking between cycles and to provide an upper limit for the recapturable energy in a given drive cycle.

$$IWF_{AB\_DEC} = \frac{CE_{AB-T}}{CE_{DEC}} \quad \text{(Eq. 77)}$$

6.3.4 Road Load Work Fraction (RLWF)

The fraction of the total target cycle energy that the engine must provide that is due to road load work. Because the road load work and the inertial work together represent all of the work done by the engine, the road load work fraction can be defined in terms of the IWF. The RLWF is a unitless quantity.

$$RLWF = 1 - IWF \quad \text{(Eq. 78)}$$

6.4 Cycle Comparison Table

Table 1 provides a comparison of intensity metrics for various cycles. Note that since ASC per time is obtained strictly from the drive schedule, it does not depend on vehicle-specific data (e.g., ETW, dynamometer target coefficients). For this reason, ASC per time (and ASC) may be regarded as fixed properties of a given test cycle. This is not true for other intensity metrics that are tabulated in Table 1, hence the inclusion of a mean and standard deviation.

For a particular combination of metric and drive schedule, the mean and standard deviation were obtained by performing the calculations using the ETW and dynamometer target coefficients for the 988 unique vehicle configurations listed in the 2023 EPA test car database. Entries for which the reported set and target dynamometer coefficients were equal were excluded from the population.

Table 1 - Cycle intensity metrics for vehicles in 2023 EPA test car database

Test Cycle/Metric	CE_{DIST} (J/m)		CE_{DIST_ab} (J/m)		IWF (fraction)		IWF_{ab} (fraction)		IWF_{ab_dec} (fraction)		APC_{TIME} (W/s)		ASC_{TIME} (m/s^2)
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	--
UDDS Phase 1, 3	642	128	242	51	0.57	4%	0.38	5%	0.67	3%	2644	497	0.41
UDDS Phase 2	549	105	282	59	0.68	4%	0.52	6%	0.75	4%	1621	306	0.40
UDDS (Three-bag)	609	119	256	54	0.60	4%	0.42	5%	0.69	3%	2172	409	0.40
UDDS (Four-bag)	594	114	263	55	0.62	4%	0.44	5%	0.71	3%	1997	376	0.40
Highway (HWFET)	567	136	56	14	0.27	4%	0.10	2%	0.37	4%	2146	401	0.17
US06	914	205	256	57	0.47	5%	0.28	5%	0.60	4%	10427	1950	0.60
SC03	651	125	311	66	0.67	4%	0.48	5%	0.71	3%	2624	494	0.42
MCT first phase(1) (before steady state)	583	120	178	38	0.48	4%	0.31	4%	0.64	3%	2029	381	0.35
SMCT(1)	629	131	189	41	0.48	4%	0.30	4%	0.63	3%	2691	504	0.37

(1) The MCT and SMCT are drive cycles used for BEV range testing and are comprised of UDDS, HWFET, and US06 cycles combined in a pattern specified by the 2021 version of SAE J1634 Battery Electric Vehicle Energy Consumption and Range Test Procedure.

7. LOCAL METRIC

It is possible for the measured fuel economy and/or emissions to be significantly affected by severe, short-duration excursions from the scheduled drive trace. Due to their short duration, the impact of these excursions might not be reflected in drive metrics that are summed or averaged over the entire cycle, such as those described in Sections 5 and 6. The development of suitable “local” metrics that are capable of identifying significant, discrete drive events may be addressed in a future revision of the document.

8. NOTES

8.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE LIGHT DUTY VEHICLE PERFORMANCE AND ECONOMY MEASURE COMMITTEE

APPENDIX A - COEFFICIENT RESOLUTION AND TARGET REFERENCE VALUES

A.1 COEFFICIENT AND METRIC RESOLUTION

Number of decimal digits:

F_0 xxx.xx lbf
F_1 x.xxxx lbf/(mph)
F_2 0.xxxxx lbf/(mph)^2
ETW, M_E 1 pound
ER xx.xx%
DR xx.xx%
EER xx.xx%
ASCR xx.xx%

A.2 TARGET CYCLE REFERENCE VALUES

Table A1 shows the cycle energy reference values for each phase.

Table A1 - Example target cycle energy reference values

Test/Target Values	Cycle	CE_T* (MJ)
FTP	UDDS Phase 1	3.434
FTP	UDDS Phase 2	3.132
FTP	UDDS Phase 3	3.434
FTP	Three-Bag FTP	10.000
FTP	Four-Bag FTP	13.132
FTP	Three-Bag FTP (Weighted)	6.566
FTP	Four-Bag FTP (Weighted)	6.566
Highway	Highway (HFEDS)	8.947
SC03	SC03	3.455
US06	US06 Total	10.829
US06	US06 City	3.163
US06	US06 Highway	7.666
MCT	MCT high SOC (refer to SAE J1634)	22.078
MCT	MCT complete-no steady state (refer to SAE J1634)	44.156
SMCT	SMCT (refer to SAE J1634)	54.985

* CE_T determined using the following reference values: ETW = 4000 pounds, F0 = 40, F1 = 0.4, and F2 = 0.02.

Target driving traces are found in the respective CFR sections:

FTP and COLD FTP: 40 CFR Appendix I to Part 86(a)

https://www.ecfr.gov/current/title-40/appendix-Appendix%20I%20to%20Part%2086#p-Appendix-I-to-Part-86(a)

HFEDS: 40 CFR Appendix I to Part 600

https://www.ecfr.gov/current/title-40/chapter-I/subchapter-Q/part-600/appendix-Appendix%20I%20to%20Part%20600

US06: 40 CFR Appendix I to Part 86(g)

https://www.ecfr.gov/current/title-40/appendix-Appendix%20I%20to%20Part%2086#p-Appendix-I-to-Part-86(g)

SC03: 40 CFR Appendix I to Part 86(h)

https://www.ecfr.gov/current/title-40/appendix-Appendix%20I%20to%20Part%2086#p-Appendix-I-to-Part-86(h)

APPENDIX B - EXCEL-BASED CALCULATOR FOR EBDM DATA

An Excel-based calculator is available to perform the EBDM calculations on one or more tests at a time. The calculator operates on input files that contain the data required for the calculations and produces an output report sheet that can be saved as a separate worksheet. The calculator is included with this document and can be downloaded from sae.org.

A template for the input files can also be obtained along with the calculator. Otherwise, input files should meet the following criteria:

- Files should be comma separated value (.csv), or Microsoft Excel (.xls, .xlsx, .xlsm) type.
- There should be no embedded images or other data in the file.
- Field locations and formatting for the input parameters and 10 Hz drive trace data are shown in Figure B1.
- Cycle ID numbers are defined in Table B1.
- Field locations for the test/vehicle parameters and calculated EBDM drive ratings are shown in Figure B2.

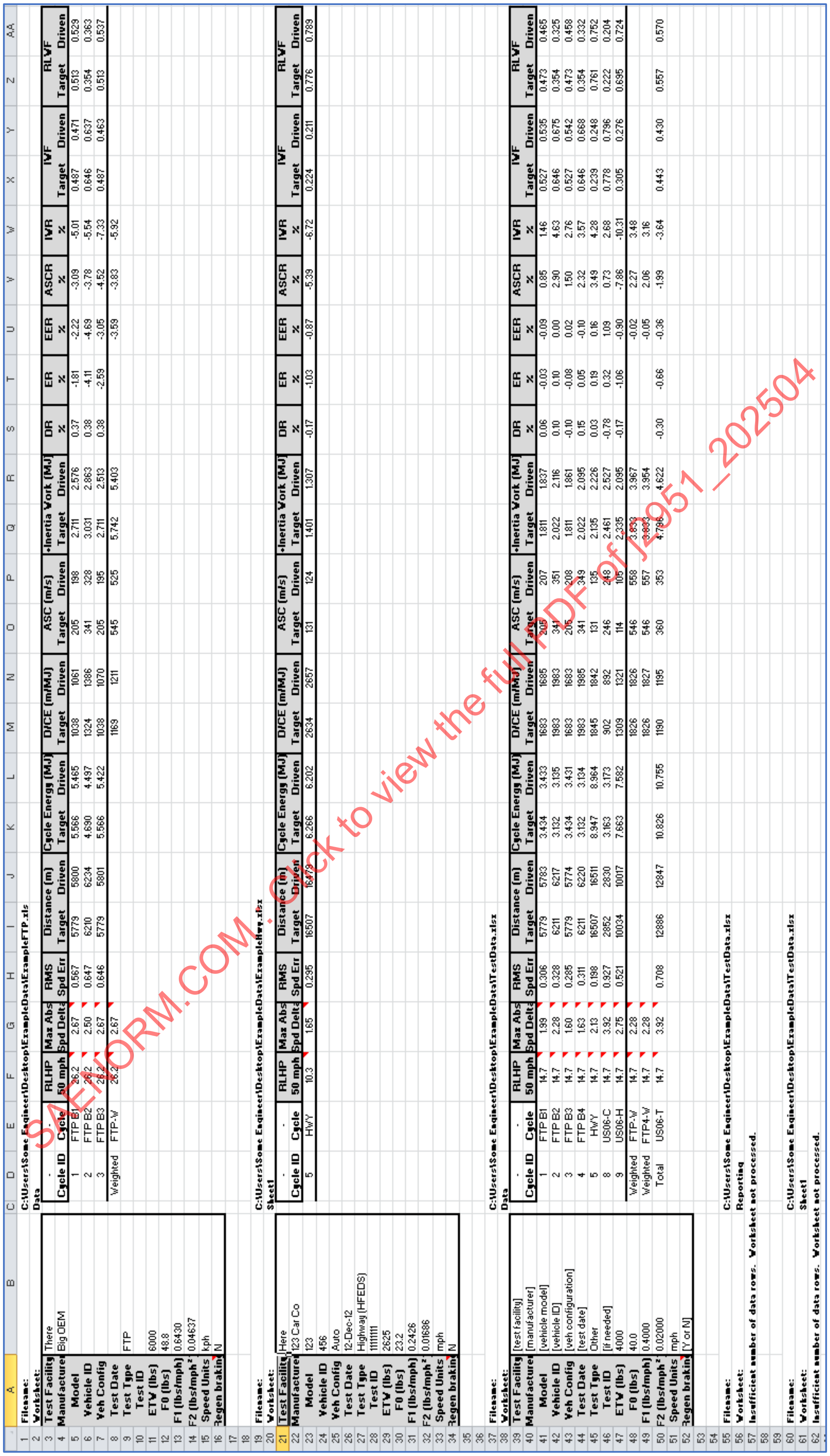
	A	B	C	D	E	F	G	H
1	Test Facility	*[test facility]*			**Time**	**Cycle ID**	**V_{ROLL_i}**	**V_{SCHED_i}**
2	Manufacturer	*[manufacturer]*		10Hz Data-->	*[0]*	*[cycle ID]*	[V_{ROLL_1}]	[V_{SCHED_1}]
3	Model	*[vehicle model]*			*[0.1]*	*[cycle ID]*	[V_{ROLL_2}]	[V_{SCHED_2}]
4	Vehicle ID	*[vehicle ID]*			*[0.2]*	*[cycle ID]*	[V_{ROLL_3}]	[V_{SCHED_3}]
5	Veh Configuration	*[veh configuration]*						
6	Test Date	*[test date]*						
7	Test Type	*[FTP, Highway, etc.]*						
8	Test ID	*[Test ID]*						
9	ETW (lbs)	*[xxxxx]*						
10	F0 (lbs)	*[xxx.xx]*						
11	F1 (lbs/mph)	*[x.xxxx]*						
12	F2 (lbs/mph^2)	*[0.xxxxx]*						
13	Speed Units	*[mph or kph]*						
14	Regen braking	*[Y or N]*						
15	*(For Cold FTP, F0,F1,F2 are multiplied by 1.1)*							
16								
17								
18								
19	**Sampled Phase Definitions**							
20	**Test Type**	**Test Phase**	**Cycle ID**					
21		FTP/FTP4 Phase 1	1					
22	FTP/FTP4	FTP/FTP4 Phase 2	2					
23		FTP/FTP4 Phase 3	3					
24		FTP4 Phase 4	4					
25	Highway*	Highway (HFEDS)	5					
26	SC03*	SC03	6					
27		Full Cycle	7					
28	US06*	US06 City	8					
29		US06 Highway	9					
30		Cold FTP Phase 1	10					
31	Cold FTP	Cold FTP Phase 2	11					
32		Cold FTP Phase 3	12					
33	for all tests*	Unsampled Phases	0					
34	**Report sampled phases only. Unsampled phases should be removed or identified by Cycle ID = 0*							

Figure B1 - File format for drive trace data

Table B1 - Cycle ID definitions for sampled phases

Test Type	Test Phase	Cycle ID
FTP/FTP4	FTP/FTP4 Phase 1	1
	FTP/FTP4 Phase 2	2
	FTP/FTP4 Phase 3	3
	FTP4 Phase 4	4
Highway	Highway (HFEDS)	5
SC03	SC03	6
US06	Full Cycle	7
	US06 City	8
	US06 Highway	9
Cold FTP	Cold FTP Phase 1	10
	Cold FTP Phase 2	11
	Cold FTP Phase 3	12
for all tests*	Unsampled Phases	0

* Unsampled phases are removed from the 10 Hz test data or identified by cycle ID = 0.



Filename: C:\Users\Some Engineer\Desktop\ExampleData\ExampleFTP.xls
Worksheet: Data

Test Facility	There
Manufacturer	Big OEM
Model	
Vehicle ID	
Veh Config	
Test Date	
Test Type	FTP
Test ID	
ETW (lbs)	6000
F0 (lbs)	48.8
F1 (lbs/mph)	0.6430
F2 (lbs/mph²)	0.04637
Speed Units	kph
Regen braking	N

-	-	RLHP	Max Abs	RMS	Distance (m)		Cycle Energy (MJ)		D/CE (m/MJ)		ASC (m/s)		Inertia Work (MJ)		DR	ER	EER	ASCR	IWR	IWF		RLWF	
Cycle ID	Cycle	50 mph	Spd Delta	Spd Err	Target	Driven	Target	Driven	Target	Driven	Target	Driven	Target	Driven	%	%	%	%	%	Target	Driven	Target	Driven
1	FTP B1	26.2	2.67	0.567	5779	5800	5.566	5.465	1038	1061	205	198	2.711	2.576	0.37	-1.81	-2.22	-3.09	-5.01	0.487	0.471	0.513	0.529
2	FTP B2	26.2	2.50	0.647	6210	6234	4.690	4.497	1324	1386	341	328	3.031	2.863	0.38	-4.11	-4.69	-3.78	-5.54	0.646	0.637	0.354	0.363
3	FTP B3	26.2	2.67	0.646	5779	5801	5.566	5.422	1038	1070	205	195	2.711	2.513	0.38	-2.59	-3.05	-4.52	-7.33	0.487	0.463	0.513	0.537
Weighted	FTP-W	26.2	2.67						1169	1211	545	525	5.742	5.403			-3.59	-3.83	-5.92				

Filename: C:\Users\Some Engineer\Desktop\ExampleData\ExampleHwy.xlsx
Worksheet: Sheet1

Test Facility	Here
Manufacturer	123 Car Co
Model	123
Vehicle ID	456
Veh Config	Auto
Test Date	12-Dec-12
Test Type	Highway (HFEDS)
Test ID	11111111
ETW (lbs)	2625
F0 (lbs)	23.2
F1 (lbs/mph)	0.2426
F2 (lbs/mph²)	0.01686
Speed Units	mph
Regen braking	N

-	-	RLHP	Max Abs	RMS	Distance (m)		Cycle Energy (MJ)		D/CE (m/MJ)		ASC (m/s)		Inertia Work (MJ)		DR	ER	EER	ASCR	IWR	IWF		RLWF	
Cycle ID	Cycle	50 mph	Spd Delta	Spd Err	Target	Driven	Target	Driven	Target	Driven	Target	Driven	Target	Driven	%	%	%	%	%	Target	Driven	Target	Driven
5	HWY	10.3	1.65	0.295	16507	16479	6.266	6.202	2634	2657	131	124	1.401	1.307	-0.17	-1.03	-0.87	-5.39	-6.72	0.224	0.211	0.776	0.789

Filename: C:\Users\Some Engineer\Desktop\ExampleData\TestData.xlsx
Worksheet: Data

Test Facility	[test facility]
Manufacturer	[manufacturer]
Model	[vehicle model]
Vehicle ID	[vehicle ID]
Veh Config	[veh configuration]
Test Date	[test date]
Test Type	Other
Test ID	[if needed]
ETW (lbs)	4000
F0 (lbs)	40.0
F1 (lbs/mph)	0.4000
F2 (lbs/mph²)	0.02000
Speed Units	mph
Regen braking	[Y or N]

-	-	RLHP	Max Abs	RMS	Distance (m)		Cycle Energy (MJ)		D/CE (m/MJ)		ASC (m/s)		Inertia Work (MJ)		DR	ER	EER	ASCR	IWR	IWF		RLWF	
Cycle ID	Cycle	50 mph	Spd Delta	Spd Err	Target	Driven	Target	Driven	Target	Driven	Target	Driven	Target	Driven	%	%	%	%	%	Target	Driven	Target	Driven
1	FTP B1	14.7	1.99	0.306	5779	5783	3.434	3.433	1683	1685	205	207	1.811	1.837	0.06	-0.03	-0.09	0.85	1.46	0.527	0.535	0.473	0.465
2	FTP B2	14.7	2.28	0.328	6211	6217	3.132	3.135	1983	1983	341	351	2.022	2.116	0.10	0.10	0.00	2.90	4.63	0.646	0.675	0.354	0.325
3	FTP B3	14.7	1.60	0.285	5779	5774	3.434	3.431	1683	1683	205	208	1.811	1.861	-0.10	-0.08	0.02	1.50	2.76	0.527	0.542	0.473	0.458
4	FTP B4	14.7	1.63	0.311	6211	6220	3.132	3.134	1983	1985	341	349	2.022	2.095	0.15	0.05	-0.10	2.32	3.57	0.646	0.668	0.354	0.332
5	HWY	14.7	2.13	0.198	16507	16511	8.947	8.964	1845	1842	131	135	2.135	2.226	0.03	0.19	0.16	3.49	4.28	0.239	0.248	0.761	0.752
8	US06-C	14.7	3.92	0.927	2852	2830	3.163	3.173	902	892	246	248	2.461	2.527	-0.78	0.32	1.09	0.73	2.68	0.778	0.796	0.222	0.204
9	US06-H	14.7	2.75	0.521	10034	10017	7.663	7.582	1309	1321	114	105	2.335	2.095	-0.17	-1.06	-0.90	-7.86	-10.31	0.305	0.276	0.695	0.724
Weighted	FTP-W	14.7	2.28						1826	1826	546	558	3.833	3.967			-0.02	2.27	3.48				
Weighted	FTP4-W	14.7	2.28						1826	1827	546	557	3.833	3.954			-0.05	2.06	3.16				
Total	US06-T	14.7	3.92	0.708	12886	12847	10.826	10.755	1190	1195	360	353	4.798	4.622	-0.30	-0.66	-0.36	-1.99	-3.64	0.443	0.430	0.557	0.570

Filename: C:\Users\Some Engineer\Desktop\ExampleData\TestData.xlsx
Worksheet: Reporting
Insufficient number of data rows. Worksheet not processed.

Filename: C:\Users\Some Engineer\Desktop\ExampleData\TestData.xlsx
Worksheet: Sheet1
Insufficient number of data rows. Worksheet not processed.

Figure B2 - Field locations for EBDM drive ratings