SAE INTERNATIONAL

SURFACE VEHICLE RECOMMENDED PRACTICE

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SAE Fuel Consumption Test Procedure (Engineering Method)

RATIONALE

Minor revisions and updates were noted during the standard review. In some paragraphs, simplification and clarity were added to aid the user in test setup, data collection, and analysis.

FORWARD

The demand for greater fuel efficiency drives continual comparison of vehicle configurations. While some configuration differences may have a small impact on fuel economy on an individual basis, they have a large impact on a total fleet operation. This has led to a growing need for an accurate procedure to determine the difference in fuel consumption between various vehicles. To address these needs, the SAE Truck and Bus Aerodynamics and Fuel Economy Committee sponsored the SAE Truck and Bus SAE J1526 Revision Task Force to revise and update this SAE Recommended Practice.

This SAE Recommended Practice describes fuel consumption test procedures for vehicle to vehicle testing only. The test procedure utilizes rigorous engineering procedures and accepted statistical analysis methods to determine the fuel consumption differences between commercial vehicles of classes three through eight or between trailers.

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1. SCOPE

This document describes a fuel-consumption test procedure that utilizes industry accepted data collection and statistical analysis methods to determine the difference in fuel consumption between vehicles with a gross vehicle weight of more than 10000 pounds. This test procedure can be used for an evaluation of two or more different vehicles but is not to be used to evaluate a component change. Although on-road testing is allowed, track testing is the preferred method because it has the greatest opportunity to minimize weather and traffic influences on the variability of the results. All tests shall be conducted in accordance with the weather constraints described within this procedure and shall be supported by collected data and analysis. This document provides information that may be used in concert with SAE Recommended Practices SAE J1264, SAE J1252, SAE J1321, and SAE J2966, as well as additional current and future aerodynamic and vehicle performance SAE standards.

1.1 Purpose

The purpose of this document is to provide a standardized test procedure to determine the difference in fuel consumption between test vehicles. Two or more vehicles may be compared simultaneously and directly or by non-concurrent (indirect) comparison through the use of an unchanging control vehicle. The method by which this is achieved is described in 4.9.

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 J1252 SAE Wind Tunnel Test Procedure for Trucks and Buses

SAE J1263 Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques

SAE J1264 Joint RCCC/SAE Fuel Consumption Test Procedure (Short Term In-Service Vehicle) Type 1

SAE J1321 Fuel Consumption Test Procedure - Type II

SAE J1594 Vehicle Aerodynamics Terminology

SAE J2084 Aerodynamic Testing of Road Vehicles - Testing Methods and Procedures

SAE J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques

SAE J2711 Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles

SAE J2881 Measurement of Aerodynamic Performance for Mass-Produced Cars and Light-Duty Trucks

SAE J2966 Guidelines for Aerodynamic Assessment of Medium and Heavy Commercial Ground Vehicles Using Computational Fluid Dynamics

R-430 Aerodynamics of Road Vehicles

Buckel, H., "Transit Bus Fuel Economy Test," SAE Technical Paper 810025, 1981, https://doi.org/10.4271/810025.

Surcel, M. and Michaelsen, J., "Fuel Consumption Tests for Evaluating the Accuracy and Precision of Truck Engine Electronic Control Modules to Capture Fuel Data," SAE Technical Paper 2009-01-1605, 2009, https://doi.org/10.4271/2009-01-1605.

2.2 Other Publications

Coleman, H. and Steele, G., “Experimental Validation and Uncertainty Analysis for Engineers,” 3rd ed., Wiley, 2009.

TMC Report, “Report of Frederick, Maryland, Truck and Bus Fuel Economy Demonstration, Conducted October 22-November 1, 1979, by the Joint TMC/SAE Task Force for In-Service Test Procedures of The American Trucking Industry,” November 1980.

RP 1102A TMC Fuel Consumption Test Procedure - Type II

RP 1103A TMC Fuel Consumption Test Procedure - Type III

RP 1109B TMC Type IV Fuel Economy Test Procedure

3. DEFINITIONS

ACCURACY: The extent to which a given measurement agrees with the standard value for that measurement. Accuracy cannot be determined for this test procedure because of the lack of a standard value.

ASTM: An international standards organization, known until 2001 as the American Society for Testing and Materials, which develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

AERODYNAMIC DEVICE: A structure or system on the exterior of the vehicle for altering the aerodynamic forces acting on the vehicle.

CARGO WEIGHT (CW): Equal to the gross vehicle weight minus the tare weight.

COLD START: The initial operation of the vehicle after 12 hours of no operation (including no engine idling).

CONFIDENCE INTERVAL: A range about the result which 95% of the population (i.e., repeated sample runs) will fall within when subjected to the same test conditions.

CONTROL VEHICLE (CV): A control vehicle obtains reference data for the test and is not modified in any way or used for any other purpose during the entire test.

COMBINATION VEHICLE: An equipment configuration that includes a separate power unit and at least one unpowered pulled vehicle (trailer).

COMPONENT: A component is defined as an individual part of the test vehicle or tractor or trailer or truck-trailer; i.e., tires, bumper, fairings, mirrors, etc. The tractor, truck, truck-trailer, trailer, or entire vehicle as a single entity is not a component.

DATA POINT (DP): The quantity of fuel consumed by a single vehicle during a run.

DIESEL EXHAUST FLUID (DEF): An aqueous urea solution used with selective catalytic reduction exhaust after-treatment systems to reduce NO_X emissions.

DIESEL OXIDATION CATALYSTS (DOC): A part of the exhaust system designed to remove harmful emissions from the exhaust gas of a diesel engine.

DRIVER: Operator of a vehicle.

DUTY/DRIVING CYCLE: The test cycle as defined by length in miles, number of complete stops, distance between stops, average road speed, road grade, engine on time, number of idle periods, length of total idle time and length of idle periods/stops, total time to complete the cycle, engine speed and accessories used during idle period, reverse driving, and any unique transmission shifting or operational activity during which time test fuel is consumed.

DPF REGENERATION EVENT, ACTIVE: An emission reduction event that may temporarily alter the vehicles fuel consumption rate and substantially increase the DPF outlet exhaust temperature in the range 200 to 300 °C above normal operating range.

DPF REGENERATION EVENT, PASSIVE: An emission reduction event that may alter engine operating parameters to oxidize diesel soot in the DPF. This may occur without substantially increasing DPF outlet exhaust temperatures as would occur during an active regeneration event. It may, or may not, affect the vehicles fuel consumption rate.

ENGINE RUN TIME: Time accumulated during which the engine is running. This includes all time whether consuming test fuel or not and may also include time between runs.

EXHAUST GAS RECIRCULATION (EGR): The recirculation of a portion of engine exhaust gas back to the combustion chambers for the purpose of reducing emissions.

FIFTH WHEEL: A pivoting coupling device attached to a leading vehicle or component of a combination vehicle that supports the front of a trailer.

FLOW METER: An instrument used to measure the flow rate or volume of a fluid.

FUEL WEIGH TANK (PORTABLE FUEL TANK, TEST TANK): An easily removable fuel tank.

GAP, AERODYNAMIC: Longitudinal distance between the aft most point of the cab external surface, including aerodynamic side fairings, and the forward most point of the cargo carrying portion of the trailer.

GAP, TRACTOR TO TRAILER: Longitudinal distance between the vertical flat surface of the back of the cab/sleeper to the vertical flat surface on the front of the trailer.

GASEOUS FLUID: A medium other than pure liquid.

GLOBAL POSITIONING SYSTEM (GPS): A device capable of measuring and/or displaying vehicle speed, latitude, longitude, and elevation using a system of satellites, computers, and receivers.

GROSS COMBINED WEIGHT (GCW): Applies to combination vehicles. The combination of the total weight of the tractor (powered unit), the total weight of the trailer, and the weight of the freight load.

GROSS VEHICLE WEIGHT (GVW): Applies to single unit vehicles. The total weight of a vehicle and the weight of the freight load.

GROSS VEHICLE WEIGHT RATING (GVWR): The maximum allowable total mass of a road vehicle when loaded including the weight of the vehicle, fuel, passengers, cargo, and trailer tongue weight.

MEAN: The sum of the sample values divided by the number of values.

NIST: National Institute of Standards and Technology.

OBSERVER: A passenger in the vehicle responsible for maintaining and recording various test operational conditions and assisting the driver. The observer may also perform checks of elapsed times and intervals between test vehicles.

ODOMETER READING: The distance (mileage or kilometers) accumulated by the vehicle as displayed on the odometer on the vehicles instrument panel.

OEM: Original equipment manufacturer.

ON-BOARD DIAGNOSTICS (OBD): A system which monitors emission related components to ensure compliant operation.

POWERED UNIT: The portion of the vehicle which includes the primary propulsion system.

PRECISION: The extent to which a given set of measurements of the same sample agree with their mean.

RUN (R): A complete and simultaneous circuit of the specified test route by the test vehicle(s) and the control vehicle (if used) or one test vehicle and the control vehicle when such test method is being conducted as described in 4.9. The run shall be completed without the occurrence of an equipment failure or malfunction, driver error, or a failure to obtain all required weather and operational data. Each run generates one data point for each vehicle.

RUN RATIO: The ratio of fuel efficiency (miles per gallon (mpg)), fuel quantity, or DEF quantity of one test vehicle divided by another test vehicle.

RUN TIME: The time required for a vehicle to complete a run. This may or may not include engine idling prior to and/or after actual vehicle movement.

SEGMENT: A minimum of three runs with the vehicles under test.

SEMITRAILER: Trailer supported at the rear by its own wheels and at the front by a fifth wheel mounted to a tractor or dolly.

SINGLE UNIT VEHICLE: A vehicle which has the powered portion and freight carrying unit mounted to the same chassis.

STANDARD DEVIATION: A measure of the spread or scatter of measurements around the mean of those measurements.

SELECTIVE CATALYTIC REDUCTION (SCR) AFTERTREATMENT SYSTEMS: A system which employs a chemical reductant fluid (referred to as diesel exhaust fluid (DEF)) in conjunction with a catalyst to convert nitrogen oxides into elemental nitrogen and oxygen.

TARE WEIGHT (TW): Weight of an empty vehicle with full fuel tanks, lubricants and trailer but without occupants or load.

TEST (T): A test is composed of two segments (Segment 1 and Segment 2) with sufficient valid data acquired from each test vehicle and the control vehicle when applicable.

TEST FUEL: Fuel consumed and measured/quantified during the test run.

TEST ROUTE—ON ROAD: The route shall be representative of the desired drive cycle under investigation. The route shall have minimal traffic to increase repeatability. For consideration, roadways using a cloverleaf at the turn around point will allow consistent and repeatable operation of both vehicles for every run. The route shall have a start and stop point at the same approximate geographical location.

TEST ROUTE—ON-TRACK: For on-track tests, a test route consists of a specified number of laps around the test track.

TEST TANK: The fuel source tank used during a test run.

THERMALLY STABLE FUEL CONSUMPTION: Fuel consumed while operating over the duty cycle with the vehicle in a thermally stable state. This state is achieved by conducting a vehicle warm-up drive.

TRACK (TEST TRACK): A continuous closed circuit that allows for the safe operation of test vehicles at the selected test speed over the complete track circuit. The track road surface shall be similar to that found on a U.S. highway.

TEST VEHICLE (TV): The vehicle(s) that are being compared.

TMC: The Technology and Maintenance Council of American Trucking Associations

TRACTOR: A vehicle designed primarily to pull a semi-trailer by the use of the fifth wheel which is mounted over its drive axle(s). May be called a highway tractor to differentiate it from a farm tractor.

TRAILER: A freight carrying unpowered unit pulled by a powered unit.

TRUCK: A vehicle which carries cargo in a body (van, tank, etc.) which is mounted to a chassis, possibly in addition to a trailer which is towed by the vehicle.

TRUCK-TRAILER: A truck-trailer combination consists of a truck that holds cargo in its body which is connected to its chassis, and which tows a trailer.

UNCERTAINTY: Having limited knowledge where it is impossible to exactly determine the true value, thus having more than one possible outcome.

VEHICLE CLASSES: Class of the vehicle based on gross vehicle weight (Table 1).

Table 1 - Vehicle classes weight range

Class	Gross Vehicle Weight	
	Pounds	Kilograms
Class 3	10001 to 14000	4536 to 6350
Class 4	14001 to 16000	6351 to 7258
Class 5	16001 to 19500	7259 to 8845
Class 6	19501 to 26000	8846 to 11794
Class 7	26001 to 33000	11795 to 14969
Class 8	33001 or more	14970 or more

VEHICLE RELATIVE VELOCITY (V): "V" is the sum of the vehicle velocity and the component of wind velocity along the longitudinal axis of the vehicle.

VEHICLE VELOCITY (VT): Velocity of the vehicle relative to the roadway.

WARM-UP: Operation of the vehicle for a specified duration over the duty cycle to achieve a thermally stable condition.

WIND ANGLE (Φ): Angle of the mean wind direction relative to the vertical center plane of the vehicle.

WIND VELOCITY (VW): The rate of motion of the air past a fixed point on the ground.

WIND GUST: A sudden and brief increase in wind velocity.

YAW ANGLE (Ψ): Is the effective wind angle experienced by the vehicle based upon vehicle ground velocity, wind velocity, and wind angle, relative to the vehicle heading.

4. TEST PREPARATION

NOTE: A separate file (Information Form) is provided for your convenience to document the test details.

4.1 Test Site

4.1.1 Test Track

A controlled test environment that has a closed loop test track is recommended for this procedure to minimize variations in the test results. Grades are acceptable; however, it should be noted they may affect the vehicles differently and the resultant fuel consumption. Track selection shall be consistent with the vehicle evaluation of interest. For instance, if the test vehicles normally run in relatively flat terrain, then it would be most representative to compare the vehicles on a track that is also relatively flat.

Track shape should also be considered when selecting a location. Since wind can affect vehicles differently, the shape of the track is preferably either oval or circular so that the effects of steady wind blowing in a constant direction are minimized.

NOTE: If the test vehicles normally operate in off-road soft surface type conditions, the road surface will have a significant impact and thus the test track road surface should match normal operating conditions.

4.1.2 Public Roadways

For on-road tests, a test route shall have a start and stop point at the same approximate geographical location (for instance, within 1/2 mile of each other to minimize the effect of any net elevation change). The route shall have minimal traffic to increase repeatability. The road surface may have a significant impact and thus the road surface shall represent the operating conditions for the vehicles under investigation. For consideration, roadways using a cloverleaf at the turn around point will allow consistent and repeatable operation of both vehicles for every run.

NOTE: If testing is chosen to be conducted on public roadways, be aware that the results may have a large variation due to uncontrollable factors such as traffic and changing weather patterns over the route. As a result, the statistically calculated confidence interval may be equally large and the results may show no differences between the vehicles. If test results obtained on public roadways produce statistical confidence interval results greater than the nominal difference between the vehicles or is greater than acceptable to the test operator, it is advised that the test be conducted on a test track. (See Appendix A for effects weather may have on the results.)

4.2 Test Speed

The test speed shall be representative of in-service operation and be within the capability of the test vehicles and road conditions. Vehicles are to be operated according to vehicle, engine, and transmission manufacturers' recommendations (engine speeds and shift points). If the test vehicles can be operated in more than one transmission gear or differential ratio over any part of the test run at the speed selected, a pre-determined driving procedure shall be specified and used for all vehicles to ensure repeatability. All vehicles shall be operated at the same duty/driving cycle test speed(s).

4.3 Drivers and Observers

Drivers selected shall be sufficiently skilled so that test results are not affected by the driver's technique improving during the test period. Drivers shall also have a strong motivation for unbiased results and excellence of test procedure conduct.

Observers may be assigned (but are not required) to each driver to record data and assist with complex driving cycles. The observer shall record elapsed times for each run overall and between any landmarks previously identified. Slight adjustments to the driving style between landmarks can be made during a run to meet the elapsed time profile but care shall be taken as to not attempt to make up relatively large amounts of time. Doing so may adversely affect the fuel consumption and thus affect the results.

4.4 Fuel Source

Fuel used for the test shall be from a single dedicated source that is large enough to complete the test without refilling. To ensure all vehicles are powered with identical fuel, all fuel in the vehicles test tanks prior to testing shall be removed to less than 1% by volume and then be refueled from the dedicated source. It is acceptable to combine the fuel removed from the vehicles with the dedicated source provided all fuel is combined and mixed prior to any filling for testing.

4.5 Fuel Measurement

The only two methods approved for measuring the fuel consumed during a test are gravimetric (direct measurement of the weight of the fuel consumed) and volumetric by flow meter. The chosen method shall not change during a test. See more information in 4.6.

4.5.1 Gravimetric

With this method, a scale is used to weigh the portable fuel tanks both before a run (when full of fuel) and after a run (after fuel has been consumed from the tank). The difference between the pre-run and post run weight is therefore the amount of fuel used for the run. The weight of the fuel consumed for a run can then be converted to volume if desired by using a density value which may be obtained using a standard scientific and/or engineering method or from the fuel supplier.

4.5.2 Volumetric by Flow Meters

The volumetric method utilizes fuel flow meters placed in-line between the on-board fuel tank and the engine. The volume of fuel consumed during the run is measured by the meter. Because volumetric measurement of a fluid changes with its temperature, a thermal coefficient of expansion calculation shall be used to correct for density changes.

Data collection rate for the flow meter shall be at least 1 Hz (one measurement per second) and the thermal coefficient of expansion calculation shall be applied to each data point.

CAUTION: Applying a thermal coefficient of expansion calculation to the entire volume of fuel utilizing only the beginning and ending fuel temperatures will produce inaccurate results.

Return flow from the engine needs to be either measured separately from the supply flow, or (ideally) introduced back into the supply flow, beyond the flow meter, after being cooled. The latter method requires only one flow meter, which measures the actual amount of fuel being consumed by the engine.

Engines that introduce a large amount of gaseous fluid in the return flow may be problematic to measure fuel consumption, unless a separator is introduced into the system. Additionally, flow meters may not be suitable for engines with very high return flow.

4.5.3 Other Methods

Volumetric measurement of fuel in the tank and/or as metered from a fuel dispensing nozzle shall not be used because it is not sufficiently accurate even when compensated for thermal expansion to meet the intentions of this procedure. Additionally, the data obtained from the engine electronic control module (ECM) shall not be used because it is not sufficiently accurate or repeatable to meet the intentions of this procedure.

4.6 Test Equipment

All instrumentation used in the test process shall have valid NIST traceable calibration records and all fuel consumed shall meet all applicable ASTM standards for the intended fuel application. All instrumentation type, specifications, calibration information, and placement in regards to weather measurement instrumentation shall be documented.

4.6.1 Fuel Tank (for Use with Gravimetric Fuel Measurement Method)

An easily removable fuel tank shall be appropriately sized to complete a test run without risk of inducing air into the fuel lines as a result of low fuel. A good rule of thumb is that the fuel tank should contain approximately two times the estimated fuel necessary to complete a run. Adequate tank volume should also be allowed for thermal expansion of the fuel. The tank should be fitted with quick disconnect fuel lines so that it can be removed from the vehicle for weighing. The supply and return lines should be adequately spaced to ensure gaseous fluid does not enter the supply line as a result of gaseous fluid in the return line.

Installing two or more removable tanks per test vehicle can be used to save time between runs. This can substantially reduce the stopped time between test runs while tanks are switched. To prevent error in tank switching, they should be color coded and/or numbered. Having these tanks simultaneously installed on the vehicle so that only the lines are diverted from one tank to another will further reduce the stopping time between runs.

The installation of the tanks shall affect all vehicles equally by weight and aerodynamics. This can be minimized by ensuring all tanks are identical in construction and installation.

4.6.2 Fuel Cooler

A fuel cooler/radiator capable of maintaining the temperature of the fuel in the tank below the engine OEMs maximum allowed temperature (normally 160 °F per engine OEM recommendations, but should be validated by the engine OEM) may be required. Failing to keep the fuel temperature below the maximum allowed value may trigger an engine derate strategy which will affect the fuel consumption. The cooler shall be located in a manner to obtain the necessary air flow while minimizing the aerodynamic impact on the vehicle. Pressure drop across the fuel cooler shall not impede flow to a point where the manufacturer specified delivery pressure and volume is not maintained which may result in a performance derate condition. An alternative to a fuel cooler may be to increase the volume of the fuel tank so that the return fuel does not overheat the source fuel.

4.6.3 Scale (for Use with Gravimetric Fuel Measurement Method)

A single calibrated digital scale having sufficient capacity and capability to accurately weigh the portable fuel tanks throughout the full range of tested fuel levels shall be used for all tank weight measurements.

The scale shall have a display resolution of no more than 0.1% of the minimum fuel consumption value for a test run. The scale shall be verified by calibration to be accurate within ±0.25% of the measurement range observed throughout the test.

To minimize measurement error, the scale manufacturer's recommendations shall be followed for leveling, warming of electronics, and zeroing; weight measurements shall be recorded immediately after the display has settled to a final value; the scale shall be shielded from wind and/or drafts as they will cause unstable and/or biased measurement values; and portable fuel tanks shall be placed on the scale platform in the same location and orientation.

A calibration weight within the range of tank weights shall be used to verify the scale repeatability prior to each sequence of measurements.

4.6.4 Flow Meters

A positive displacement flow meter intended for gasoline or diesel fuel may be used if it has sufficient capacity and capability to accurately measure fuel flow and volume throughout the full range of vehicle operating conditions. It is required that the values obtained from this instrument are temperature compensated per the fuel temperature at the inlet to the flow meter and at the data collection rate. The data collection rate for the flow meter shall be at least 1 Hz (one measurement per second) and the thermal coefficient of expansion (temperature compensation) calculation shall be applied to each data point.

CAUTION: Applying a thermal coefficient of expansion calculation to the entire volume of fuel utilizing only the beginning and ending fuel temperatures will produce inaccurate results.

All flow meter systems shall be calibrated and accurate within ±0.25% of the reading throughout the measurement range of flow rates. Depending on the method of evaluation being conducted, the meter may or may not require swapping between vehicles (see 4.9 for clarification). Swapping may be omitted if all flow meters can be proven to measure the same quantity and report a value within 0.25% of each other.

NOTE: To ensure a gross error did not occur with the installation of the flow meter and data acquisition system, a validation check should be performed. This can be accomplished by comparing the flow as measured by the meter to actual flow as measured using either a graduated container or gravimetric tank. The accuracy and resolution of the equipment used to perform this validation will affect the precision of the comparison.

If using a graduated container, record the dispensed volume of fuel and its temperature for comparison purposes. Depending on the flow meter system, the dispensed volume may be corrected to the industry standard value of 60 °F (15.6 °C). For instance, if the fuel in the container is at 80 °F (27.7 °C), a 1 gallon change as indicated by the graduated container may be reported by the flow meter as less than 1 gallon. The formula used to determine a correction factor for thermal expansion of a liquid will affect the comparison. If possible, it is best to use the same formula and calculation process as the meter system.

If using a gravimetric tank to perform the "as installed" validation check, the density of the fuel sample shall be precisely known to avoid errors when converting volume to mass.

CAUTION: Be aware that flow meters are typically calibrated at steady state conditions and typically have a varying accuracy at different flow rates. Ensure that the calibration is performed in the range of the expected flow rates. Additionally, because actual fuel consumed by the engine will include many transients throughout the range, a more complete and useful calibration curve would include such transients. Because of these inherent potential errors in the accuracy of a flow meter, the most accurate comparisons can thus be achieved under steady state conditions.

4.6.5 Weather Measurement Station(s)

Wind speed, wind direction, and true air temperature (shielded from direct sun light or sources of thermal radiation) shall be measured and recorded throughout the test at a minimum sampling rate of one sample/minute. It is recommended that weather measurements be obtained at multiple locations but is not required. (See Appendix A for effects weather may have on the results.)

The device and its location shall meet the following requirements:

a. The weather measurement station(s) shall have accuracies within ±1.5 mph for wind speed, ±5 degrees for wind direction, and ±1 °F for temperature.

b. The weather measurements shall be obtained at an elevation distance above the road surface that is greater than 4 feet and not more than 30 feet.

c. The measurement devices shall be located in an open area such that they are not influenced by vehicles or other obstacles and shall not be shielded from above or from the wind in any direction.

d. Good engineering judgment shall be used when determining the weather measurement location along the route.

4.7 Wind Speed Normalization and Weather Constraints

See Appendix A for more information.

4.7.1 Wind Speed Normalization

To ensure consistency in the application of the wind speed test criteria, all wind speed measurements shall be corrected to a height of 10 feet using the 1/7th power law relationship shown in Equation 1.

$$V_{W,10} = V_M\,(10/H_M)^{1/7} \quad \text{(Eq. 1)}$$

where:

$V_{W,10}$ = the test reference wind speed at 10 feet above the road surface

V_M = the measured wind speed

H_M = the elevation height for the wind measurement

Listed in Table 2 are scaling factors to correct wind speed measurements obtained at a height other than 10 feet to a test reference wind speed at 10 feet above ground level.

Table 2 - Wind speed normalization per height above ground

H_M (feet)	Scale Factor	H_M (feet)	Scale Factor
4	1.140	14	0.953
5	1.104	15	0.944
6	1.076	16	0.935
7	1.052	18	0.919
8	1.032	20	0.906
9	1.015	22	0.893
10	1.000	24	0.882
11	0.986	26	0.872
12	0.974	28	0.863
13	0.963	30	0.855

EXAMPLE: A wind speed (V_M) of 10.50 mph is obtained at a measurement height (H_M) of 5 feet above ground level. The corrected wind speed at 10 feet above ground level is:

$$V_{W,10} = V_M \times H_M = 10.5 \times 1.104 = 11.59 \text{ mph}$$

4.7.2 Weather Constraints

Weather data of each run shall be reviewed to ensure the constraints listed in Table 3 are not violated. Measured wind speed conditions shall be normalized per 4.7.1 before being compared to the requirements.

Table 3 - Weather constraints

Criteria	Requirements
Mean wind speed during a run	≤12 mph (19 km/h)
Mean wind speed change between segments and between runs	≤5 mph (8 km/h)
Max wind gust	15 mph (24 km/h)
Allowable temperature range	40 to 100 °F (4 to 38 °C)
Temperature change within a test	≤30 °F (17 °C) (e.g., 50 to 80 °F (10 to 27 °C) within a test)
Rain	None allowed

For a more complete understanding of the difference between two vehicles, additional complete tests should be conducted under different weather conditions within these constraints.

CAUTION: Wind direction will have an impact on aerodynamics and thus fuel consumption. The requirements in Table 3 are intended to minimize such affects but are not all encompassing. For example, although wind speed may be similar between runs and/or segments, different wind directions may produce significantly different yaw angles and thus could increase test result variability. Therefore, to minimize data variability, wind direction and wind speed of all runs and segments should be similar.

4.8 Test Vehicles

This procedure is to be used to evaluate the difference in fuel consumption between vehicles for a given drive cycle with no requirements for the vehicles to be similar in any manner.

It should be noted that large differences in vehicle type (external geometry and/or powertrain) may adversely affect the test repeatability of the measured differences between vehicles. It should also be noted that many factors affect fuel consumption and those factors shall be identical between the vehicles if their impact is not the objective of the comparison.

If the intent of a test is to evaluate a specific difference between vehicles such as vehicle aerodynamics, driveline configurations, or vehicle setup (e.g., trailer gap, engine parameters, etc.), it is suggested that all other vehicle components and setups be as similar as possible to minimize their impact on the test results. For example, if two tractors are being compared, the trailers connected to each tractor shall be of the same manufacturer, type (for instance, reefer versus reefer or dry van versus dry van), tire manufacturer and model and tread depth, aerodynamic features (side skirts, boat-tail, front of trailer fairing, etc.), trailer height, door type, exterior surface roughness, undercarriage, bogies, brakes, etc. Equally important, if two trailers are being compared, the tractors connected to each trailer shall be of the same manufacturer and model (for instance, high roof sleeper versus high roof sleeper or day cab versus day cab), tire manufacturer and model and tread depth, aerodynamic features (side fairings, roof fairings, bumpers, etc.), wheel base, mirrors, axle types, etc.

4.8.1 Vehicle Checklist

In general, each vehicle shall be checked for proper operating condition prior to testing. The following is not an all-inclusive list of items that should be checked, but it does give a direction on the type of items that can have an effect on the results.

a. Vehicle wheel and axle alignment checked and proper.

b. New air cleaner element and fuel filters are recommended.

c. Each vehicle properly lubricated prior to test. All fluid levels should be checked and be at prescribed levels.

d. Cold tire pressures measured and inflated to vehicle or tire manufacturer standard. Tire pressures need to be set at the beginning of the day following overnight cold soaks. Ensure solar loading on all tires is consistent prior to adjusting pressures.

e. Tread depth of all tires measured and recorded.

f. A stall check made on vehicles equipped with automatic transmissions and torque converters.

g. Exhaust system free of mechanical and operational defects.

h. Proper brake adjustment.

i. Odometers and speedometers should be validated to ensure vehicle speed accuracy. Methods to determine accuracy may be: (1) measure the actual revolutions per mile of the drive tires and adjust the appropriate electronic parameters to match, (2) measure the elapsed time to complete a predefined distance, or (3) use a GPS capable of measuring road speed within 0.1 mph. If the speedometer is not accurate, then a vehicle speed adjustment may be necessary to match the indicated speed to the actual speed.

j. Mile per gallon (mpg) displays should be turned off or covered up. Such information can potentially alter the driver habits.

k. The fuel lines of the measurement system shall be purged of air.

l. The installation of the fuel measurement system shall not adversely affect the mechanical or aerodynamic performance of the vehicle.

The following items should not only be checked prior to testing but should also be checked before each run. The pre-run checks need not be as extensive as during the initial vehicle preparation but can be conducted as a general observation.

a. Cab windows for all vehicles are closed. If windows are open, the openings shall be the same in each vehicle for the entire test. For transit buses, all windows shall stay the same (open or closed) for entire test.

b. Accessory loads for each vehicle as consistent as possible (for example, by turning air conditioning off or to the same setting, defroster off, blower speed at the same setting, and lights on).

c. Fully functional engine and aftertreatment systems without diagnostic trouble codes or other engine/emission service indicators illuminated (MIL, DEF).

d. All emission aftertreatment components shall be in proper working condition. Vehicles that rely on a reductant chemical (e.g., DEF) to control pollutants shall have sufficient volume on board to complete all testing.

e. Temperature controlled fan drives shall be set to the same operating mode throughout the test.

f. Entire vehicle clean and free of damage or missing body parts.

g. Free of brake air system leaks.

h. Full air tank pressure.

i. Oil pressure and no oil leaks (engine, transmission, axles, etc.).

j. Coolant temperature and no coolant leaks.

k. No excessive exhaust smoke.

l. Observed ability to maintain selected test speed.

m. Aftertreatment condition, i.e., state of DPF loading and regeneration state. Drivers should note dash displays that indicate or broadcast regeneration state or a DPF illuminated before keying off.

n. Check/investigate all vehicle diagnostic caution and warning signals/alarms and resolve all vehicle operational concerns prior to proceeding with the test.

o. Engine brake on the same setting—preferably off.

p. Diesel particulate filter regeneration switch off (if equipped)

4.8.2 Break-in

To ensure overall vehicle break-in is not greatly affecting the results, all test vehicles, including the control vehicle if used, shall have at least 500 miles on the odometer. In the case of testing new vehicles or vehicles with new tires, the tires shall have a minimum of 500 miles of use.

All vehicles tested shall conform to the rules in Table 4.

Table 4 - Vehicle mileage requirements

Case	Maximum Odometer Difference
The odometer on all vehicles is less than 10000 miles (8050 km)	2000 miles (3219 km)
The odometer on all vehicles is greater than 10000 miles (16093 km) but less than 30000 miles (48280 km)	4000 miles (6437 km)
The odometer on all vehicles is greater than 30000 miles (48280 km) but less than 100000 miles (160934 km)	8000 miles (12875 km)
The odometer on all vehicles is greater than 100000 miles (160934 km)	50000 miles (80467 km)

If the test vehicles reside in different mileage groupings, then the tighter mileage delta constraint shall apply.

EXAMPLE 1: If the odometer on Vehicle A is 8000 miles while the odometer on Vehicle B is 11000, then Vehicle A shall accumulate miles to be within 2000 miles of Vehicle B; thus, 9000 or more miles for Vehicle A. In this case, the vehicles reside in two groupings at the start of the test.

EXAMPLE 2: If the odometer on Vehicle A is 24000 miles while the odometer on Vehicle B is 35000, then Vehicle A shall accumulate miles to be within 4000 miles of Vehicle B; thus, 31000 or more miles for Vehicle A. In this case, the vehicles are now in the same grouping.

4.8.3 Weight and Distribution

Weight and distribution is dependent upon the evaluation being conducted. The following are two types of possible comparisons and the associated considerations for each.

4.8.3.1 Identical cargo weights automatically places a weight penalty on the vehicle with the greatest tare weight. This is best for evaluating not only how the vehicle configurations differ but also how the weight difference of the vehicles has an effect on fuel consumption. Axle weight distribution in this case is dependent upon the cargo weight distribution. The cargo weight distribution in each case shall be as close as possible but preferably identical. This simulates the condition where the two different vehicles carry the same payload.

4.8.3.2 Identical gross vehicle weight takes the vehicle weight effect out of the evaluation and is best for evaluating conditions where the vehicle, in actual operations, would perform as if at a similar vehicle weight condition. Weight distribution on the axles of the vehicles shall be matched as closely as possible. If the weight distribution cannot be matched between the vehicles, the difference on each axle load shall be ≤5% or ≤500 pounds, whichever is less. Total gross vehicle weight differences between the vehicles shall be less than 200 pounds. In the case of combination vehicles where trailers are swapped between segments, the weight shall be adjusted to maintain the appropriate distribution. This can be accomplished using smaller ballast type weights that can be easily repositioned.

4.8.4 Aftertreatment Preconditioning

Vehicles equipped with advanced aftertreatment systems such as diesel particulate filters (DPF), lean NO_X traps, catalysts (LNT, LNC), selective catalytic reduction (SCR) systems, or others not mentioned require aftertreatment preconditioning per the vehicle manufacturer's recommendations and/or procedures before conducting each test sequence or even before each run depending on the run length. The objective of the process is to minimize variability due to increases in exhaust backpressure as a result of soot loading which may result in regeneration events and associated increase in fuel consumption.

The DPF preconditioning consists of a stationary forced regeneration using a service tool or other passive regeneration methods recommended by the engine or aftertreatment manufacturer.

(See Appendix B for additional information on advanced aftertreatment systems and Appendix C for test strategies.)

4.8.5 Vehicle Warm Up

Test vehicles shall be operated at vehicle test speeds for 1 hour prior to the start of a test segment to insure that the vehicles achieve stabilized operating conditions in all components. A test run shall begin within 45 minutes or within a time period equal to 30% of the time to complete a run, whichever is less. (See Table 5 for a quick reference guide.) If commencement of a run within the allowed time is not possible, additional warm-up time shall be conducted per Equation 2 in 5.2.3.

If the objective of the test is to measure the fuel consumption difference between vehicles during warm-up, all vehicles shall not be operated for a minimum of 12 hours prior to starting each run.

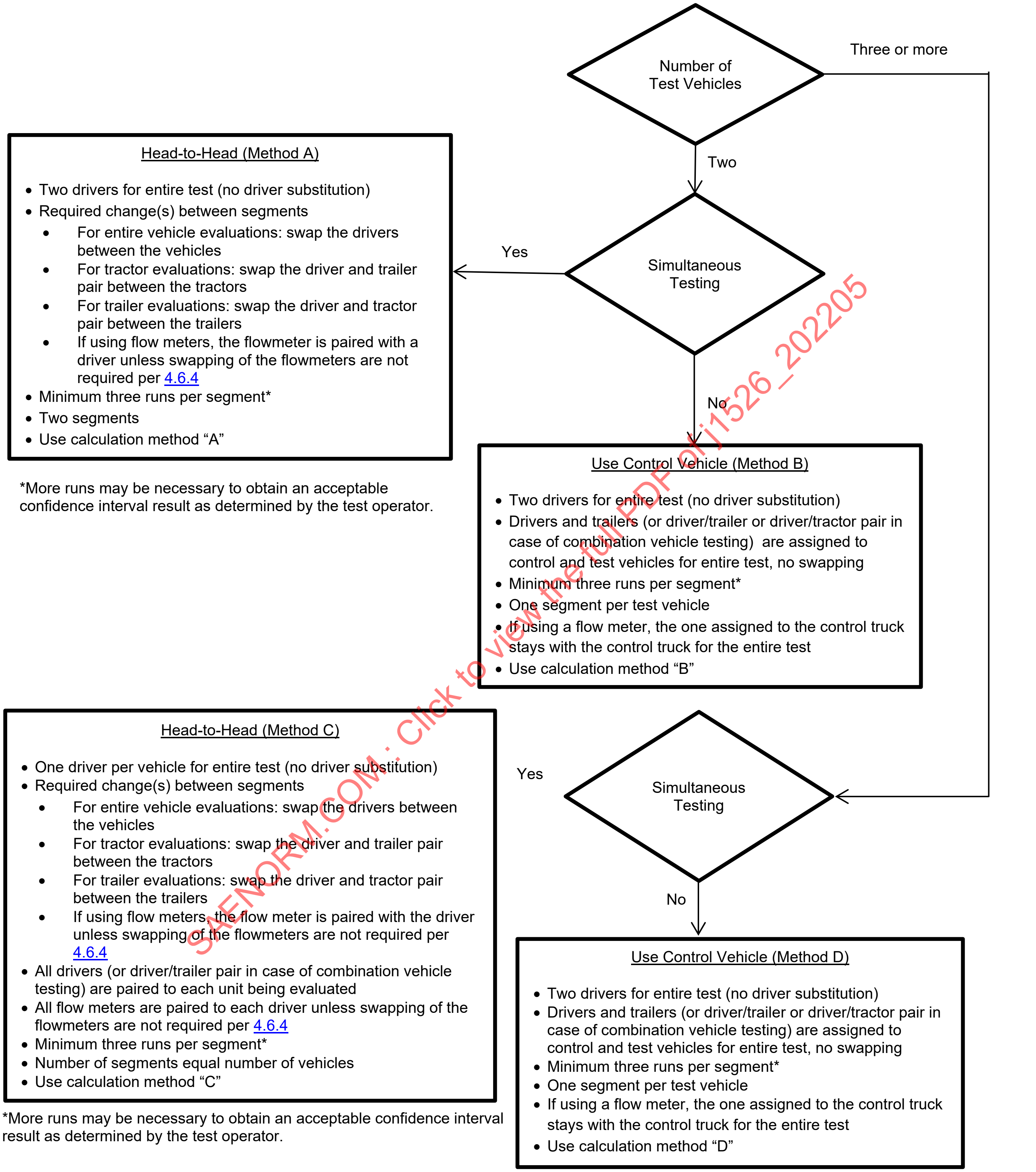
NOTE: To minimize test run variability through precise duplication of the drive cycle from run to run, it is recommended that during the warm-up process each driver and observer (if used) should note the precise location where brakes are used and for how long, where shifting of gears occur, and areas of acceleration and deceleration.

4.9 Vehicle Test Comparison Method(s)

Simultaneous (head-to-head) testing is recommended; however, if it is not possible to evaluate all vehicles simultaneously, use the flow chart to determine the test comparison method.

NOTE: Each test may only use one of the four comparison methods depicted in the following flowchart.

Comparison Method Selection Flowchart



For methods B and D, the control vehicle shall not be modified in any way or used for any other purpose during the entire test. The mileage break-in requirements described in 4.8.2 shall be adhered to throughout the entire test. To minimize potential undetectable differences in performance of the control vehicle as a result of sitting unused between tests for relatively long periods of time, it is highly recommended that all tests be conducted within three months. In the case that testing cannot be completed within three months, a complete mechanical functional check and performance evaluation shall be conducted which shall include the following: (1) the fuel shall be drained and the tanks filled from the same source at the time the test truck is filled, (2) the engine oil and filters should be considered for changing, (3) and a complete vehicle check and test setup as described in 4.8 shall be performed.

5. TEST PROCEDURE

This section defines the basic steps to execute the test process and offers example procedures to perform each step.

Results from different tests that do not use the same procedures to perform each step are not equivalent and shall not be compared.

NOTE: The provided analysis spreadsheet is intended to supplement the SAE J1526 procedure. The data analysis calculations are detailed in Appendices C, E, and F of the document.

5.1 General Information

The overall objective is to determine differences in fuel consumption between warmed up vehicles while operated under identical drive cycles without excessive soot loading in the DPF and without active DPF regeneration (DPF regeneration system turned off or disabled). If an active DPF regeneration occurs during a run, the run will be invalid and shall be removed from the test data set. If the user lacks the capability to monitor appropriate regeneration messages over the CAN data bus, the exhaust temperature exiting the DPF can be measured to determine occurrence of an active regeneration event. Active regeneration is indicated by a significant temperature rise above typical exhaust temperature values measured during a run (usually increase in the range of 200 to 300 °C above nominal operating temperatures) and it may also be indicated by an increase in fuel consumption although it may not be obvious from the Run ratio of the affected run. (See Appendices B, C, and D for additional information on advanced aftertreatment systems and test strategies.)

NOTE: Since the introduction of DPF systems, the general trend has been toward more frequent passive regeneration events and less frequent active regeneration events. Passive regeneration events occur regardless if the active DPF regeneration system is disabled. Thus, disabling or turning off the active DPF regeneration system may result in an unintentional penalty against the vehicle which operates with more frequent passive regeneration events. Without OEM software tools, detecting passive regeneration events may be impossible. Therefore, awareness of this risk should be understood when comparing the fuel consumption of different emission level vehicles of the same or different manufacturers (i.e., 2017 emission system in a 2020 vehicle versus a 2021 emission system of the same manufacturer and vehicle model but of a 2021 vehicle).

The test vehicles are run according to the selected method per the flowchart in 4.9 on the test track (or public road). At least three runs per segment are required; however, additional runs may be necessary to achieve an acceptable confidence interval. During each run, the vehicles shall be spaced at a distance of at least 1500 feet. Be aware that distance from other non-test vehicles on public roads will have an influence on the test results. Each run shall have the same length, shall be greater than 50 miles, shall be completed without the occurrence of equipment or driver malfunction, shall be completed without a failure to obtain the required weather data, and shall start and end at the same geographical location. Maximizing the use of cruise control while also minimizing or eliminating downshifting, if at all possible, will obtain the highest repeatability and thus the lowest uncertainty of each run and ultimately the test results. The use of the throttle pedal vehicle speed limiter for speed control is not recommended for reasons which included, but are not limited to, ensuring the drivers foot does not lift during the run can be challenging and may result in run time variations and fuel consumption repeatability issues; some truck OEMs have a feature which provides additional engine power for passing when a 100% throttle pedal is detected (in this case, if the driver is continually at 100% throttle to maintain the speed limiter, the engine may consume more fuel than normal), and some engines may perform differently at the speed limiter in comparison to being in cruise control and therefore the fuel consumption may be affected.

The following is a general outline of the test process. Details of the steps are explained in 5.2.

Step:

1. Prepare for Segment 1.
2. Conduct Segment 1 evaluation.
3. Prepare for Segment 2.
4. Conduct Segment 2 evaluation.
5. Analyze and publish the results.

Test results are valid only for the vehicle configurations, test conditions, and duty cycle under which the test was conducted. Different vehicle configurations, test conditions, and/or duty cycles may produce different results.

5.2 Test Process

5.2.1 Vehicle Preparation for Segment 1

a. Prepare the vehicles as described in 4.8.

b. Precondition the DPF and allow the vehicles to cool to ambient temperature or at least 12 hours before continuing with the warm-up.

c. Record the odometer readings before the vehicle warm-up.

d. Warm-up the test vehicles.

e. Fill and weigh the test tanks.

f. Record the odometer reading after the vehicle warm-up.

g. Commence with Test Segment 1.

5.2.2 Test Segment 1

5.2.2.1 Run Start

The start of a run for a given vehicle is commenced with (1) the consumption of fuel from the test tank or, if applicable, (2) a point in the recorded flowmeter data set which is identified as the start of the run. Simultaneously, a timer is started to record the run time. The method by which fuel begins to be consumed from the test tank shall be identical throughout the test and for each test vehicle.

To ensure the minimum spacing between vehicles (see 5.1), each vehicle subsequently begins the run with an adequate time interval after the previous vehicle.

The following are two possible methods to start a run. Others may be equally valid.

Example A Step 1: Switch the fuel lines to the test tanks. Step 2: start the engine and run timer. Step 3: after a 60 second idle period, begin accelerating the vehicle to test speed. The subsequent vehicle(s) follow(s) the same sequence of events (steps 1, 2, and 3) after a waiting period to ensure the minimum spacing between vehicle(s).

Example B All vehicles start the engines and run timers at the same time. The first vehicle departs on the test route. The subsequent vehicle(s) sit and idle while waiting a fixed time period to ensure a minimum spacing between vehicles.

5.2.2.2 Run End

The end of a run for each vehicle concludes with the stoppage of fuel consumption from the test tank. Simultaneously the timer is stopped which is recording the run time for that given vehicle. The method for fuel stoppage shall be identical throughout the test and for each test vehicle.

The following are two possible methods to end a run. Others may be equally valid.

Example A Step 1: placing the vehicle in neutral at a landmark and applying the brakes to bring the vehicle to a stop.* Step 2: idling the engine for 60 seconds. Step 3: stopping the engine and run timer then immediately disconnecting the fuel lines.

*The purpose of placing the vehicle in neutral ensures that the engines experience the same loading while coming to a stop.

Example B Step 1: placing the vehicle in neutral at a landmark and applying the brakes to bring the vehicle to a stop. Step 2: the returning truck(s) idles while waiting for the other truck(s) to arrive. Step 3: All vehicles turn off the engines and run timers simultaneously.

Whichever starting and ending methods are used, the total idling time during a run (at the start plus at the end of the run) shall be equal for all the vehicles.

The first segment is considered complete after a minimum of three runs is completed and after the result variability is acceptable to the test operator.

5.2.3 Events Between Runs

a. Tank weigh and refill: At the end of a run, the test tanks are weighed and the weight is recorded. The test tanks are filled, reweighed, and prepped for a subsequent run. The amount of fuel consumed during the run is the difference between the beginning and ending weight of the test tank. (In the case of fuel flow meters, the fuel consumption value is simply recorded and the meter is prepped for the subsequent run.) (See 4.5 for information regarding fuel measurement methods.)

b. Record the odometer reading.

c. Run time difference calculation: The time for each vehicle to complete a run (run time) shall be within 0.5% of the largest run time for the same vehicle within the same segment. If comparing identically configured vehicles, the run time difference between the fastest and slowest vehicle shall not be greater than 0.5% for any given run based on the largest run time vehicle. Runs that do not fall within these constraints are invalid and shall not be included in the results.

d. Driver/observer questioning: All drivers and observers (if used) shall be questioned to ascertain any differences in the apparent handling, power, and/or braking characteristics of their respective vehicles and their comments shall be noted. If damage or an event occurred to the vehicle during the run that would affect the fuel consumption, the data shall be discarded and documented as such.

e. Vehicle check: The vehicles shall be given a quick overall check for abnormality (see 4.8).

f. Time constraint: The time required performing the preceding steps results in a cooling down of the test vehicles and care shall be taken to insure that the cool-down periods are near identical for all vehicles between all runs. The maximum allowed cool-down period shall be the lesser of 45 minutes or a time period equal to 30% of the time to complete a run. Table 5 can be used as a quick reference guide.

Table 5 - Maximum allowed cool down time

Max Allowed Cool Down Time	
Run Time [min]	30% of run time (up to max of 45 min)
45	14
60	18
90	27
120	36
150	45
180	45
...	45
...	45

If the start of a subsequent run within the allowed time is not possible, additional warm-up time shall be conducted per Equation 2.

$$\text{Additional warm-up time} = \text{Actual cool down time} - \text{Allowed cool down time} \quad \text{(Eq. 2)}$$

EXAMPLE: If the run time is equal to 60 minutes, the maximum allowed cool down time is 18 minutes. If the actual cool down time is 35 minutes, then the additional warm-up (driving) time required shall be no less than 35 - 18 = 17 minutes.

Suggestions to minimize the cool-down period: (1) The tank weigh and refill process can be shortened by having a second set of marked fuel tanks so that the cool down period is kept to a minimum by simply swapping the empty fuel tanks with full tanks. (2) The run time difference calculation can be performed after the vehicles have begun the subsequent run. (3) The vehicle check can be performed simultaneously with the driver/observer questioning provided sufficient personnel are available such that key vehicle checks are not inadvertently overlooked.

a. Optional driver swap between runs: For methods described in 4.9 where swapping of drivers and paired trailers and/or flowmeters is required between segments, it should be noted, although not required per this procedure, that swapping between runs of a segment will produce data with an evenly distributed effect throughout the segment and test. If swapping between runs is implemented, the minimum number of runs per segment shall be four and swapping shall occur in both segments. For clarification, runs will be conducted in the following manner:

   - Segment 1 Run 1
   - Segment 2 Run 1
   - Segment 1 Run 2
   - Segment 2 Run 2
   - Segment 1 Run 3
   - Segment 2 Run 3
   - Segment 1 Run 4
   - Segment 2 Run 4

   If following this method, runs pairs shall be conducted such that changing weather conditions are equally weighted between the segments. (See Appendix A for effects weather may have on the results.)

b. Run ratio check: Although not required per this procedure, obtaining a Run ratio of less than 2% for all runs should be the objective of each segment. Data points outside this range are an indication of uncontrolled and/or uncontrollable test variables and may be natural occurrences in the operation of the vehicle. These data points shall be included in the statistical analysis. These data points shall not be discarded unless they are associated with mechanical failure, driver errors, active DPF regeneration.

5.2.4 Vehicle Prep for Segment 2

In addition to the steps (listed in 5.2.1) for vehicle preparation for Segment 1, the swapping of drivers, flow meters, and/or trailers may need to be performed as directed by the method chosen in 4.9. Preconditioning of the DPF, cool down, and warm-up may be waived if testing can resume within the max allowed cool down period as described in 5.2.3, item (f).

5.2.5 Test Segment 2

Perform the same steps as in test Segment 1.

5.3 Data Processing

Using the supplied Excel spreadsheet, enter the fuel weight or fuel quantity and run times into the appropriate tab and cells. The results are calculated automatically. DEF quantity can also be entered for comparison analysis but is not a required measurement for this procedure. DEF measurement information is provided in Appendix D.

NOTE: Comparisons of two vehicles not run in a direct head-to-head evaluation must use the same control vehicle for comparison. Comparison of two vehicles using the same control vehicle must be conducted by entering the data into the two vehicle with control analysis spreadsheet. It is statistically incorrect to simply subtract the results of two different vehicles which were compared to a control vehicle, i.e., (% Diff Veh A versus Veh B) ≠ (% Diff Veh A versus Control) - (% Diff Veh B versus Control).

Step 1: Conduct a minimum three runs for Segment 1 and enter the data into the table. If any of the run time rule requirements of the procedure are violated, the associated cells will turn red. (See Figure 1.)

Segment 1							
Vehicle ID		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13035	41.560	13040	-1.96	0.04%
2	Yes	40.270	13050	42.250	13130	-1.98	0.61%
3	Yes	40.500	13040	42.900	13055	-2.40	0.11%
4	Yes	39.860	13030	41.800	13035	-1.94	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		40.058	0.15%	42.128	0.72%	0.46	
		Average	Range	Average	Range	Range	

Figure 1 - Segment 1 run data - all runs with a run time rule violation

To correct, toggle the switch in the "Valid" column to "No" to discard a run from the calculations. (See Figures 2 and 3.)

Segment 1							
Vehicle ID		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13035	41.560	13040	-1.96	0.04%
2	Yes (Yes / No)	0.270	13050	42.250	13130	-1.98	0.61%
3		0.500	13040	42.900	13055	-2.40	0.11%
4	Yes	39.860	13030	41.800	13035	-1.94	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		40.058	0.15%	42.128	0.72%	0.46	
		Average	Range	Average	Range	Range	

Figure 2 - Invalid run toggle selection

Segment 1							
Vehicle ID		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13035	41.560	13040	-1.96	0.04%
2	No	40.270	13050	42.250	13130		
3	Yes	40.500	13040	42.900	13055	-2.40	0.11%
4	Yes	39.860	13030	41.800	13035	-1.94	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		39.987	0.08%	42.087	0.15%	0.46	
		Average	Range	Average	Range	Range	

Figure 3 - Segment 1 run data - valid runs

Step 2: Set the "Estimate Confidence Interval" to "Yes" and review the predicted confidence interval (Conf Int). (See Figures 4 and 5.)

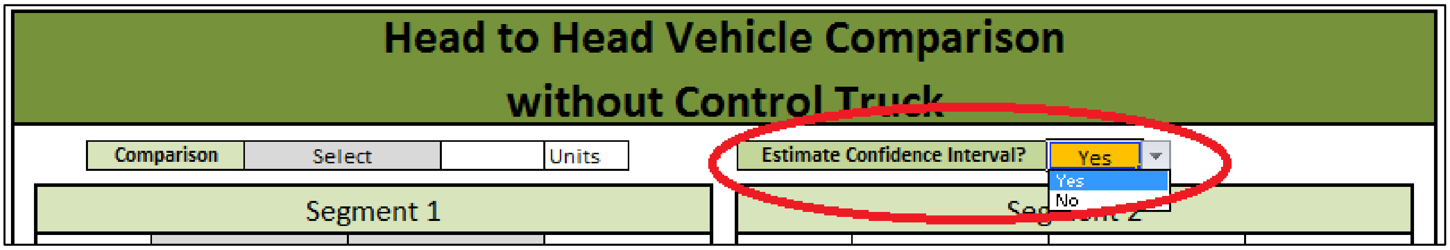


Figure 4 - Estimate confidence interval - "yes"

Veh A Compared to Veh B with 95% Confidence Interval			
	Result		Conf Int
Average Difference in Fuel Quantity	-2.10	±	0.24
% Less Fuel Consumed by Veh A	5.0%	±	0.6%
Is fuel consumption proven different w/ at least 95% confidence?	Yes		

Figure 5 - Estimated results

If the confidence interval is larger than desired, additional runs or tighter controls on the process may be necessary. Once a user defined acceptable confidence interval is achieved, proceed to Step 3.

Step 3: Conduct a minimum three runs for Segment 2/Test Segment following the same data entry and review of results as in the previous two steps. If the "Estimate Confidence Interval" remains set to "Yes" after data is entered into the cells of Segment 2/Test Segment, the "Delta qty Fuel/Diff A-B" will indicate "Est ON" and the Results will indicated "Not Calc." Simply change the "Estimate Confidence Interval" to "No" and review the results. (See Figures 6, 7, 8, and 9.)

Estimate Confidence Interval? Yes

Segment 2							
		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	36.110	13060	38.100	13045	Est ON	0.11%
2	Yes	37.800	13055	39.570	13070	Est ON	0.11%
3	Yes	38.470	13045	40.120	13060	Est ON	0.11%
4	Yes					-1.94	
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		37.460	0.11%	39.263	0.19%	0.00	
		Average	Range	Average	Range	Range	

Figure 6 - Segment 2 data with estimate confidence interval set to "yes"

Veh A Compared to Veh B with 95% Confidence Interval			
	Result		Conf Int
Average Difference in Fuel Quantity	Not Calc	±	Not Calc
Not Calc	Not Calc	±	Not Calc
Is fuel consumption proven different w/ at least 95% confidence?	**Not Calc**		

Not Calc - Indicates that insufficient data is available, the data is stastically indeterminate, the comparison type is not selected, or data is entered in Segment 2 with Estimate Test Tolerance set to Yes.

Figure 7 - Results with Segment 2 data entered and with estimate confidence interval set to "yes"

Estimate Confidence Interval?	No

Segment 2								
		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	36.110	13060	38.100	13045	-1.99	0.11%
2	Yes	37.800	13055	39.570	13070	-1.77	0.11%
3	Yes	38.470	13045	40.120	13060	-1.65	0.11%
4	Yes						
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		37.460	0.11%	39.263	0.19%	0.34	
		Average	Range	Average	Range	Range	

Figure 8 - Segment 2 data with estimate confidence interval set to "no"

Step 4: If both segments are valid and complete, the overall results are shown in the following table. If the test for statistical difference is validated, the indicator will display "Yes" as shown in Figure 9.

Veh A Compared to Veh B with 95% Confidence Interval			
	Result		Conf Int
Average Difference in Fuel Quantity	-1.95	±	0.27
% Less Fuel Consumed by Veh A	4.8%	±	0.7%
Is fuel consumption proven different w/ at least 95% confidence?	**Yes**		

Figure 9 - Results with Segment 2 data entered and with estimate confidence interval set to "no"

If the test for statistical difference is not validated, the indicator will display “No” as shown in Figure 10. In this case, it is recommended that the process be reviewed for errors and/or conduct additional runs to reduce the variability and confidence interval value.

Veh A Compared to Veh B with 95% Confidence Interval			
	Result		Conf Int
Average Difference in Fuel Quantity	-0.45	±	1.59
% Less Fuel Consumed by Veh A	1.1%	±	3.9%
Is fuel consumption proven different w/ at least 95% confidence?	No		

Figure 10 - Statistical difference not valid - large confidence interval

In the case shown in Figure 11, the test for statistical difference is not validated as indicated with “No.” It is also evident that operational repeatability is not the reason for the invalidated statistical difference as indicated by the ±0.02 confidence interval. In this case, it should be accepted that the two vehicles have similar fuel consumption under the test conditions.

Veh A Compared to Veh B with 95% Confidence Interval			
	Result		Conf Int
Average Difference in Fuel Quantity	-0.02	±	0.02
% Less Fuel Consumed by Veh A	0.1%	±	0.1%
Is fuel consumption proven different w/ at least 95% confidence?	No		

Figure 11 - Statistical difference not valid - small confidence interval

In a rare circumstance when the fuel consumption of the two vehicles is identical, the spreadsheet will not calculate a result. It will indicate “Not Calc” because there is no difference between the vehicles and there is no statistical difference. (See Figure 12.)

Head to Head Vehicle Comparison without Control Truck

Comparison	Fuel Quantity	Pounds	Units	Estimate Confidence Interval?	No

Segment 1

Vehicle ID		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13035	39.600	13040	0.00	0.04%
2	Yes	40.270	13050	40.270	13045	0.00	0.04%
3	Yes	40.500	13040	40.500	13055	0.00	0.11%
4	Yes	39.860	13030	39.860	13035	0.00	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		40.058	0.15%	40.058	0.15%	0.00	
		Average	Range	Average	Range	Range	

Segment 2

		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	40.250	13060	40.250	13045	0.00	0.11%
2	Yes	42.560	13055	42.560	13070	0.00	0.11%
3	Yes	42.600	13045	42.600	13060	0.00	0.11%
4	Yes	40.150	13030	40.150	13040	0.00	0.08%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		41.390	0.23%	41.390	0.23%	0.00	
		Average	Range	Average	Range	Range	

Veh A Compared to Veh B with 95% Confidence Interval

	Result		Conf Int
Average Difference in Fuel Quantity	0.00	±	Not Calc
% More Fuel Consumed by Veh A	0.0%	±	Not Calc
Is fuel consumption proven different w/ at least 95% confidence?	Not Calc		

Not Calc - Indicates that insufficient data is available, the data is stastically indeterminate, the comparison type is not selected, or data is entered in Segment 2 with Estimate Confidence Interval set to Yes.

Figure 12 - Vehicle comparison with identical fuel consumption

In the rare circumstance the fuel consumption of the two vehicles is different but there is no variation in the difference from run to run, the spreadsheet will calculate a result but not a confidence interval. This is because there is no statistical difference. This may be a result of insufficient resolution of the measurement device and therefore the device should be verified to meet the minimum requirements of 4.6.3 and 4.6.4. (See Figure 13.)

Head to Head Vehicle Comparison without Control Truck

Comparison	Fuel Quantity	Pounds	Units	Estimate Confidence Interval?	No

Segment 1

Vehicle ID		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13035	38.600	13040	1.00	0.04%
2	Yes	40.270	13050	39.270	13045	1.00	0.04%
3	Yes	40.500	13040	39.500	13055	1.00	0.11%
4	Yes	39.860	13030	38.860	13035	1.00	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		40.058	0.15%	39.058	0.15%	0.00	
		Average	Range	Average	Range	Range	

Segment 2

		Veh A		Veh B		Delta qty Fuel	Run Time % Diff
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time		
1	Yes	39.600	13060	38.600	13045	1.00	0.11%
2	Yes	40.270	13055	39.270	13070	1.00	0.11%
3	Yes	40.500	13045	39.500	13060	1.00	0.11%
4	Yes	39.860	13030	38.860	13040	1.00	0.08%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		40.058	0.23%	39.058	0.23%	0.00	
		Average	Range	Average	Range	Range	

Veh A Compared to Veh B with 95% Confidence Interval

	Result		Conf Int
Average Difference in Fuel Quantity	1.00	±	Not Calc
% More Fuel Consumed by Veh A	2.6%	±	Not Calc
Is fuel consumption proven different w/ at least 95% confidence?	**Not Calc**		

Not Calc - Indicates that insufficient data is available, the data is stastically indeterminate, the comparison type is not selected, or data is entered in Segment 2 with Estimate Confidence Interval set to Yes.

Figure 13 - Vehicle comparison with no run to run fuel consumption variation

5.4 Documentation for the Report

It should be recognized that every aspect of the vehicles being compared has some amount of influence upon the results. The significance of each individual difference is mostly dependent upon the purpose of the evaluation. In all cases, the major components such as large aerodynamic components (roof and side fairings) and driveline components (engine, transmission, axle ratio) will have a significant impact and shall be thoroughly reviewed and documented as part of the evaluation.

The following list of information shall be included in the report. It identifies the most significant items; however, it is not intended to be an all-inclusive list of items. Other items determined to potentially have significant impact upon the results shall be documented and a copy of the vehicle specification (if available) shall be included in the report for a complete description of the vehicle.

A form is provided with the data analysis spreadsheet for convenience. However, it is recognized that individual users may have different preferences for layout of information and therefore the use of the form is not a requirement.

Conditions and test equipment:

a. Test date

b. Test facility name and location

c. Duty cycle description including speed and elevation profile

d. Fuel measurement equipment specifications (i.e., resolution, accuracy, capacity, manufacturer, model, serial number, etc.)

e. Weather station manufacturer, model, and specifications

f. Weather station dimensions and site location(s) dimensions relative to the test route

g. Calibration records of all measurement equipment (weather station, scale or flow meters, tire pressure gauge, etc.)

Powered unit (tractor/bus/truck):

a. Manufacturer

b. Model

c. Date of manufacture and VIN

d. General description

   1. Wheelbase

   2. Fuel tank capacity and level of fill during testing

   3. Cab/sleeper configuration and/or size

   4. Fifth wheel height to ground at test load

e. Aero components

   1. Roof fairing

   2. Chassis fairings

   3. Aero bumper

   4. Cab/sleeper extenders

   5. Sun visor

   6. Hood mirrors

f. Engine label information

   1. Model year

   2. Advertised peak power at rpm

   3. Advertised peak torque at rpm

   4. Displacement

5. Engine serial number
6. Model
7. Engine family
8. Emissions family

g. Engine software version (if accessible)

h. Aftertreatment software version (if accessible)

i. Transmission (make/model)

j. Drive axle (make/model)

k. Drive axle ratio

l. Steer tires (make/model/psi/size/tread depth)

m. Drive tires (make/model/psi/size/tread depth)

n. Trailer tires (make/model/psi/size/tread depth)

o. Odometer reading

Trailers (cargo carrier):

a. Trailer manufacturer

b. Trailer model

c. Trailer date of manufacture and VIN

d. General trailer description

e. Height (at normal ride height)
   1. Front
   2. Rear

f. Aero components
   1. Trailer fairing devices
   2. Front fairings
   3. Underbody fairings
   4. Rear fairings
   5. Other (specify)

Other:

a. Tractor to trailer gap

b. Aerodynamic trailer gap

c. Loaded steer axle weight

d. Loaded drive axle weight

e. Loaded trailer axle weight

f. Descriptive photographs sufficient to clearly describe the vehicles

Method and operation:

a. Selected test method

b. Driver/observer identification and vehicle assignments, and test coordinator/support staff identification

c. Describe the method for commencing and ending of a run and any idle times

d. Records for each run

    1. Pre and post run test tank weight

    2. Run time

    3. Driver and observer (if applicable) interviews

    4. Start and end time of run

    5. Weather measurements

5.5 Reporting of Test Results

CAUTION: Test results are valid only for the vehicle configurations, duty cycles, and test conditions under which the test was conducted. For example, the general applicability of a valid test result to different environmental conditions may be determined when a subsequent valid test result produces a statistically similar value to the initial valid test result when tested in the different environmental conditions.

Only calculated values from the supplied software may be used in the reporting of test results. Test results from the test procedure shall be reported according to the following format. An image of the spreadsheet shall also be included as shown in Figure 14.

(Calculated Percent Change in Fuel Consumed) ± (Percent Confidence Interval of Calculated Value)

- Mean vehicle speed, vehicle weight, tractor trailer gap, aerodynamic gap
- Min air temperature, mean air temperature, max air temperature
- Min wind speed, mean wind speed, max wind speed, each corrected to an elevation of 10 feet above the road surface

EXAMPLE: 4.8% change in fuel consumption ±0.7% confidence interval.

- 65 mph, 65000 pounds, 42 inches, 36 inches
- Temp [min, avg, max] = 50 °F, 70 °F, 80 °F
- Wind [min, avg, max] = Calm, 3 mph, 10 mph

Head to Head Vehicle Comparison without Control Truck

Comparison	Fuel Quantity	Pounds	Units

Estimate Confidence Interval?	No

Segment 1

Vehicle ID		Veh A		Veh B		Delta	Run
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time	qty Fuel	Time % Diff
1	Yes	39.600	13035	41.560	13040	-1.96	0.04%
2	No	40.270	13050	42.250	13130		
3	Yes	40.500	13040	42.900	13055	-2.40	0.11%
4	Yes	39.860	13030	41.800	13035	-1.94	0.04%
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		39.987	0.08%	42.087	0.15%	0.46	
		Average	Range	Average	Range	Range	

Segment 2

		Veh A		Veh B		Delta	Run
Run	Valid	qty Fuel	Run Time	qty Fuel	Run Time	qty Fuel	Time % Diff
1	Yes	36.110	13060	38.100	13045	-1.99	0.11%
2	Yes	37.800	13055	39.570	13070	-1.77	0.11%
3	Yes	38.470	13045	40.120	13060	-1.65	0.11%
4	Yes						
5	Yes						
6	Yes						
7	Yes						
8	Yes						
9	Yes						
10	Yes						
11	Yes						
12	Yes						
13	Yes						
14	Yes						
15	Yes						
		37.460	0.11%	39.263	0.19%	0.34	
		Average	Range	Average	Range	Range	

Veh A Compared to Veh B with 95% Confidence Interval

	Result	Conf Int
Average Difference in Fuel Quantity	-1.95	± 0.27
% Less Fuel Consumed by Veh A	4.8%	± 0.7%
Is fuel consumption proven different w/ at least 95% confidence?	Yes	

Figure 14 - Final report image

6. NOTES

6.1 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 THE SAE TRUCK AND BUS J1526 REVISION TASK FORCE OF THE SAE TRUCK AND BUS AERODYNAMICS AND FUEL ECONOMY COMMITTEE

APPENDIX A - WEATHER EFFECTS

Environmental factors such as air temperature, barometric pressure, wind speed, and wind direction can affect the aerodynamic resistance of all test vehicles. Wind speed and direction will have the largest impact on test data quality. Additionally, wind speed and direction are highly heterogeneous in location and time, resulting in significant variation in wind characteristics at a test site and over a test time period. Wind speed and direction will affect each vehicle differently. As a result of these factors, it is recognized that all fuel consumption test procedures do not provide wind average effects, but are best suited to provide a high quality fuel consumption value over a limited range of wind conditions.

A vehicle operating at a velocity (V_T) will experience a wind velocity (V_W) that impinges on the vehicle at an angle (Φ); this results in a vehicle relative velocity (V) acting at a yaw angle (Ψ) as depicted in Figure A1.

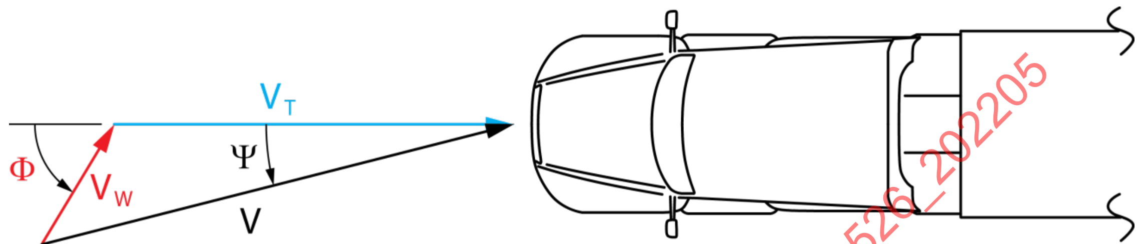


Figure A1 - Vehicle wind velocity and yaw diagram

Vehicles operating in the continental United States may routinely experience wind speed values in excess of 12 mph (refer to the 2009 Department of Energy (DOE) wind energy data, Wind Energy Resource Atlas of America, DOE/CH 10093-4, Oct. 1986, DE86004442). An analysis of more than 30 years of historical data compiled by the National Oceanic and Atmospheric Administration (NOAA) results in a historical mean wind speed of 7.5 mph (12.1 km/h) at a mid-vehicle elevation distance of 10 feet (3.05 m). The information is based on data available up to 2009. Regional and local wind averages may vary significantly from national averages.

As noted above, the fuel consumption of medium and heavy trucks and buses is highly influenced by environmental conditions and especially by wind speed and direction. Trucks and buses differ from automobiles in that the rate of change of aerodynamic resistance with yaw angle is greatly increased (approximately ten times higher). Figure A2 shows comparative drag coefficient versus yaw response for various vehicle types. The shape of the yaw curve will vary with vehicle design and aerodynamic treatments. For example, it is possible that an aerodynamic device may reduce drag at low yaw angles and increase drag at higher yaw angles relative to a baseline configuration.

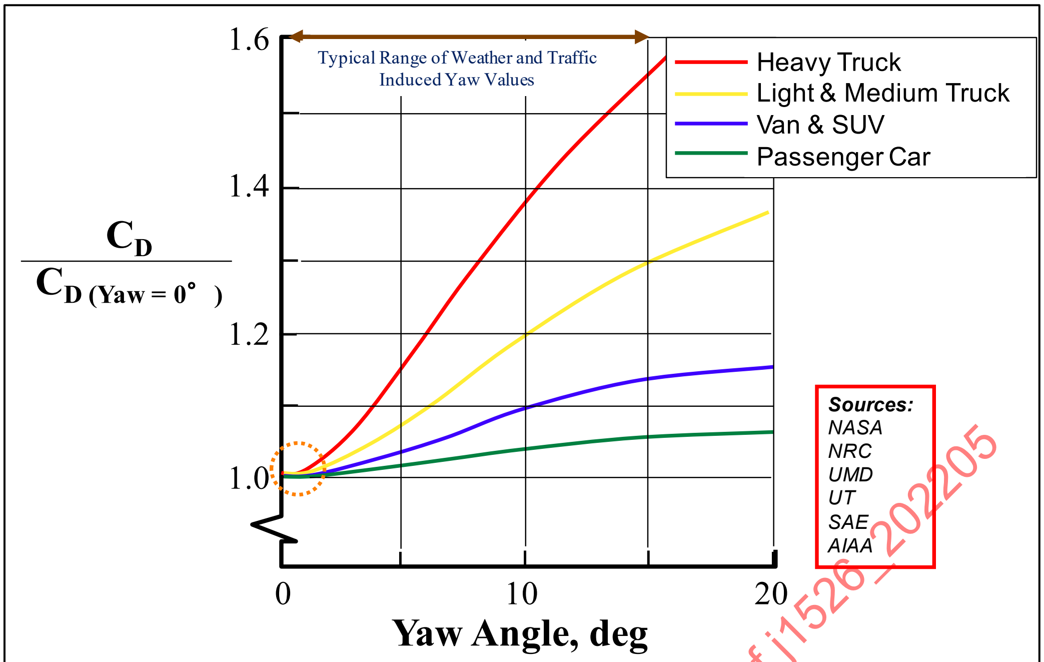


Figure A2 - Yaw effect on drag coefficient for families of vehicles

The heterogeneous nature of wind with small changes in time and location results in significant differences in wind-induced effects between vehicles on either a test track or public roads. Weather conditions are known to be a primary contributor to test data error such that wind velocity is the leading source of data contamination for the class of trucks and buses covered under this test procedure. Wind will impact the effective speed of the vehicles as well as the yaw angle. These effects can alter the measured fuel consumption values by more than 6%. The error in the measured fuel consumption may be greater if the test vehicles are not identical. Testing in conditions with significant variations in wind speed will negatively impact data quality and limit the ability to assess the effect of vehicle modifications from environmental aerodynamic effects particularly when evaluating devices with sensitivity to high yaw angle changes.

Adequate assessment of the impact of aerodynamic resistance on fuel consumption for in-service conditions requires the determination of fuel consumption over the full range of wind speeds and directions experienced by the vehicle. The addition of traffic and roadside structure interference adds complexity to the wind effect and may increase the yaw angle. While it is desirable to obtain a wind averaged fuel consumption value, it is not possible with this procedure or any other current fuel consumption test procedure due to the limited test mileage and the lack of control over environmental factors.

An approach to improve the understanding of the effect of yaw angle on vehicle performance is to obtain aerodynamic yaw trend data with the SAE J1252 wind tunnel test procedure and to combine these results with fuel consumption data obtained from this procedure for wind velocities less than 5 mph.

APPENDIX B - ADVANCED AFTERTREATMENT SYSTEM INFORMATION

B.1 SYSTEM TYPES

U.S. light-, medium-, and heavy-duty truck regulations were implemented in 2007 to reduce diesel particulate emissions. Diesel particulate filters (DPF) were added to exhaust systems to trap the soot produced in diesel combustion. With continued operation, the soot levels build in the DPF, increasing the exhaust backpressure. Additional fuel introduced into the filter in an active regeneration event elevates the exhaust temperature converting the soot to CO_2 through oxidation, restoring the lower backpressure. These aftertreatment systems come in various sizes and physical configurations, each is designed for the specific application to maximize fuel economy. Design variables and operating conditions affect the regeneration frequency and duration. Some examples include: physical constraints of packaging, vocation, service application, duty cycle, useful life, engine hour run time, and ambient conditions.

U.S. mandated reductions in nitrogen oxide (NO_X) emissions beginning in 2010 led to the use of selective catalytic reduction (SCR) systems in many light, medium, and heavy-duty vehicles. These SCR systems use a urea based reductant commonly known as Diesel Exhaust Fluid (DEF). These additional aftertreatment systems are designed to work cooperatively with existing DPFs.

B.2 SYSTEMS OPERATIONS

Manufacturers have developed DPF and SCR systems to rely upon either active or passive DPF regeneration processes depending on the duty cycle. In an active DPF regeneration, the engine controls may be modified to reduce EGR rates, change injection timing, and supply fuel to the DPF to provide a controlled oxidation of the accumulated particulate matter. In a passive DPF regeneration, the engine controls may be modified to operate in a manner that provides an optimized exhaust gas that will react with DPF and SCR catalyst to oxidize the particulate matter to CO_2 without the addition of diesel fuel to the exhaust stream.

As engine and after-treatment technology progresses and revisions are made to software, it is possible that two seemingly identical vehicles can have different fuel consumption rates purely as a result of internal changes to the after-treatment system or control strategy that is not publicly released information.

B.3 EXHAUST SYSTEM WARM-UP

With the introduction of advanced after-treatment in 2007, engine manufacturers have relied upon a range of exhaust warm up strategies to ensure emission compliance. These exhaust system warm up strategies may vary by model year, from manufacturer to manufacturer, and by type of advanced after-treatment used. The result may be increased engine fuel consumption when these strategies are active.

B.4 COMPLEXITY IN MEASURING CONSUMPTION RATES

A number of factors can affect the regeneration process and frequency and the associated total vehicle fuel economy and DEF consumption rates for SCR equipped engines. Among these factors are duty cycle, engine and after-treatment calibration, after-treatment system design, and ambient conditions.

In the absence of a comprehensive knowledge of the interaction of these highly variable, complex factors, and the ability to measure both consumable fluids simultaneously, it is recommended that only driving segments which do not include active regeneration events be used to determine differential fuel economy improvement.

APPENDIX C - TOTAL VEHICLE FUEL CONSUMPTION

NOTE: This process is not intended to be a step by step procedure as the procedure may vary by model year, manufacturer to manufacturer, and by engine displacement; however, it is intended to provide the user with a general method of evaluating advanced aftertreatment fuel consumption.

NOTE: This process will generate results that are representative of the conditions under which the evaluation is conducted. A change in ambient weather conditions, gross vehicle weight, duty cycle, etc., may alter the results.

NOTE: The Excel spreadsheet is supplied with a worksheet titled “Total Veh Fuel Consumption” which can be used to quantify the fuel consumption as described in the following process. An example worksheet is also supplied within the spreadsheet.

CAUTION: Before proceeding with this section, read Appendix B to understand the potential uncertainty of the results.

CAUTION: Since the introduction of advanced after-treatment exhaust systems in 2007, the amount of fuel consumed during an active regeneration event has continually decreased, as engine manufacturers searched for ways to improve efficiency. An additional outcome of these more efficient systems is the increasing number of miles that can accumulate between each active regeneration event. As a result, accurately measuring the amount of fuel consumed during an active regeneration event has become more difficult and time consuming. Where possible, it is recommended to compare vehicles with similar emission system technologies. If the objective is to compare vehicles with dissimilar emission system technologies (e.g., DOC, DPF, EGR, and/or SCR), there may be a statistically significant difference in active regen fuel consumption. If the objective is to compare vehicles equipped with SCR systems, this process may require in excess of 1000 miles to achieve a single active regeneration. Moreover, because of this higher mileage requirement, the ability to adhere to the required weather constraints of this procedure may be impossible. In this case, it should be recognized that the measurement uncertainty may be greater than the measured amount of fuel per active regeneration. Therefore using this process to compare vehicles all of which contain SCR systems may not produce useful information.

CAUTION: Since the introduction of DPF systems, the general trend has been toward more frequent passive regeneration events and less frequent active regeneration events. Passive regeneration events occur regardless if the active DPF regeneration system is disabled. Thus, disabling or turning off the active DPF regeneration system may result in an unintentional penalty against the vehicle which operates with more frequent passive regeneration events. Without OEM software tools, detecting passive regeneration events may be impossible. Therefore, awareness of this risk should be understood when comparing the fuel consumption of different emission level Vehicles of the same or different manufacturers (i.e., 2017 emission system in a 2020 vehicle versus a 2021 emission system of the same manufacturer and vehicle model but of a 2021 vehicle).

C.1 PREPARATION

Begin with a preconditioned aftertreatment system as described in 4.8.4. Record all miles accumulated in each of the following parts for the purpose of determining the regen interval discussed in Equation C4.

C.2 PROCEDURE

When considering total fuel consumption of a vehicle, it is necessary to not only include the thermally stable operating conditions primarily addressed in this document but to also include the vehicle warm-up contribution and any active regenerations that occur in normal frequency.

C.2.1 Evaluate Each Contributing Fuel Consumption Part

C.2.1.1 Warm-up Fuel Consumption (aka Warm-up Run)

To evaluate fuel consumption in real world operations, the fuel consumed during normal vehicle warm-up following a parked condition shall be included. The purpose is to determine the fuel consumption during the thermal stabilization process.

NOTE: Fuel consumption rate may be higher as fluids, tires, exhaust system, engine, etc., reach steady state condition.

Measure the fuel consumption and mileage accumulation of the vehicle from a cold start (12 hours no operation).

- If testing vehicles head-to-head (methods A or C of 4.9), the warm-up fuel consumption process of all vehicles shall be conducted simultaneously.
- If testing using a control vehicle (methods B or D of 4.9), the warm-up fuel consumption process of both the control and test vehicle shall be conducted simultaneously. Each control to test vehicle comparison shall be conducted under nearly identical ambient weather conditions.
- Conduct the warm-up run identical to a run as described in 5.2.2. The warm-up run time shall be approximately 1 hour and start and end at the same general geographical location. After the warm-up run is complete, 5.2.3 shall be followed.
- A minimum of three warm-up runs are required per segment.

Use the following equation to determine the warm-up fuel rate per mile.

$$\text{Warm-up Fuel per Mile} = \frac{\text{Warm-up Fuel Consumption}}{\text{Warm-up Test Miles}} \quad \text{(Eq. C.1)}$$

where:

Warm-up fuel consumption = the total fuel consumed for all valid warm-up runs

Warm-up test miles = the total miles traveled for all valid warm-up runs

C.2.1.2 Thermally Stable Fuel Consumption

The fuel consumed during this state of operation is the rate at which the fuel is consumed after the vehicle has achieved a thermally stable state.

Measure the fuel consumption as defined in Section 5. Before starting this part, review the active regeneration fuel consumption part. (See C.2.1.3.)

In addition to the requirements in Section 5, the engine run time shall be tightly controlled to within 0.5% between all vehicles at all times. This is to ensure time triggered active regenerations do not bias the results. Engine run time includes idling in addition to the test run time; idling prior to and after a run shall be included with that same run.

Use the following equation to determine the thermally stable fuel consumption rate per mile.

$$\text{Thermally Stable Fuel per Mile} = \frac{\text{Therm Stable Fuel Consumption}}{\text{Therm Stable Test Miles}} \quad \text{(Eq. C.2)}$$

where:

Therm stable fuel consumption = the total fuel consumed as defined in Section 5

Therm stable test miles = the total miles traveled while consuming test fuel as defined in Section 5

C.2.1.3 Active Regeneration Fuel Consumption

The amount of fuel consumed by an active regeneration event is dependent upon numerous factors. (See Appendix B for more information.)

Measure the fuel consumption for this part following the Section 5 steps. Alternatively, you may measure the active regeneration fuel consumption while conducting the thermally stable fuel consumption (C.2.1.2).

Runs that are identified to include active regenerations (by a significant increase in the exhaust stream or by CAN bus data) shall be noted and separated from the non-active regeneration runs.

An active regeneration event may not start and end within a given run. Extending the run to complete the active regeneration event is recommended, provided sufficient fuel is available in the test tank and the route is repeated until the active regeneration event is complete. If on a test track, the vehicles continue on the track to the end point for final fuel consumption determination. If on a public roadway, the vehicles turn around either at the designated turn around location, or when the active regeneration event ceases, whichever occurs first, while obeying all appropriate traffic laws, and continue to the original ending location for final fuel consumption determination. All vehicles shall be operated over an equivalent drive cycle during the route extension.

An alternative to extending the run is to continue the active regeneration event in the subsequent run(s). In this case, the time to change the test fuel tanks shall be less than 5 minutes and the engine shall be turned off. Turning the engine off is to reduce cooling of the aftertreatment system which may trigger a warm-up strategy activation on the subsequent run. Without OEM software tools, it is impossible to know if a warm-up strategy has been activated.

The accuracy of the measured active regeneration fuel consumption improves with the number of samples; therefore, it is recommended that at least two active regeneration events are captured on the test vehicle(s). The minimum recommended two active regeneration events can either occur in the same segment or in separate segments.

Use the following equation to determine the amount of fuel consumed by an active regeneration event. The fuel consumed to power the vehicle during an active regeneration event is automatically excluded by the equation. The event start and stop can be identified by either CAN messages or a substantial increase in the DPF outlet exhaust temperature (see Section 3 for more detail).

$$\text{Active regen fuel consumption} = \text{Regen veh fuel cons} - (\text{Rv/NRv ratio avg} * \text{NonRegen veh fuel cons}) \quad \text{(Eq. C.3)}$$

where:

Rv = the vehicle which undergone active regeneration(s)

NRv = the vehicle which did not undergo active regeneration(s)

Regen veh fuel cons = the sum of fuel consumed by Rv during active regeneration run(s)

NonRegen veh fuel cons = the sum of fuel consumed by NRv during Rv active regeneration run(s)

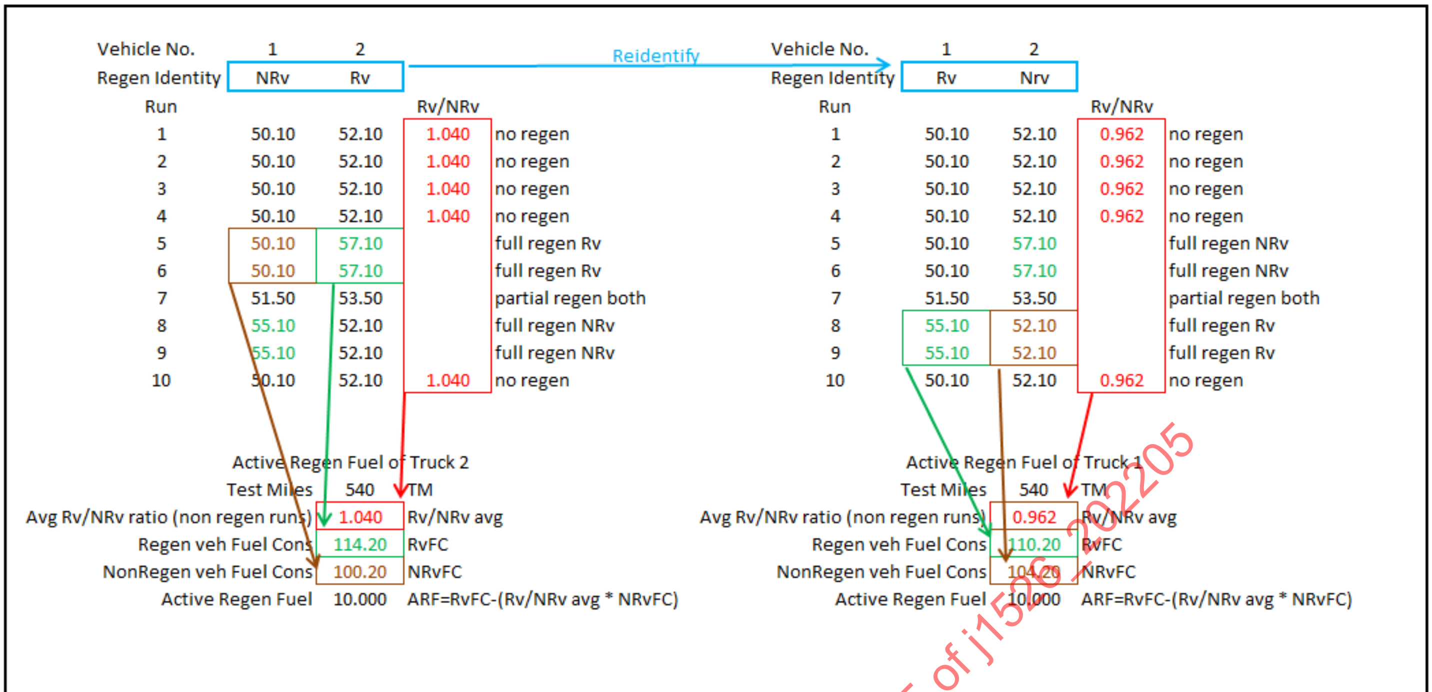
Rv/NRv ratio avg = the average of the Rv/NRv fuel consumption ratios during non-active regeneration runs

Active regeneration run(s) = a run where Rv is undergoing active regeneration

Non-active regeneration run(s) = a run where Rv is not undergoing active regeneration

Identification of Rv and NRv are assigned to a particular vehicle once one of the vehicles undergoes an active regeneration event. If both vehicles undergo an active regeneration event during the same run, that run is invalid (see run 7 in Figure B1).

If the vehicle identified as the NRv undergoes an active regeneration event but the vehicle identified as Rv does not (see runs 8 and 9 in Figure B1), the data point is not valid for calculating active regen fuel of the Rv; however, it can be used to calculate the active regen fuel of the NRv. This is accomplished by continuing runs until the vehicle successfully completes the active regeneration event. Data is then grouped appropriately and vehicle identifications are changed to represent their activity. (See the calculation method as illustrated in Figure B1 which is also located in the Excel spreadsheet on a separate worksheet. This represents one segment of the test.)



Vehicle No.	1	2		
Regen Identity	NRv	Rv		
Run			Rv/NRv	
1	50.10	52.10	1.040	no regen
2	50.10	52.10	1.040	no regen
3	50.10	52.10	1.040	no regen
4	50.10	52.10	1.040	no regen
5	50.10	57.10		full regen Rv
6	50.10	57.10		full regen Rv
7	51.50	53.50		partial regen both
8	55.10	52.10		full regen NRv
9	55.10	52.10		full regen NRv
10	50.10	52.10	1.040	no regen

Active Regen Fuel of Truck 2		
Test Miles	540	TM
Avg Rv/NRv ratio (non regen runs)	1.040	Rv/NRv avg
Regen veh Fuel Cons	114.20	RvFC
NonRegen veh Fuel Cons	100.20	NRvFC
Active Regen Fuel	10.000	ARF=RvFC-(Rv/NRv avg * NRvFC)

Reidentify

Vehicle No.	1	2		
Regen Identity	Rv	Nrv		
Run			Rv/NRv	
1	50.10	52.10	0.962	no regen
2	50.10	52.10	0.962	no regen
3	50.10	52.10	0.962	no regen
4	50.10	52.10	0.962	no regen
5	50.10	57.10		full regen NRv
6	50.10	57.10		full regen NRv
7	51.50	53.50		partial regen both
8	55.10	52.10		full regen Rv
9	55.10	52.10		full regen Rv
10	50.10	52.10	0.962	no regen

Active Regen Fuel of Truck 1		
Test Miles	540	TM
Avg Rv/NRv ratio (non regen runs)	0.962	Rv/NRv avg
Regen veh Fuel Cons	110.20	RvFC
NonRegen veh Fuel Cons	104.20	NRvFC
Active Regen Fuel	10.000	ARF=RvFC-(Rv/NRv avg * NRvFC)

Figure B1 - Active regeneration fuel calculation example

Use the following equation to determine the normalized fuel consumption per mile based on the active regeneration interval (frequency).

$$\text{Regen Fuel per Mile} = \frac{\text{Active Regen Fuel Consumption}}{\text{Regen Interval}} \quad \text{(Eq C.4)}$$

where:

Active regen fuel consumption = the value obtained from Equation C.3

Regen interval = the sum of the distance in miles between the end of an active regeneration event and the end of a subsequent active regeneration event for each active regeneration event encountered; this distance is highly dependent upon a number of factors and therefore may vary during this evaluation

C.2.2 Total Vehicle Fuel Consumption Calculation

The following equation shall be used to determine a vehicles total fuel consumption representative of in-service operation for the conditions (weather, duty cycle, etc.) under which the evaluation is conducted.

$$\begin{aligned}\text{Total Vehicle Fuel Consumption} = &(\text{Warm-up Fuel per Mile} \times \text{Wu Miles})\\ +&(\text{Therm Stable Fuel per Mile} \times \text{Therm Stable Miles})\\ +&(\text{Regen Fuel per Mile} \times \text{Wu Miles} + \text{Therm Stable Miles})\end{aligned} \quad \text{(Eq C.5)}$$

where:

Warm-up fuel per mile = the value obtained from Equation C.1

Wu miles = A value in miles that represents the first hour of in-service operation. A standard value of 60 miles can be used. This is based on starting a vehicle, maneuvering to a main roadway, accelerating to highway speeds and driving for 1 hour.