6. FUEL ECONOMY

6-I. TEST OBJECTIVE

The objective of this test is to provide accurate comparable fuel consumption data on transit buses produced by different manufacturers. This fuel economy test bears no relation to the calculations done by the Environmental Protection Agency (EPA) to determine levels for the Corporate Average Fuel Economy Program. EPA's calculations are based on tests conducted under laboratory conditions intended to simulate city and highway driving. This fuel economy test, as designated here, is a measurement of the fuel expended by a vehicle traveling a specified test loop under specified operating conditions. The results of this test will not represent actual mileage but will provide data that can be used by recipients to compare buses tested by this procedure.

6-II. TEST DESCRIPTION

This test requires operation of the bus over a course based on the Transit Coach Operating Duty Cycle (ADB Cycle) at seated load weight using a procedure based on the Fuel Economy Measurement Test (Engineering Type) For Trucks and Buses: SAE 1376 July 82. The procedure has been modified by elimination of the control vehicle and by modifications as described below. The inherent uncertainty and expense of utilizing a control vehicle over the operating life of the facility is impractical.

The fuel economy test will be performed as soon as possible (weather permitting) after the completion of the GVW portion of the structural durability test. It will be conducted on the bus test lane at the Penn State Test Facility. Signs are erected at carefully measured points which delineate the test course. A test run will comprise 3 CBD phases, 2 Arterial phases, and 1 Commuter phase. An electronic fuel measuring system will indicate the amount of fuel consumed during each phase of the test. The test runs will be repeated until there are at least two runs in both the clockwise and counterclockwise directions in which the fuel consumed for each run is within " 4 percent of the average total fuel used over the 4 runs. A 20-minute idle consumption test is performed just prior to and immediately after the driven portion of the fuel economy test. The amount of fuel consumed while operating at normal/low idle is recorded on the Fuel Economy Data Form. This set of four valid runs along with idle consumption data comprise a valid test.

The test procedure is the ADB cycle with the following four modifications:

1. The ADB cycle is structured as a set number of miles in a fixed time in the following order: CBD, Arterial, CBD, Arterial, CBD, and Commuter. A separate idle fuel consumption measurement is performed at the beginning and end of the fuel economy test. This phase sequence permits the reporting of fuel consumption for each of these phases separately, making the data more useful to bus manufacturers and transit properties.

2. The operating profile for testing purposes shall consist of simulated transit type service at seated load weight. The three test phases (figure 6-1) are: a central business district (CBD) phase of 2 miles with 7 stops per mile and a top speed of 20 mph; an arterial phase of 2 miles with 2 stops per mile and a top speed of 40 mph; and a commuter phase of 4 miles with 1 stop and a maximum speed of 40 mph. At each designated stop the bus will remain stationary for seven seconds. During this time, the passenger doors shall be opened and closed.

3. The individual ADB phases remain unaltered with the exception that 1 mile has been changed to 1 lap on the Penn State Test Track. One lap is equal to 5,042 feet. This change is accommodated by adjusting the cruise distance and time.

4. The acceleration profile, for practical purposes and to achieve better repeatability, has been changed to "full throttle acceleration to cruise speed".

Several changes were made to the Fuel Economy Measurement Test (Engineering Type) For Trucks and Buses: SAE 1376 July 82:

1. Sections 1.1, and 1.2 only apply to diesel, gasoline, methanol, and any other fuel in the liquid state (excluding cryogenic fuels).

   1.1 SAE 1376 July 82 requires the use of at least a 16-gal fuel tank. Such a fuel tank when full would weigh approximately 160 lb. It is judged that a 12-gal tank weighing approximately 120 lb will be sufficient for this test and much easier for the technician and test personnel to handle.

   1.2 SAE 1376 July 82 mentions the use of a mechanical scale or a flow meter system. This test procedure uses a load cell readout combination that provides an accuracy of 0.5 percent in weight and permits on-board weighing of the gravimetric tanks at the end of each phase. This modification permits the determination of a fuel economy value for each phase as well as the overall cycle.

2. Section 2.1 applies to compressed natural gas (CNG), liquefied natural gas (LNG), cryogenic fuels, and other fuels in the vapor state.

   2.1 A laminar type flow meter will be used to determine the fuel consumption. The pressure and temperature across the flow element will be monitored by the flow computer. The flow computer will use this data to calculate the gas flow rate. The flow computer will also display the flow rate (scfm) as well as the total fuel used (scf). The total fuel used (scf) for each phase will be recorded on the Fuel Economy Data Form.

3. Use both Sections 1 and 2 for dual fuel systems.

FUEL ECONOMY CALCULATION PROCEDURE

A. For diesel, gasoline, methanol and fuels in the liquid state.

The reported fuel economy is based on the following: measured test quantities--distance traveled (miles) and fuel consumed (pounds); standard reference values--density of water at 60EF (8.3373 lbs/gal) and volumetric heating value of standard fuel; and test fuel specific gravity (unitless) and volumetric heating value (BTU/gal). These combine to give a fuel economy in miles per gallon (mpg) which is corrected to a standard gallon of fuel referenced to water at 60EF. This eliminates fluctuations in fuel economy due to fluctuations in fuel quality. This calculation has been programmed into a computer and the data processing is performed automatically.

The fuel economy correction consists of three steps:

1.) Divide the number of miles of the phase by the number of pounds of fuel consumed

phase	miles per phase	total miles per run
CBD	1.9097	5.7291
ART	1.9097	3.8193
COM	3.8193	3.8193

$$\mathbf{FEo_{mi/lb}} = \text{Observed fuel economy} = \frac{\text{miles}}{\text{lb of fuel}}$$

2.) Convert the observed fuel economy to miles per gallon [mpg] by multiplying by the specific gravity of the test fuel Gs (referred to water) at 60EF and multiply by the density of water at 60EF

$$\mathbf{FEo_{mpg}} = \mathbf{FEc_{mi/lb}} \times Gs \times Gw$$

where **Gs** = Specific gravity of test fuel at 60EF (referred to water)
Gw = 8.3373 lb/gal

3.) Correct to a standard gallon of fuel by dividing by the volumetric heating value of the test fuel (H) and multiplying by the volumetric heating value of standard reference fuel (Q). Both heating values must have the same units.

$$\mathbf{FEc} = \mathbf{FEo_{mpg}} \times \frac{Q}{H}$$

where

H = Volumetric heating value of test fuel [BTU/gal]
Q = Volumetric heating value of standard reference fuel

Combining steps 1-3 yields

$$\Rightarrow FEc = \frac{\text{miles}}{\text{lbs}} \times (Gs \times Gw) \times \frac{Q}{H}$$

4.) Covert the fuel economy from mpg to an energy equivalent of miles per BTU. Since the number would be extremely small in magnitude, the energy equivalent will be represented as miles/BTUx10^6.

Eq = Energy equivalent of converting mpg to mile/BTUx10^6.

$Eq = ((mpg)/(H))x10^6$

B. CNG, LNG, cryogenic and other fuels in the vapor state.

The reported fuel economy is based on the following: measured test quantities--distance traveled (miles) and fuel consumed (scf); density of test fuel, and volumetric heating value (BTU/lb) of test fuel at standard conditions (P=14.73 psia and T=60 EF). These combine to give a fuel economy in miles per lb. The energy equivalent (mile/BTUx10^6) will also be provided so that the results can be compared to buses that use other fuels.

1.) Divide the number of miles of the phase by the number of standard cubic feet (scf) of fuel consumed.

phase	miles per phase	total miles per run
CBD	1.9097	5.7291
ART	1.9097	3.8193

COM	3.8193	3.8193

$FEo_{mi/scf}$ = Observed fuel economy = $\frac{\text{miles}}{\text{scf of fuel}}$

2.) Convert the observed fuel economy to miles per lb by dividing FEo by the density of the test fuel at standard conditions (Lb/ft^3).

Note: The density of test fuel must be determined at standard conditions as described above. If the density is not defined at the above standard conditions, then a correction will be needed before the fuel economy can be calculated.

$$\mathbf{FEo_{mi/lb}} = FEo / Gm$$

where Gm = Density of test fuel at standard conditions

3.) Convert the observed fuel economy (FEomi/lb) to an energy equivalent of (miles/BTUx10^6) by dividing the observed fuel economy (FEomi/lb) by the heating value of the test fuel at standard conditions.

$$Eq = ((FEomi/lb)/H)x10^6$$

where

Eq = Energy equivalent of miles/lb to mile/BTUx10^6
H = Volumetric heating value of test fuel at standard conditions

6-III. DISCUSSION

This is a comparative test of fuel economy using diesel fuel with a heating value of 19,631 btu/lb. The driving cycle consists of Central Business District (CBD), Arterial (ART), and Commuter (COM) phases as described in 6-II. The fuel consumption for each driving cycle and for idle is measured separately. The results are corrected to a reference fuel with a volumetric heating value of 127,700.0 btu/gal.

An extensive pretest maintenance check is made including the replacement of all lubrication fluids. The details of the pretest maintenance are given in the first three Pretest Maintenance Forms. The fourth sheet shows the Pretest Inspection. The next sheet shows the correction calculation for the test fuel. The next four Fuel Economy Forms provide the data from the four test runs. Finally, the summary sheet provides the average fuel consumption. The overall average is based on total fuel and total mileage for each phase. The overall average fuel consumption values were; CBD – 7.40 mpg, ART – 7.99 mpg, and COM – 13.74 mpg. Average fuel consumption at idle was 0.43 gph.

FUEL ECONOMY PRE-TEST MAINTENANCE FORM

Bus Number: 0706	Date: 8-27-07	SLW (lbs): 14,420
Personnel: S.C. & T.S.		

FUEL SYSTEM	OK	Date	Initials
Install fuel measurement system	✓	8-27-07	S.C.
Replace fuel filter	✓	8-27-07	S.C.
Check for fuel leaks	✓	8-27-07	S.C.
Specify fuel type (refer to fuel analysis)			
Remarks: None noted.			
BRAKES/TIRES	OK	Date	Initials
Inspect hoses	✓	8-27-07	S.C.
Inspect brakes	✓	8-27-07	S.C.
Relube wheel bearings	✓	8-27-07	T.S.
Check tire inflation pressures (mfg. specs.)	✓	8-27-07	T.S.
Remarks: None noted.			
COOLING SYSTEM	OK	Date	Initials
Check hoses and connections	✓	8-27-07	S.C.
Check system for coolant leaks	✓	8-27-07	S.C.
Remarks: None noted.			

FUEL ECONOMY PRE-TEST MAINTENANCE FORM (page 2)

Bus Number: 0706	Date: 8-27-07
Personnel: S.C. & T.S.	

ELECTRICAL SYSTEMS	OK	Date	Initials
Check battery	✓	8-27-07	S.C.
Inspect wiring	✓	8-27-07	S.C.
Inspect terminals	✓	8-27-07	S.C.
Check lighting	✓	8-27-07	S.C.
Remarks: None noted.			
DRIVE SYSTEM	**OK**	**Date**	**Initials**
Drain transmission fluid	✓	8-27-07	T.S.
Replace filter/gasket	✓	8-27-07	T.S.
Check hoses and connections	✓	8-27-07	T.S.
Replace transmission fluid	✓	8-27-07	T.S.
Check for fluid leaks	✓	8-27-07	T.S.
Remarks: None noted.			
LUBRICATION	**OK**	**Date**	**Initials**
Drain crankcase oil	✓	8-27-07	T.S.
Replace filters	✓	8-27-07	T.S.
Replace crankcase oil	✓	8-27-07	T.S.
Check for oil leaks	✓	8-27-07	T.S.
Check oil level	✓	8-27-07	T.S.
Lube all chassis grease fittings	✓	8-27-07	T.S.
Lube universal joints	✓	8-27-07	T.S.
Replace differential lube including axles	✓	8-27-07	T.S.
Remarks: None noted.			

FUEL ECONOMY PRE-TEST MAINTENANCE FORM (page 3)

Bus Number: 0706	Date: 8-27-07
Personnel: S.C. & T.S.	

EXHAUST/EMISSION SYSTEM	OK	Date	Initials
Check for exhaust leaks	✓	8-27-07	S.C.
Remarks: None noted.			
ENGINE	OK	Date	Initials
Replace air filter	✓	8-27-07	T.S.
Inspect air compressor and air system	✓	8-27-07	T.S.
Inspect vacuum system, if applicable	✓	8-27-07	T.S.
Check and adjust all drive belts	✓	8-27-07	T.S.
Check cold start assist, if applicable	✓	8-27-07	T.S.
Remarks: None noted.			
STEERING SYSTEM	OK	Date	Initials
Check power steering hoses and connectors	✓	8-27-07	S.C.
Service fluid level	✓	8-27-07	S.C.
Check power steering operation	✓	8-27-07	S.C.
Remarks: None noted.			
	OK	Date	Initials
Ballast bus to seated load weight	✓	8-27-07	S.C.
TEST DRIVE	OK	Date	Initials
Check brake operation	✓	8-27-07	S.C.
Check transmission operation	✓	8-27-07	S.C.
Remarks: None noted.			

FUEL ECONOMY PRE-TEST INSPECTION FORM

Bus Number: 0706	Date: 8-28-07
Personnel: S.C.	

PRE WARM-UP	If OK, Initial
Fuel Economy Pre-Test Maintenance Form is complete	S.C.
Cold tire pressure (psi): Front 95 Middle N/A Rear 95	S.C.
Tire wear:	S.C.
Engine oil level	S.C.
Engine coolant level	S.C.
Interior and exterior lights on, evaporator fan on	S.C.
Fuel economy instrumentation installed and working properly.	S.C.
Fuel line -- no leaks or kinks	S.C.
Speed measuring system installed on bus. Speed indicator installed in front of bus and accessible to TECH and Driver.	S.C.
Bus is loaded to SLW	S.C.
WARM-UP	**If OK, Initial**
Bus driven for at least one hour warm-up	S.C.
No extensive or black smoke from exhaust	S.C.
POST WARM-UP	**If OK, Initial**
Warm tire pressure (psi): Front 99 Middle N/A Rear 98	S.C.
Environmental conditions Average wind speed <12 mph and maximum gusts <15 mph Ambient temperature between 30°F(-1C°) and 90°F(32°C) Track surface is dry Track is free of extraneous material and clear of interfering traffic	S.C.

FUEL ECONOMY DATA FORM (Liquid Fuels)

Bus Number: 0706	Manufacturer: Dallas Smith Corp.	Date: 8-28-07
Run Number: 1	Personnel: B.S. & S.C.	
Test Direction: ▫CW or ■CCW	Temperature (°F): 63	Humidity (%): 85
SLW (lbs): 14,420	Wind Speed (mph) & Direction: Calm	Barometric Pressure (in.Hg): 30.21

Cycle Type	Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°C)	Load Cell Reading (lb)		Fuel Used (lbs)
	Start	Finish		Start	Start	Finish	
CBD #1	0	8:10	8:10	29.0	0	.255	.255
ART #1	0	3:50	3:50	29.0	0	.246	.246
CBD #2	0	8:07	8:07	29.5	0	.249	.249
ART #2	0	3:55	3:55	29.5	0	.233	.233
CBD #3	0	8:05	8:05	30.0	0	.252	.252
COMMUTER	0	6:00	6:00	30.5	0	.264	.264
						Total Fuel =	1.499 lbs

20 minute idle : Total Fuel Used = .136 lbs

Heating Value = 19,631 BTU/LB

Comments: None noted.

FUEL ECONOMY DATA FORM (Liquid Fuels)

Bus Number: 0706	Manufacturer: Dallas Smith Corp.	Date: 8-28-07
Run Number: 2	Personnel: B.S. & S.C.	
Test Direction: ■CW or ▫CCW	Temperature (°F): 69	Humidity (%): 81
SLW (lbs): 14,420	Wind Speed (mph) & Direction: Calm	Barometric Pressure (in.Hg): 30.21

Cycle Type	Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°C)	Load Cell Reading (lb)		Fuel Used (lbs)
	Start	Finish		Start	Start	Finish	
CBD #1	0	8:15	8:15	30.5	0	.242	.242
ART #1	0	3:53	3:53	30.5	0	.225	.225
CBD #2	0	8:09	8:09	31.5	0	.238	.238
ART #2	0	3:58	3:58	32.5	0	.220	.220
CBD #3	0	8:11	8:11	33.0	0	.243	.243
COMMUTER	0	5:58	5:58	33.0	0	.260	.260
						Total Fuel = 1.428 lbs	

20 minute idle : Total Fuel Used = N/A lbs

Heating Value = 19,631 BTU/LB

Comments: None noted.

FUEL ECONOMY DATA FORM (Liquid Fuels)

Bus Number: 0706	Manufacturer: Dallas Smith Corp.	Date: 8-28-07
Run Number: 4	Personnel: B.S. & S.C.	
Test Direction: □CW or ■CCW	Temperature (°F): 78	Humidity (%): 65
SLW (lbs): 14,420	Wind Speed (mph) & Direction: Calm	Barometric Pressure (in.Hg): 30.21

Cycle Type	Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°C)	Load Cell Reading (lb)		Fuel Used (lbs)
	Start	Finish		Start	Start	Finish	
CBD #1	0	8:09	8:09	38.0	0	.248	.248
ART #1	0	3:55	3:55	38.5	0	.228	.228
CBD #2	0	8:13	8:13	39.0	0	.244	.244
ART #2	0	3:54	5:54	39.0	0	.224	.224
CBD #3	0	8:15	8:15	39.0	0	.249	.249
COMMUTER	0	6:03	6:03	39.5	0	.275	.275
						Total Fuel =	1.468 lbs

20 minute idle : Total Fuel Used = .141

Heating Value = 19,631 BTU/LB

Comments: None noted.

FUEL ECONOMY SUMMARY SHEET

BUS MANUFACTURER :Dallas Smith Corp. BUS NUMBER :0706
BUS MODEL :Low Floor Friendly B TEST DATE :08/28/07

FUEL TYPE : DIESEL
SP. GRAVITY : .8095
HEATING VALUE : 19631.00 BTU/Lb
FUEL TEMPERATURE : 60.00 deg F
Standard Conditions : 60 deg F and 14.7 psi
Density of Water : 8.3373 lb/gallon at 60 deg F

CYCLE	TOTAL FUEL USED(GAL)	TOTAL MILES	FUEL ECONOMY MPG(Measured)	FUEL ECONOMY MPG (Corrected)
Run # :1, CCW				
CBD	.756	5.73	7.579	7.25
ART	.479	3.82	7.975	7.63
COM	.264	3.82	14.470	13.84
TOTAL	1.499	13.37	8.919	8.53
Run # :2, CW				
CBD	.723	5.73	7.925	7.58
ART	.445	3.82	8.584	8.21
COM	.260	3.82	14.692	14.05
TOTAL	1.428	13.37	9.363	8.95
Run # :3, CW				
CBD	.744	5.73	7.702	7.37
ART	.455	3.82	8.396	8.03
COM	.265	3.82	14.415	13.79
TOTAL	1.464	13.37	9.133	8.73
Run # :4, CCW				
CBD	.741	5.73	7.733	7.39
ART	.452	3.82	8.451	8.08
COM	.275	3.82	13.891	13.28
TOTAL	1.468	13.37	9.108	8.71

IDLE CONSUMPTION (MEASURED)

First 20 Minutes Data : .14GAL Last 20 Minutes Data : .14GAL
Average Idle Consumption : .42GAL/Hr

RUN CONSISTENCY: % Difference from overall average of total fuel used

Run 1 : -2.3 Run 2 : 2.5 Run 3 : .1 Run 4 : -.2

SUMMARY (CORRECTED VALUES)

Average Idle Consumption : .43 G/Hr
Average CBD Phase Consumption : 7.40 MPG
Average Arterial Phase Consumption : 7.99 MPG
Average Commuter Phase Consumption : 13.74 MPG
Overall Average Fuel Consumption : 8.73 MPG
Overall Average Fuel Consumption : 65.90 Miles/ Million BTU