

SURFACE VEHICLE INFORMATION REPORT

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Supportive Information Report for the Fuel Economy Measurement Test (Engineering Type) for Trucks and Buses

1. **Scope**—This information report provides background information related to the development of the SAE Recommended Practice that produces relative fuel economy data.

- 1.1 **Overview**—The objective of this test procedure is to enable one to conduct a relatively simple test employing driving patterns for the purpose of evaluating relative fuel economy expressed in mpg between vehicles or the effects of various devices on fuel economy when these devices are installed on a vehicle.

The test procedure requires a reference or a control vehicle to be run simultaneously with the test vehicle on the same course and at the same time. The mpg ratio of the control vehicle to the test vehicle is applied to check the repeatability and validity of the test results. The corrections applied to the observed mpg are: (1) the test fuel heating value is corrected to standard fuel heating value, and (2) the corrected fuel density is to standard 60 °F fuel temperature. At the time of this writing, not enough test data has been generated to develop a correction factor for ambient temperature and barometric pressure. To minimize the effect of the ambient temperature, the test procedure recommends a rather narrow temperature band.

This information report is a companion document to SAE Recommended Practice J1376, Fuel Economy Measurement Test (Engineering Type) for Trucks and Buses. It provides background information and explanations to better understand the measurement procedure and its use. It also provides references and data which were developed by the SAE/DOT Program in support of the particular limitations or parameters selected for the various items in the test procedure. The format used in this document is similar to the recommended practice so that corresponding topics can be found under the same headings.

2. References

- 2.1 **Applicable Publications**—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

- 2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1082 SEP80—Fuel Economy Measurement—Road Test Procedure

SAE J1376 JUL82—Fuel Economy Measurement Test (Engineering Type) for Trucks and Buses

SAE Paper 831784—Development of Fuel Economy Test Procedures by Richard S. Johnson, presented at the 1983 Truck and Bus Meeting and Exposition, November 7–10, 1983.

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2.1.2 DOT PUBLICATION

"Baseline Advanced Design Transit Coach Specification," Part II paragraph 1.2, published by DOT.

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

1. The DOT/SAE Truck and Bus Fuel Economy Measurement Conference Report, P-59, April 21–23, 1975, Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096.
2. "For Presentation to the DOT/SAE Truck and Bus Fuel Economy Study OEM Test Procedure Subcommittee," by Richard S. Johnson, included in Feb. 1, 1979, "OEM Vehicle Test Procedure Subcommittee" Meeting.
3. Minutes S. 11 Vehicle Energy Conservation Study Group, Dec. 11, 1979, Phoenix, AZ.
4. Minutes of Oct. 13, 1976, "OEM Vehicle Test Procedure Subcommittee" Meeting.
5. SAE/DOT Advisory Committee correspondence, Mr. C. Harold Ek, Dec. 3, 1980.
6. Minutes of May 17, 1978, "OEM Vehicle Test Procedure Subcommittee" Meeting. Richard S. Johnson's report.
7. OEM Vehicle Test Procedure Subcommittee correspondence, Richard S. Johnson, Apr. 14, 1977.

3. Definitions

3.1 Test Cycles—The criterion in the development of the test cycles was to have relatively simple test cycles which in many cases could be run on a public highway if a suitable test track were not available. A complicated test cycle could cause the drivers to neglect safety and adequate attention to the driving pattern and also increase the manpower required to conduct the test. Universal test cycles to reflect the real world are impossible to develop. The driving patterns in the real world are changing - less idle time, slower speeds, and closer selection of gears. By developing simple test cycles, a more complicated driving pattern to fit someone's specific needs can be approximated by combining portions of the recommended test cycles, such as 50% of the long haul and 50% of the short haul into a specialized test cycle.

Relatively short test cycles are desirable. More test cycles can be run in a given time frame and more data points collected. Also, test repeatability problems and other errors can be noticed early and corrected. The test procedure provides the means for evaluating only the relative fuel economy of a vehicle or vehicles. It provides a measure of percent change in fuel economy due to a modification of a test vehicle or a change in a vehicle's mode of operation from a baseline condition.

An absolute mpg value at standard ambient conditions cannot be easily obtained. It is not known what the correction factor for ambient conditions for the various types of vehicles should be. If a reference vehicle is available with a known mpg value at the standard conditions, an approximate absolute value can be obtained but very few organizations have a reference vehicle.

The procedure provides means for obtaining data for possible fuel savings calculations or fuel economy calculations at some ambient conditions other than standard. This is illustrated in Figure 1 where the relative improvement in fuel economy between radial versus bias ply tires is shown based on actual test data.

- 3.1.1 **LONG HAUL CYCLE**—Refer to SAE Paper 831784, Development of Fuel Economy Test Procedures by Richard S. Johnson, presented at the 1983 Truck and Bus Meeting and Exposition, November 7–10, 1983.
- 3.1.2 **SHORT HAUL CYCLE**—Refer to SAE Paper 831784, Development of Fuel Economy Test Procedures by Richard S. Johnson, presented at the 1983 Truck and Bus Meeting and Exposition, November 7–10, 1983.
- 3.1.3 **LOCAL CYCLE**—Refer to SAE Paper 831784, Development of Fuel Economy Test Procedures by Richard S. Johnson, presented at the 1983 Truck and Bus Meeting and Exposition, November 7–10, 1983.

- 3.1.4 TRANSIT CYCLE—Refer to "Baseline Advanced Design Transit Coach Specification," Part II paragraph 1.2, published by DOT.

3.2 Test Vehicles

- 3.2.1 MODEL IDENTIFICATION—No background information is required.
- 3.2.2 COMPONENT IDENTIFICATION—No background information is required.
- 3.2.3 CONTROL VEHICLE—The ambient conditions during a test can change and do change. To neutralize these effects, the control vehicle is employed. The assumption is made that the test vehicle and control vehicle are affected by the changes in the ambient conditions in the same manner, thus changing the power requirements of both vehicles proportionally by the same amount.

The control vehicle is run together with the test vehicle at some reasonable distance so as not to change the aerodynamic conditions of the vehicle running behind.

Test data indicate that this method of testing provides good test-to-test repeatability and early detection of errors in driving the cycle. It provides a reliable tool for evaluating the test results. The same control vehicle must be used during the duration of any specific series of tests. If a prolonged series of tests is expected, the control vehicle must be maintained so as to give identical results under the same ambient conditions each time the same test cycle is run. Test data indicate that a relatively large aerodynamic difference can exist between the test and the control vehicles and still provide reliable test data.

In the calculation of the test results, the mpg ratio of the two vehicles is used. Regardless of the ambient conditions, the ratio remains approximately the same (as shown in Figure 1) for all the same test runs. Any substantial change in the ratio usually indicates a bad run.

A reference vehicle can be employed in place of a control vehicle in conducting the tests. A reference vehicle is a control vehicle for which the fuel economy is known at reference conditions of 70 °F ambient and 29.00 in Hg barometric pressure with fuel of standard heating value. If a reference vehicle were available, a rough estimate of absolute mpg values of a vehicle on a specific test cycle at reference conditions could be attained. For a one time test only, relative values can be obtained. Because very few organizations have such a vehicle, the test procedure deals only with the use of the control vehicle. A sample calculation employing a reference vehicle is shown below.

Sample Calculation with Reference Vehicle: A reference vehicle was tested simultaneously with the test vehicle and the control vehicle shown in paragraph 11.5 of the test procedure. (Ambient conditions are the same as in paragraph 11.5).

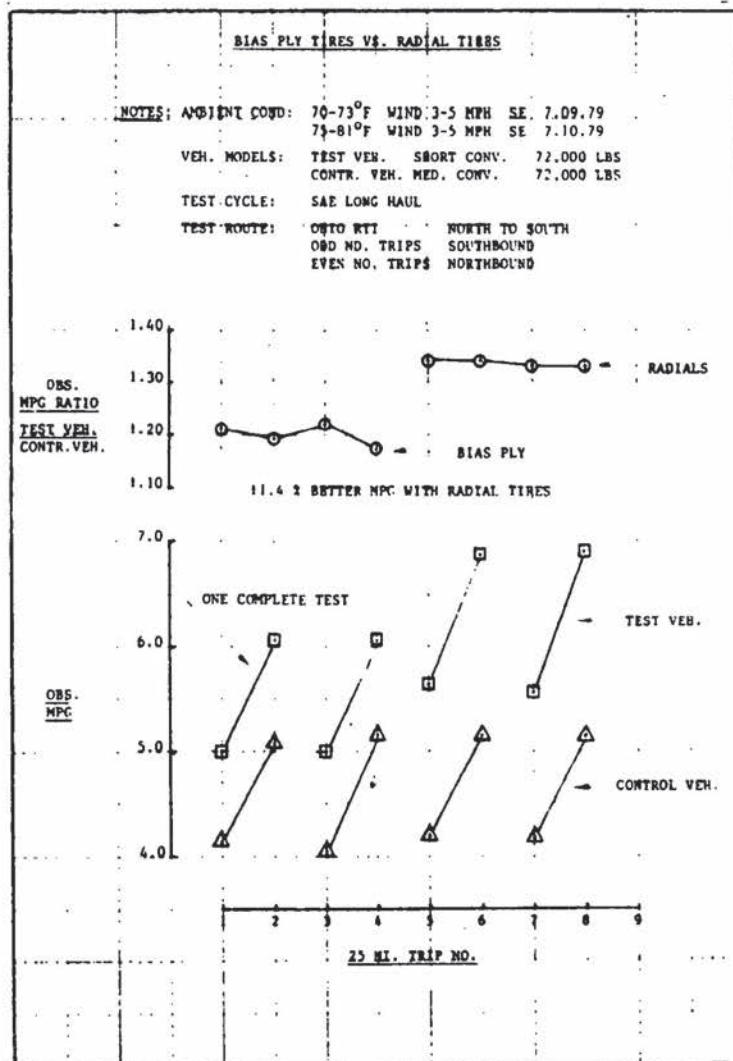


FIGURE 1—REFERENCE VEHICLE DIESEL POWERED (30.12 MILES)

Run No.	Obs. Gal.	Fuel ^a Temp °F	FE _O Obs. mpg	C ₁ C.F. to Std. H.V.	C ₂ C.F. to 60°F Fuel	FE _C Corr. mpg
1	4.78	86.0	6.301	0.9860	1.0104	6.277
2	5.32	86.0	5.662	0.9860	1.0104	5.641
3	4.90	78.5	6.147	0.9860	1.0073	6.105
4	4.87	83.0	6.185	0.9860	1.0092	6.115
Mean			6.074			6.0445
% Spread			10.5%			10.5%
Std. Deviation			0.282			0.278
<u>Std. Dev.</u>						
Mean			4.64%			4.61%

The data for run No. 2 may appear to be questionable. Without run No. 2, the mean mpg column is 6.211 and the spread only 2.8%. It will be shown later that these data are probably part of a normal variation due to weather conditions.

Run No.	$FE_0 \times C_1 \times C_2$			mpg Ratios			FE_c : mpg Corrected by Ref. Vehicle Method		
	Veh. 1	Veh. 2	Ref. Veh.	<u>Veh. 1</u> Ref.	<u>Veh. 2</u> Ref.	<u>Veh. 2</u> Veh. 1	Veh. 1	Veh. 2	Ref. Veh.
1	5.825	9.344	6.277	0.928	1.489	1.604	5.634	9.040	6.071
2	5.474	8.860	5.641	0.970	1.571	1.619	5.889	9.538	6.071
3	5.839	9.268	6.105	0.956	1.518	1.587	5.804	9.216	6.071
4	5.714	9.258	6.155	0.928	1.504	1.620	5.634	9.131	6.071
Mean	5.713	9.182	6.044	0.945	1.520	1.608	5.740	9.231	6.071
Std. Dev.	0.169	0.218	0.278	0.021	0.036	0.016	0.127	0.217	
<u>Std. Dev.</u>									
Mean	3.0%	2.4%	4.6%	2.2%	2.3%	1.0%	2.2%	2.3%	
% Spread	6.4%	5.3%	10.5%	4.4%	5.4%	2.1%	4.4%	5.4%	

This reference vehicle, from previous tests, is known to have a fuel economy of 6.071 mpg at 70 °F and 29.00 in Hg after correction to the standard fuel heating value for #2 diesel fuel and the standard fuel temperature of 60 °F.

Even though the mpg values for individual vehicles change with weather conditions, ratios of mpg tend to be constant because vehicles are affected similarly. The reference vehicle correction method assumes that the mpg ratio between test vehicle and reference vehicle is the same for all ambient conditions.

$$FE_c (\text{test veh. corr. to std. cond.}) = \frac{\text{mpg (test vehicle)}}{\text{mpg (reference vehicle)}} \times 6.071 \quad (\text{Eq. 1})$$

where

$$6.071 = FE_c (\text{reference vehicle at std. cond.})$$

This method reflects effects of all ambient conditions such as humidity, wind, and road surface temperatures, as well as ambient temperature and pressure, whether these data are measured and recorded or not. Knowledge of accurate correction factors for each of these effects is not required with this method of correction.

Ambient conditions are the same for two or more vehicles tested together. Fuel type and fuel temperatures are not necessarily the same. The ratio of observed fuel economies is not adequate for this method unless by the volumetric method.

$$\frac{FE_0 (\text{test vehicle})}{FE_0 (\text{reference vehicle})} = \frac{FE_0 \times C_1 \times C_2 (\text{test vehicle})}{FE_0 \times C_1 \times C_2 (\text{reference vehicle})} \quad (\text{Eq. 2})$$

For the example, the factors C_1 and C_2 are almost the same for vehicle 2 and the reference vehicle (same fuel and same fuel temperature within 2.5 °F) so FE_0/FE_0 could be used. Vehicle 1 burned gasoline and had a different fuel temperature. The factor $FE_0 \times C_1 \times C_2$ and the corrected FE_c have been calculated for all three vehicles. (See example below.)

The mpg values corrected by the reference vehicle method should be close to those which would be observed if these vehicles ran the same test cycle with standard fuel and at standard atmospheric conditions.

Vehicle 1	5.74 mpg
Vehicle 2	9.23 mpg
Ref. Veh.	6.07 mpg

Test vehicle 2 gives 60.8 % better mpg than test vehicle 1 (mean ratio is 1.608).

Test vehicle 1 gives 5.5 % lower mpg than the reference vehicle (ratio is 0.945).

Test vehicle 2 gives 52.0% better mpg than the reference vehicle (ratio is 1.520).

Run No. 2 appeared to give a questionable low mpg value for the reference vehicle in the previous tabulation. Vehicles 1 and 2 also showed low mpg values for run No. 2, but the mpg ratios of these vehicles relative to the reference vehicle are 0.970 and 1.571 with only 2.2% and 2.3% coefficient of variation. Some unrecorded test condition has caused the mpg values for all three vehicles to be low. The mpg ratio is relatively unchanged.

The same effect, that the mpg ratio is much more consistent than mpg values, is also clearly shown in Figures 1 and 2. The mpg values northbound and southbound on Figure 1 show 23% better economy northbound than southbound, but the ratios show little effect. The ratios on Figure 2 also show much less variation than do the mpg values for the four test runs, the three road runs, and all seven runs together. The mpg values for the Cleveland-Toledo road run are substantially lower than the other runs, but the ratio changes only slightly.

3.3 Test Vehicle Description

3.3.1 CATEGORY—No background information is required.

3.3.2 VEHICLE SPECIFICATIONS—No background information is required.

3.4 Test Vehicle Weight—The test procedure specifies that the chosen test cycle be run at 100% and 50% of the gross vehicle or combination test weight. The objective of running tests at more than one weight is to determine the variation of mpg with weight. To separate better the weight effect from test to test variability, the test weights should be as different as possible. Testing at 100% of rated gross weight and at empty weight represents the extremes, but empty weight is not consistently the same percentage of rated gross weight. For this reason, a value of 50% of gross test weight was selected.

3.4.1 UNLOADED VEHICLE WEIGHT—No background information is required.

3.4.2 GROSS VEHICLE TEST WEIGHT (GVTW)—No background information is required.

3.4.3 GROSS COMBINATION TEST WEIGHT (GCTW)—No background information is required.

3.4.4 AXLE-BY-AXLE WEIGHT—No background information is required.

3.4.5 The gross vehicle weight rating is the preferred maximum vehicle test weight, but in some states the legal loads are less than the rating. For example, a single drive axle rating of 23 000 lb is frequently specified. In the fifty states, this load is legal only in Hawaii. A reduced weight is necessary if the test is to be conducted on public roads.

- 3.5 Observed Economy**—Observed economy is the fuel economy determined during a test cycle by dividing the actual miles driven on the cycle by the measured and uncorrected number of gallons consumed. Economy is expressed as miles per gallon. Fuel consumption is expressed as gallons per mile and is a different parameter. If fuel is measured by weight, the observed fuel economy is the miles travelled divided by the fuel weight converted to gallons using the fuel specific weight determined at 60 °F fuel temperature. This corresponds to the volumetric measurement as: Volumetric observed mpg x C₂, refer to Section 11 of test procedure.
- 3.6 Corrected Economy**—Corrected fuel economy is the observed fuel economy corrected for fuel net heating value and to 60°F fuel temperature. Correction factors for ambient conditions and altitude. To minimize the effect of the ambient temperature, the procedure recommends a rather narrow temperature band. Barometric pressure effects on aerodynamic drag and engine power (and possibly other factors) at a given test location will normally be too small to be detected outside normal test-to-test variability. Pressure differences due to widely different altitudes affect absolute mpg, but may have little effect on relative fuel economy. No specific limits are set on barometric pressure.

Figures 4, 5, and 6 show the effect of the various variables influencing the fuel economy. For Figure 5, 42 points were used to calculate a best fit straight line. Eleven points added later fit the previous data quite well, but alone these eleven points would appear to show a different trend with air temperature. Any future attempts to determine the effect of air temperature for specific vehicles must cover a wide spread of the variable.

Figures 10, 11, and 12 show the results of a regression analysis on thirty runs of 24.563 miles. Southbound runs were made as well and total fuel for each pair of runs is shown on Figure 5. There were actually 42 runs, but only thirty had winds which were reasonable consistent for the entire test. Figure 10 shows that air temperature, air density, and relative velocity squared are all important as single variables. Barometric pressure is not. Figure 11 shows that relative velocity is more important when air temperature is included and that yaw angle is important only after air temperature and speed squared are included. Figure 12 shows the complete analysis.

For equations 29, 34, 22, 39, 19, and 1 in sequence, the coefficients remain relatively unchanged until equation 1 is reached, when large changes occur in all coefficients. Air density is interdependent with temperature and pressure and should not be included. The best equation for this particular set of data is equation 22:

$$\text{Gallons/Trip} = 4.440 - 0.0129 (TA) + 0.000238 (\text{Rel } V)^2 + 0.0201 (\text{yaw angle}) \quad (\text{Eq. 3})$$

for:

TA = °F
 Rel V = miles per hour
 Yaw Angle = degrees absolute

Dividing by 49.126 gives gallons per mile.

- 3.7 Reference Conditions**—No background information is required.
- 4. Instrumentation**—Instruments selected in the performance of the fuel economy tests should be of good quality and be accurate within the prescribed tolerances of the test procedure. The repeatability of the test results depends on instruments that record accurate and consistent test data. Inaccurate instruments will cause a wide variation in the test results.