PARTIAL

STURAA TEST

10 YEAR

350,000 MILE BUS

from

THOMAS BUILT BUSES, INC.

MODEL CITILINER

APRIL 1997

PTI-BT-R9704-P

PENNSTATE

1855

The Pennsylvania Transportation Institute

201 Research Office Building (814) 865-1891
The Pennsylvania State University
University Park, PA 16802

Bus Testing and Research Center

6th Avenue and 45th Street (814) 949-7944
Altoona, PA 16602

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*NOTE: Partial STURAA Testing was performed on this bus. Only those tests required by the Federal Transit Administration are included in this report. In order to remain consistent with the Time and Fee Schedule, the tests included in this report retain their original numbers and are not numbered sequentially.

EXECUTIVE SUMMARY

Thomas Built Buses, Inc. submitted a model Citiliner, CNG fueled 32 seat/32-root bus, for partial STURAA testing in the 10 350,000 mile category. The Federal Transit Administration determined that the following tests would be performed: 4. Performance and 6.0 Fuel Economy Tests. The odometer reading at the time of delivery was 0,125.0 miles. Testing started on March 25, 1997, and was competed on March 27, 1997. The Check-In Section of the report provides a description of the bus and specifies its major components.

The Performance /test was to be performed up to a maximum speed of 50 mph. In the counter clockwise direction the bus safely reached 50 mph in an average of 51.23 seconds. During the clockwise test the bus was only able to reach 48 mph safely in the distance available on the test track. The average time to reach 48 mph during the clockwise run was 54.52 seconds. Because both clockwise and counter clockwise runs could not be performed up to the test speed of 50 mph, only the data up to 40 mph was used to plot the Speed vs. Time results. The average time to obtain 40 mph for both directions was 32.06 seconds. The time to reach 50 mph, 63.35 seconds, was extrapolated from data up to 40 mph. The fitted curve of velocity vs time is attached, followed by the calculated gradeability results.

The fuel Economy Test was run on simulated central business district, arterial, and commuter courses. The results were 0.55 M/lb, 0.66 M/lb, and 0.95 M/lb respectively; with an overall average of 0.66 M/lb.

ABBREVIATIONS

ABTC	-	Altoona Bus Test Center
A/C	-	air conditioner
ADB	-	advance design bus
ATA-MC	-	The Maintenance Council of the American Trucking Association
CBD	-	central business district
CW	-	curb weight (bus weight including maximum fuel, oil, and coolant; but without passengers or driver)
dB(A)	-	decibels with reference to 0.0002 microbar as measured on the "A" scale
DIR	-	test director
DR	-	bus driver
EPA	-	Environmental Protection Agency
FFS	-	free floor space (floor area available to standees, excluding ingress/egress areas, area under seats, area occupied by feet of seated passengers, and the vestibule area)
GVL	-	gross vehicle load (150 lb for every designed passenger seating position, for the driver, and for each 1.5 sq ft of free floor space)
GVW	-	gross vehicle weight (curb weight plus gross vehicle load)
GVWR	-	gross vehicle weight rating
MECH	-	bus mechanic
mpg	-	miles per gallon
mph	-	miles per hour
NBM	-	new bus models
PM	-	Preventive maintenance
PSBRTF	-	Penn State Bus Research and Testing Facility
PTI	-	Pennsylvania Transportation Institute
rpm	-	revolutions per minute
SAE	-	Society of Automotive Engineers
SCH	-	test scheduler
SEC	-	secretary
SLW	-	seated load weight (curb weight plus 150 lb for every designed passenger seating position and for the driver)
STURAA	-	Surface Transportation and Uniform Relocation Assistance Act
TD	-	test driver
TECH	-	test technician
TM	-	track manager
TP	-	test personnel

TEST BUS CHECK-IN

I. OBJECTIVE

The objective of this task is to log in the NBM, assign a NBM number, complete the vehicle data form, and perform a safety check.

II. TEST DESCRIPTION

The test consists of assigning a NBM test number to the bus, cleaning the bus, completing the vehicle data form, obtaining any special information and tools from the manufacturer, determining a testing schedule, performing an initial safety check, and performing the manufacturer's recommended preventive maintenance. The bus manufacturer must certify that the bus meets all Federal regulations.

III. DISCUSSION

The check-in procedure is used to identify in detail the major components and configuration of the bus.

The bus consists of a Thomas Built model Citiliner. Power is provided by a CNG fueled, Cummins ERB6G-195 engine coupled to an Allison MT 643 transmission. The bus is equipped with a front door located forward of the front axle, and a rear door equipped with a Ricon model F9000 handicap lift, forward of the rear axle.

The measured curb weight is 8,500 lb for the front axle and 15,300 lb for the rear axle. These combined weights provide a total measured curb weight of 23,800 lb. There are 32 seats including the driver and room for 16 standing passengers bringing the total passenger capacity to 48. Gross load is 150 lb x 48 = 7,200 lb. At full capacity, the measured gross vehicle weight is 31,000 lb.

VEHICLE DATA FORM

Bus Number: 9704	Arrival Date: 3-13-97
Bus Manufacturer: Thomas Built Buses, Inc.	Vehicle Identification Number (VIN): 1T7CL2F23V1145367
Model Number: Citiliner	Date: 3-14-97
Personnel: Bob LaMorte & Stan Crawford	

WEIGHT:

Individual Wheel Reactions:

Weights (lb)	Front Axle		Middle Axle		Rear Axle	
	Right	Left	Right	Left	Right	Left
CW	4,100	4,400	N/A	N/A	7,900	7,400
SLW	4,300	5,100	N/A	N/A	9,400	9,200
GVW	5,500	5,900	N/A	N/A	9,800	9,800

Total Weight Details:

Weight (lb)	CW	SLW	GVW	GAWR
Front Axle	8,500	9,400	11,400	12,080
Middle Axle	N/A	N/A	N/A	N/A
Rear Axle	15,300	18,600	19,600	21,200
Total	23,800	28,000	31,000	GVWR: 33,280

Dimensions:

Length (ft/in)	32 / 9.3
Width (in)	94.0
Height (in)	126.0
Front Overhang (in)	89.5
Rear Overhang (in)	122.8
Wheel Base (in)	181.0
Wheel Track (in)	Front: 80.0
	Rear: 72.5

Bus Number: 9704	Date: 3-14-97

CLEARANCES:

Lowest Point Outside Front Axle	Location: Bottom of step Clearance(in): 10.3
Lowest Point Outside Rear Axle	Location: Transmission oil pan Clearance(in): 12.3
Lowest Point between Axles	Location: Bottom of rear step Clearance(in): 12.2
Ground Clearance at the center (in)	12.2
Front Approach Angle (deg)	8.9
Rear Approach Angle (deg)	7.0
Ramp Clearance Angle (deg)	7.7
Aisle Width (in)	18.5
Inside Standing Height at Center Aisle (ft)	77.0

BODY DETAILS:

Body Structural Type	Integral		
Frame Material	Steel		
Body Material	Steel		
Floor Material	Plywood		
Roof Material	Steel		
Windows Type	☐ Fixed	☒ Movable	
Window Mfg./Model No.	GAGC / AS-3		
Number of Doors	1 Front	1 Rear	
Mfr. / Model No.	Front- Bode / Reverse Jacknife	Rear-Bode / SXD-44	
Dimension of Each Door (in)	Front - 24.0 x 91.0	Rear - 36.3 x 96.0	
Passenger Seat Type	☒ Cantilever	☒ Pedestal	☐ Other (explain)
Mfr. / Model No.	TSI / 1111		
Driver Seat Type	☒ Air	☐ Spring	☐ Other (explain)
Mfr. / Model No.	Isringhausen / 6500		
Number of Seats (including Driver)	32		

Bus Number: 9704	Date: 3-14-97

BODY DETAILS (Contd..)

Free Floor Space (ft^2)	24.0				
Height of Each Step at Normal Position (in)	Front	1. 13.3	2. 9.3	3. 9.3	4. 9.5
	Middle	1. 14.0	2. 9.3	3. 9.3	4. 9.5
	Rear	1. N/A	2. N/A	3. N/A	4. N/A
Step Elevation Change - Kneeling (in)	N/A				

ENGINE

Type	☐ C.I.	☒ Alternate Fuel	
	☒ S.I.	☐ Other (explain)	
Mfr. / Model No.	Cummins / ERB6G 195		
Location	☐ Front	☒ Rear	☐ Other (explain)
Fuel Type	☐ Gasoline	☒ CNG	☐ Methanol
	☐ Diesel	☐ LNG	☐ Other (explain)
Fuel Tank Capacity (indicate units)	7,312 scf @ 3,600 psi.		
Fuel Induction Type	☐ Injected	☐ Carburetion	
Fuel Injector Mfr. / Model No.	N/A		
Carburetor Mfr. / Model No.	Throttle body Cummins / ERB6G 195		
Fuel Pump Mfr. / Model No.	N/A		
Alternator (Generator) Mfr. / Model No.	Leece Neville / A0012800JB		
Maximum Rated Output (Volts / Amps)	14 / 160		
Air Compressor Mfr. / Model No.	Bendix / TUFLO 550		
Maximum Capacity (ft^3 / min)	13.2		
Starter Type	☒ Electrical	☐ Pneumatic	☐ Other (explain)
Starter Mfr. / Model No.	Denso / 228000		

Bus Number: 9704	Date: 3-14-97

TRANSMISSION

Transmission Type	☐ Manual	☒ Automatic	
Mfr. / Model No.	Allison / MT 643		
Control Type	☒ Mechanical	☐ Electrical	☐ Other (explain)
Torque Convertor Mfr. / Model No.	Allison / MT 643		
Integral Retarder Mfr. / Model No.	N/A		

SUSPENSION

Number of Axles	2		
Front Axle Type	☐ Independent	☒ Beam Axle	
Mfr. / Model No.	Thomas / F3W-1200		
Axle Ratio (if driven)	N/A		
Suspension Type	☒ Air	☐ Spring	☐ Other (explain)
No. of Shock Absorbers	2		
Mfr. / Model No.	Neway / 90044915		
Middle Axle Type	☐ Independent	☐ Beam Axle	
Mfr. / Model No.	N/A		
Axle Ratio (if driven)	N/A		
Suspension Type	☐ Air	☐ Spring	☐ Other (explain)
No. of Shock Absorbers	N/A		
Mfr. / Model No.	N/A		
Rear Axle Type	☐ Independent	☒ Beam Axle	
Mfr. / Model No.	Eaton / 22133		
Axle Ratio (if driven)	5:29		
Suspension Type	☒ Air	☐ Spring	☐ Other (explain)
No. of Shock Absorbers	2		
Mfr. / Model No.	Neway / 6B13N1L		

Bus Number: 9704	Date: 3-14-97

WHEELS & TIRES

Front	Wheel Mfr./ Model No.	Motor Wheel / 22.5 x 8.25
	Tire Mfr./ Model No.	Goodyear G159 / 11R22.5
Rear	Wheel Mfr./ Model No.	Motor Wheel / 22.5 x 8.25
	Tire Mfr./ Model No.	Goodyear G159 / 11R22.5

BRAKES

Front Axle Brakes Type	⊠ Cam	□ Disc	□ Other (explain)
Mfr. / Model No.	Eaton / 16½ x 6		
Middle Axle Brakes Type	□ Cam	□ Disc	□ Other (explain)
Mfr. / Model No.	N/A		
Rear Axle Brakes Type	⊠ Cam	□ Disc	□ Other (explain)
Mfr. / Model No.	Eaton / 16½ x 8.5		
Retarder Type	Transmission		
Mfr. / Model No.	Allison / MT 643		

HVAC

Heating System Type	□ Air	⊠ Water	□ Other
Capacity (Btu/hr)	65,000		
Mfr. / Model No.	Bergstrom / 115,000 Btu		
Air Conditioner	⊠ Yes	□ No	
Location	Ceiling 1-right side / 2-left side		
Capacity (Btu/hr)	120,000		
A/C Compressor Mfr. / Model No.	Harrison Mfg (GM) / 1766		

STEERING

Steering Gear Box Type	Hydraulic gear
Mfr. / Model No.	Ross / TAS 85
Steering Wheel Diameter (in)	20
Number of turns (lock to lock)	5.5

Bus Number: 9704	Date: 3-14-97

OTHERS

Wheel Chair Ramps	Location: N/A	Type: N/A
Wheel Chair Lifts	Location: Right rear	Type: Platform
Mfr. / Model No.	Ricon / F9000	
Emergency Exit	Location: Side windows Roof hatch	Number: 9 2

CAPACITIES

Fuel Tank Capacity (units)	7,312 scf @ 3,600 psi
Engine Crankcase Capacity (gallons)	3.75
Transmission Capacity (gallons)	3.00
Differential Capacity (gallons)	4.13
Cooling System Capacity (gallons)	2.63
Power Steering Fluid Capacity (gallons)	N/A

VEHICLE DATA FORM

Bus Number: 9704	Date: 3-14-97

List all spare parts, tools and manuals delivered with the bus.

Part Number	Description	Qty.
N/A	N/A	N/A

COMPONENT/SUBSYSTEM INSPECTION FORM

Bus Number: 9704	Date: 3-14-97

Subsystem	Checked	Comments
Air Conditioning Heating and Ventilation	✓	
Body and Sheet Metal	✓	
Frame	✓	
Steering	✓	
Suspension	✓	
Interior/Seating	✓	
Axles	✓	
Brakes	✓	
Tires/Wheels	✓	
Exhaust	✓	
Fuel System	✓	PRD vent from GNC tanks are plumed to vent in the engine compartment. Venting PRD line inside engine compartment may pose a safety hazard and may not comply with ANSI/NFPA Section 3-4.52.
Power Plant	✓	
Accessories	✓	
Lift System	✓	
Interior Fasteners	✓	
Batteries	✓	

CHECK - IN

DIAMOND COACH
MODEL TC 18 FD

CHECK - IN CONT.

DIAMOND COACH MODEL TC 18 FD EQUIPPED WITH A BRAUN MODEL LZ 11V67 ARS WHEELCHAIR LIFT

4. PERFORMANCE - AN ACCELERATION, GRADEABILITY, AND TOP SPEED TEST

4-I. TEST OBJECTIVE

The objective of this test is to determine the acceleration, gradeability, and top speed capabilities of the bus.

4-II. TEST DESCRIPTION

In this test, the bus will be operated at SLW on the skid pad at the PSBRTF. The bus will be accelerated at full throttle from a standstill to a maximum "geared" or "safe" speed as determined by the test driver. The vehicle speed is measured using a Correvit non-contacting speed sensor. The times to reach speed between ten mile per hour increments are measured and recorded using a stopwatch with a lap timer. The time to speed data will be recorded on the Performance Data Form and later used to generate a speed vs time plot and gradeability calculations.

4-III. DISCUSSION

This test consists of three runs in both the clockwise and counterclockwise directions on the PSBRTF Test Track. Velocity versus time data is obtained for each run and results are averaged together to minimize any test variability which might be introduced by wind or other external factors. The test was performed up to a maximum speed of 50 mph. In the counter clockwise direction the bus safely reached 50 mph in an average of 51.23 seconds. During the clockwise test the bus was only able to reach 48 mph safely in the distance available on the test track. The average time to reach 48 mph during the clockwise run was 54.52 seconds. Because both clockwise and counter clockwise runs could not be performed up to the test speed of 50 mph, only the data up to 40 mph was used to plot the Speed vs. Time results. The average time to obtain 40 mph for both directions was 32.06 seconds. The time to reach 50 mph, 63.35 seconds, was extrapolated from data up to 40 mph. The fitted curve of velocity vs time is attached, followed by the calculated gradeability results.

PERFORMANCE DATA FORM

Bus Number: 9704	Date: 3-27-97
Personnel: Bob LaMorte, Stan Crawford & Ron Harter	
Temperature (°F): 49	Humidity (%): 52
Wind Direction: N.W.	Wind Speed (mph): 9
Barometric Pressure (in.Hg): 30.10	
Air Conditioning compressor-OFF	✓ Checked
Ventilation fans-ON HIGH	✓ Checked
Heater pump motor-Off	✓ Checked
Defroster-OFF	✓ Checked
Exterior and interior lights-ON	✓ Checked
Windows and doors-CLOSED	✓ Checked

ACCELERATION, GRADEABILITY, TOP SPEED

Counter Clockwise Recorded Interval Times

Speed	Run 1	Run 2	Run 3
10 mph	3.85	4.39	3.92
20 mph	8.91	9.28	9.09
30 mph	16.89	17.57	18.24
40 mph	28.62	30.68	31.34
Top Test Speed(mph) 50	49.21	51.69	52.80

Clockwise Recorded Interval Times

Speed	Run 1	Run 2	Run 3
10 mph	4.14	4.22	3.90
20 mph	9.49	10.04	9.37
30 mph	19.27	20.85	18.81
40 mph	33.88	34.45	33.37
Top Test Speed(mph) 50	55.62	53.83	54.12

PERFORMANCE SUMMARY SHEET

BUS MANUFACTURER :THOMAS BUILT
BUS MODEL :CITILINER
BUS NUMBER :9704
TEST DATE :3/27/97

TEST CONDITIONS :

TEMPERATURE (DEG F) : 49.0
WIND DIRECTION : NW
WIND SPEED (MPH) : 9.0
HUMIDITY (%) : 52
BAROMETRIC PRESSURE (IN. HG) : 30.1

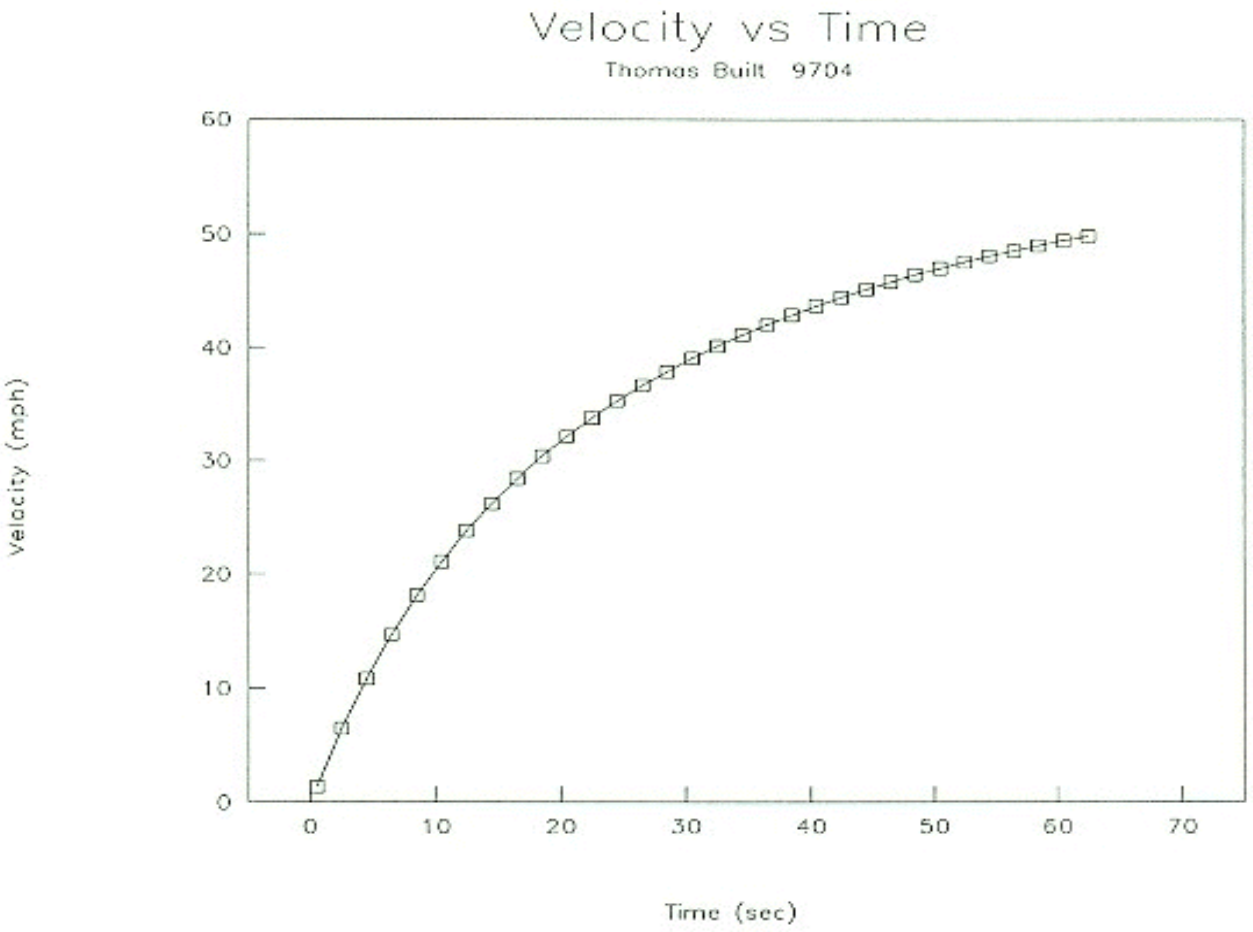
VEHICLE SPEED	AVERAGE TIME (SEC)		
(MPH)	CCW DIRECTION	CW DIRECTION	TOTAL
10.0	4.05	4.09	4.07
20.0	9.09	9.63	9.36
30.0	17.57	19.64	18.61
40.0	30.21	33.90	32.06

TEST SUMMARY :

VEHICLE SPEED (MPH)	TIME (SEC)	ACCELERATION (FT/SEC^2)	MAX. GRADE (%)
1.0	.36	4.0	12.5
5.0	1.91	3.6	11.2
10.0	4.11	3.1	9.7
15.0	6.68	2.6	8.2
20.0	9.74	2.2	6.8
25.0	13.45	1.8	5.5
30.0	18.10	1.4	4.4
35.0	24.11	1.1	3.3
40.0	32.26	.8	2.4
45.0	44.10	.5	1.6
50.0	63.35	.3	.9

NOTE:a) Gradeability results were calculated from performance test data. Actual sustained gradeability performance for vehicles equipped with auto transmission may be lower than the values indicated here.

b) Test data up to 40.0 mph was used to extrapolate the results up to 50.0 mph


Velocity vs Time
Thomas Built 9704
Velocity (mph)
Time (sec)
0
10
20
30
40
50
60
70

6. FUEL ECONOMY TEST - A FUEL CONSUMPTION TEST USING AN APPROPRIATE OPERATING CYCLE

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 PSBRTF. 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, 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 PSBRTF 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 flowmeter 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), liquified natural gas (LNG), cryogenic fuels, and other fuels in the vapor state.

2.1 A laminar type flowmeter 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 60°F (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 60°F. 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 60°F and multiply by the density of water at 60°F

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

where **Gs** = Specific gravity of test fuel at 60°F (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

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

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 °F). 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	total miles per phase	per run
CBD	1.9097	5.7291
ART	1.9097	3.8193
COM	3.8193	3.8193

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

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 LNG fuel with a heating value of 1,008.1 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 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 - 0.55 mpg, ART - 0.66 mpg, and COM - 0.95 mpg. Average fuel consumption at idle was 5.60 lb/hr (133.3 Scf/Hr).

FUEL ECONOMY PRE-TEST MAINTENANCE FORM

Bus Number: 9704	Date: 3-25-97	SLW (lbs): 28,000
Personnel: Bob LaMorte, Stan Crawford & Ken Defibaugh		

FUEL SYSTEM	OK	Date	Initials
Install fuel measurement system	✓	3-25-97	RLL
Replace fuel filter	✓	3-25-97	KJD
Check for fuel leaks	✓	3-25-97	RLL
Specify fuel type (refer to fuel analysis)	CNG		
Remarks:			
BRAKES/TIRES	**OK**	**Date**	**Initials**
Inspect hoses	✓	3-21-97	KJD
Inspect brakes	✓	3-25-97	KJD
Relube wheel bearings	✓	3-21-97	KJD
Check tire inflation pressures (mfg. specs.)	✓	3-25-97	SC
Remarks:			
COOLING SYSTEM	**OK**	**Date**	**Initials**
Check hoses and connections	✓	3-25-97	KJD
Check system for coolant leaks	✓	3-25-97	KJD
Remarks:			

FUEL ECONOMY PRE-TEST MAINTENANCE FORM (page 2)

Bus Number: 9704	Date: 3-25-97
Personnel: Bob LaMorte & Stan Crawford	

ELECTRICAL SYSTEMS	OK	Date	Initials
Check battery	✓	3-25-97	SC
Inspect wiring	✓	3-25-97	SC
Inspect terminals	✓	3-25-97	SC
Check lighting	✓	3-25-97	SC
Remarks:			

DRIVE SYSTEM	OK	Date	Initials
Drain transmission fluid	✓	3-24-97	KJD
Replace filter/gasket	✓	3-24-97	KJD
Check hoses and connections	✓	3-24-97	KJD
Replace transmission fluid	✓	3-24-97	KJD
Check for fluid leaks	✓	3-24-97	KJD
Remarks:			

LUBRICATION	OK	Date	Initials
Drain crankcase oil	✓	3-24-97	KJD
Replace filters	✓	3-24-97	KJD
Replace crankcase oil	✓	3-24-97	KJD
Check for oil leaks	✓	3-24-97	KJD
Check oil level	✓	3-24-97	KJD
Lube all chassis grease fittings	✓	3-25-97	DF
Lube universal joints	✓	3-25-97	DF
Replace differential lube including axles	✓	3-21-97	DF
Remarks:			

FUEL ECONOMY PRE-TEST MAINTENANCE FORM (page 3)

Bus Number: 9704	Date: 3-25-97
Personnel: Bob LaMorte & Stan Crawford	

EXHAUST/EMISSION SYSTEM	OK	Date	Initials
Check for exhaust leaks	✓	3-21-97	JP
Remarks:			

ENGINE	OK	Date	Initials
Replace air filter	✓	3-21-97	
Inspect air compressor and air system	✓	3-21-97	
Inspect vacuum system, if applicable	✓	3-25-97	
Check and adjust all drive belts	✓	3-24-97	
Check cold start assist, if applicable	N/A		
Remarks:			

STEERING SYSTEM	OK	Date	Initials
Check power steering hoses and connectors	✓	3-21-97	DF
Service fluid level	✓	3-21-97	DF
Check power steering operation	✓	3-21-97	DF
Remarks:			

	OK	Date	Initials
Ballast bus to seated load weight	✓	3-25-97	RLL

TEST DRIVE	OK	Date	Initials
Check brake operation	✓	3-21-97	DF
Check transmission operation	✓	3-21-97	DF
Remarks:			

FUEL ECONOMY PRE-TEST INSPECTION FORM

Bus Number: 9704	Date: 3-26-97
Personnel: Bob LaMorte & Ron Harter	

PRE WARM-UP	If OK, Initial
Fuel Economy Pre-Test Maintenance Form is complete	RLL
Cold tire pressure (psi): Front 105 Middle N/A Rear 105	RLL
Tire wear:	RLL
Engine oil level	RLL
Engine coolant level	RLL
Interior and exterior lights on, evaporator fan on	RLL
Fuel economy instrumentation installed and working properly.	RLL
Fuel line -- no leaks or kinks	RLL
Speed measuring system installed on bus. Speed indicator installed in front of bus and accessible to TECH and Driver.	RLL
Bus is loaded to SLW	RLL
WARM-UP	**If OK, Initial**
Bus driven for at least one hour warm-up	RLL
No extensive or black smoke from exhaust	RLL
POST WARM-UP	**If OK, Initial**
Warm tire pressure (psi): Front 106 Middle N/A Rear 107	RLL
Environmental conditions Average wind speed <12 mph and maximum gusts <15 mph Ambient temperature between 30°(-1°) and 90°F(32°C) Track surface is dry Track is free of extraneous material and clear of interfering traffic	RLL

FUEL ECONOMY DATA FORM (Gaseous Fuels)

Bus Number: 9704	Manufacturer: Thomas Built	Date: 3-26-97
Run Number: 1	Personnel: Bob LaMorte and Ron Harter	
Test Direction: □CW or ✘CCW	Ambient Temperature (°F): 36	Humidity (%): 72
SLW (lbs): 28,000	Wind Speed (mph) & Direction: 8 / N	Barometric Pressure (in.Hg): 30.30

Cycle Type	Run Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°F)	Total Fuel Used (SCF)
	Start	Finish		Start	
CBD #1	0	8:55	8:55	51.6	83.5
ART #1	0	4:23	4:23	64.4	69.3
CBD #2	0	8:50	8:50	51.0	84.8
ART #2	0	4:21	4:21	66.4	70.8
CBD #3	0	8:51	8:51	55.3	82.8
COMMUTER	0	6:00	6:00	72.9	95.5
Total Fuel: 486.7SCF					

20 minute idle : Total Fuel Used = 49.8 SCF	
No Load Flow Rate at Idle = 2.58 SCFM	No Load Flow Rate at Full Throttle = 24.85 SCFM
Heating Value = 1,008.1 BTU/LB	
Comments:	

FUEL ECONOMY DATA FORM (Gaseous Fuels)

Bus Number: 9704	Manufacturer: Thomas Built	Date: 3-26-97
Run Number: 2	Personnel: Bob LaMorte and Ron Harter	
Test Direction: ✘CW or □CCW	Ambient Temperature (°F): 37	Humidity (%): 69
SLW (lbs): 28,000	Wind Speed (mph) & Direction: 6 / N.W.	Barometric Pressure (in.Hg): 30.32

Cycle Type	Run Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°F)	Total Fuel Used (SCF)
	Start	Finish		Start	
CBD #1	0	8:57	8:57	68.8	81.5
ART #1	0	4:27	4:27	79.9	68.0
CBD #2	0	9:00	9:00	69.8	82.7
ART #2	0	4:24	4:24	73.5	69.2
CBD #3	0	9:03	9:03	60.0	83.1
COMMUTER		6:00	6:00	69.7	95.1
Total Fuel: SCF					

20 minute idle : Total Fuel Used = N/A SCF	
No Load Flow Rate at Idle = N/A SCFM	No Load Flow Rate at Full Throttle =N/A SCFM
Heating Value = 1,008.0 BTU/LB	
Comments:	

FUEL ECONOMY DATA FORM (Gaseous Fuels)

Bus Number: 9704	Manufacturer: Thomas Built	Date: 3-26-97
Run Number: 3	Personnel: Bob LaMorte and Ron Harter	
Test Direction: □CW or ✘CCW	Ambient Temperature (°F): 36	Humidity (%): 75
SLW (lbs): 28,000	Wind Speed (mph) & Direction: 9 / N.W.	Barometric Pressure (in.Hg): 29.9

Cycle Type	Run Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°F)	Total Fuel Used (SCF)
	Start	Finish		Start	
CBD #1	0	8:47	8:47	76.5	81.5
ART #1	0	4:20	4:20	73.0	68.7
CBD #2	0	8:48	8:48	67.9	83.0
ART #2	0	4:21	4:21	75.3	70.0
CBD #3	0	8:51	8:51	68.1	83.2
COMMUTER	0	5:59	5:59	79.5	86.3
Total Fuel: 482.7 SCF					

20 minute idle : Total Fuel Used =N/A SCF	
No Load Flow Rate at Idle =N/A SCFM	No Load Flow Rate at Full Throttle = N/A SCFM
Heating Value = 1,008.1 BTU/LB	
Comments:	

FUEL ECONOMY DATA FORM (Gaseous Fuels)

Bus Number: 9704	Manufacturer: Thomas Built	Date: 3-26-97
Run Number: 4	Personnel: Bob LaMorte and Ron Harter	
Test Direction: ✘CW or □CCW	Ambient Temperature (°F): 38	Humidity (%): 70
SLW (lbs): 28,000	Wind Speed (mph) & Direction: 7 / N	Barometric Pressure (in.Hg):30.00

Cycle Type	Run Time (min:sec)		Cycle Time (min:sec)	Fuel Temperature (°F)	Total Fuel Used (SCF)
	Start	Finish		Start	
CBD #1	0	8:51	8:51	70.2	80.0
ART #1	0	4:25	4:25	79.1	69.1
CBD #2	0	9:00	9:00	65.7	82.6
ART #2	0	4:23	4:23	80.3	68.3
CBD #3	0	8.57	8.57	68.9	81.5
COMMUTER	0	6.00	6.00	75.7	96.5
Total Fuel: 478.0 SCF					

20 minute idle : Total Fuel Used =39.0 SCF	
No Load Flow Rate at Idle =2.06 SCFM	No Load Flow Rate at Full Throttle = 24.8 SCFM
Heating Value =1,008.1 BTU/LB	
Comments:	

FUEL ECONOMY SUMMARY SHEET

BUS MANUFACTURER :THOMAS BUILT BUS NUMBER :9704
BUS MODEL :CITILINER TEST DATE :3/26/97

FUEL TYPE : NATURAL GAS
SP. GRAVITY : .5770
HEATING VALUE : 1008.10 BTU/cf
Standard Conditions : 60 deg F and 14.7 psi
Density of Air : 0.0729 lb/scf

CYCLE	TOTAL FUEL USED (Scf)	TOTAL MILES	FUEL ECONOMY M/Scf(Measured)	FUEL ECONOMY M/Lb(Corrected)
Run # :1, CCW				
CBD	251.1	5.73	.02	.54
ART	140.1	3.82	.03	.65
COM	95.5	3.82	.04	.95
TOTAL	486.7	13.37	.03	.65
Run # :2, CW				
CBD	247.3	5.73	.02	.55
ART	137.2	3.82	.03	.66
COM	95.1	3.82	.04	.95
TOTAL	479.6	13.37	.03	.66
Run # :3, CCW				
CBD	247.7	5.73	.02	.55
ART	138.7	3.82	.03	.65
COM	96.3	3.82	.04	.94
TOTAL	482.7	13.37	.03	.66
Run # :4, CW				
CBD	244.1	5.73	.02	.56
ART	137.4	3.82	.03	.66
COM	96.5	3.82	.04	.94
TOTAL	478.0	13.37	.03	.66

IDLE CONSUMPTION

First 20 Minutes Data : 49.8 Scf Last 20 Minutes Data : 39.0 Scf
Average Idle Consumption : 133.2 Scf/Hr

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

Run 1 : -1.0 Run 2 : .4 Run 3 : -.2 Run 4 : .8

SUMMARY

Average Idle Consumption : 5.60 LB/Hr
Average CBD Phase Consumption : .55 M/Lb
Average Arterial Phase Consumption : .66 M/Lb
Average Commuter Phase Consumption : .95 M/Lb
Overall Average Fuel Consumption : .66 M/Lb
Overall Average Fuel Consumption : 27.53 Miles/ Million BTU