Emissions and Fuel Economy Tests of the University of Florida Hybrid Bus

December, 1977

Environmental Protection Agency
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Technology Assessment and Evaluation Branch

Background

Several years ago the University of Florida began studies of hybrid vehicles under the sponsorship of the State of Florida Department of Transportation. Initially they designed and built a small gasoline-electric hybrid automobile. The program was later expanded to the design and construction of a hybrid diesel-electric bus with funding provided by UMTA for the demonstration phase of the project.

Extensive testing of the bus was conducted over the last two years. The vehicle was also placed in service in Gainesville for a considerable part of this time. In January 1977 UMTA asked EPA to conduct emission and fuel economy tests of the hybrid bus.

Due to the limited availability of test facilities, only a short test sequence was planned. In addition, the University of Florida personnel involved with the project and needed for vehicle testing are full time students and faculty. Thus they were unable to support a long term testing plan.

As a result, a complete evaluation of the hybrid bus' emissions and fuel economy was neither planned nor conducted. The conclusions drawn from this program are, therefore, necessarily of limited applicability and are thus neither a comprehensive evaluation of either the test vehicle or the hybrid powerplant concept. A complete evaluation of the emissions and fuel economy of this hybrid bus would require more replicate testing and more types of tests than could be performed.

Abstract

As a hybrid vehicle the bus performed well with minimal problems. For the Ann Arbor Bus Route, the hot test emissions for HC, CO and NOx were 7.07, 5.00 and 11.59 grams/mile while achieving 8.4 miles/gallon. The Univ. of Florida Bus Route, UMTA cycle and NYC cycle were also run to evaluate emissions. Results for these cycles were comparable.

Vehicle Description

The test vehicle was designed to be a prototype hybrid electric urban transit vehicle. The power system consists of a four cylinder diesel engine driving an alternator to charge the batteries. Electric power is taken from the batteries to power the electric motor which then drives the vehicle. Thus the bus can be operated as an all electric vehicle or, with the engine running, as a hybrid vehicle. The University of Florida personnel feel that with proper selection and design of components, a hybrid diesel-electric bus offers significant advantages as an urban transit vehicle.

The bus chassis is a standard Electrobus (an all electric bus) chassis that has been re-engineered and rebuilt for hybrid use. It uses a 37.5 kW (50 hp) DC electric motor to move the vehicle. A four cylinder 3590 cc John Deere industrial Diesel engine was mated to an Onan 30 kW generator. This engine is an open chamber Diesel that was designed for use as a stationary powerplant. It is governed to run at 1800 rpm and is used to drive the alternators.

The Onan generator consists of two 42 volt 3 phase alternators which are used to charge the two 630 amp hr batteries. Power is drawn from the batteries by the electric motor. The D.C. motor is series wound - the field coil is in series with the armature - thus it uses maximum field and armature current at stall and therefore generates maximum torque at stall.

The alternator power output is controlled by an automatic circuit which is designed to maintain the batteries at a constant voltage. However, during maximum acceleration, the voltage drop is so great that safety circuits limit the alternator power output to 10 kW. Thus, in practice the automatic circuit reduces the power available to a level considerably below maximum power output. To prevent this, during transient operation, the automatic circuits are manually overriden and the alternator is then manually set to a fixed power output.

The vehicle operation is regulated by a controller. It consists of multiple contact relays that are tripped in sequence by micro-switches at the accelerator pedal. The controller varies the motor armature resistance, field configuration, and field resistance. It places the batteries in parallel (low speed) then in series (high speed) configuration to obtain seven discreet steps of power. Some dynamic braking is achieved by the controller switching the motor to a generator and then dissipating the power through resistor banks.

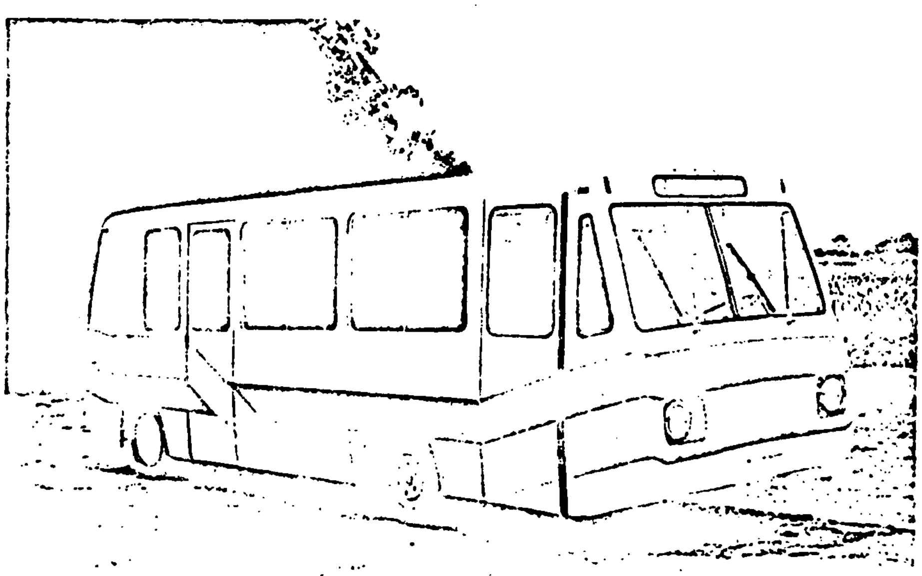
A detailed description of the vehicle is given in Appendix A. The control system schematic and vehicle layout are also in Appendix A. Pictures of the vehicle are on the following page.

Test Procedures

No prescribed gaseous emission test procedures exist for this type of vehicle. However, inasfar as possible the methods given in the 1977 Federal Test Procedure ('77 FTP, part 40, combined Federal Register, July 1, 1976) were followed. All tests were performed with the engine running (i.e. no cold or hot start tests). The tests included the Ann Arbor Bus Route (AA-1), University of Florida Bus Route (U of F), UMTA Cycle, New York City (NYC) Cycle, and Steady State.

All tests were conducted on a large roll electric chassis dynamometer and used the constant volume sampling (CVS) procedure. This procedure gives exhaust emissions of HC, CO, CO_2 and NOx in grams per mile. Fuel

- Front view of completed Urban Transit Vehicle



- Front quarter view of completed Urban Transit Vehicle economy was calculated by the carbon balance method. Because the fuel used was diesel #2, a heated flame ionization detector (HFID) was also used to measure HC. Otherwise the heavy hydrocarbons would condense out in the sampling system and not be measured.

All testing was performed on a 48" single roll chassis dynamometer. This is a large truck dynamometer which is able to simulate inertia weight and road load electrically. Thus the road load horsepower curve is adjustable to the specific type of vehicle. The road load curve was adjusted to conform to that measured by U of F personnel during road tests. No additional loads were imposed to simulate a vehicle air conditioning load.

The bus had a curb weight of 15,200 pounds. Allowance for a 50% load factor (10 passengers) would mean a test weight of 16,700 pounds. However, all tests were conducted using an inertia weight of 15,000 pounds since most tests by the University of Florida personnel were at this weight. This inertia weight allowed U of F and UMTA to correlate with previous testing. In addition, later models of the basic bus chassis weigh less and thus a chassis specifically designed for hybrid use could be expected to weigh less than the present chassis.

Test Program

The U of F hybrid bus has a top speed of 64 km/hr (40 mph). Therefore the standard test cycles such as the Federal Urban Driving Cycle or highway cycles with top speeds of 88 to 96 km/hr (55 to 60 mph) were inappropriate.

Therefore, lower speed cycles were chosen. They were:

AA-1 - a speed versus time trace generated in the summer of 1971 by attaching a fifth wheel to one of the buses of the Ann Arbor Transportation Authority. The cycle is not an official test cycle, but rather is used as an experimental tool for evaluating buses.

U of F - is a speed versus time trace generated by U of F by following buses with a vehicle equipped with a fifth wheel. This trace was then linearized to a straight line speed versus time trace for ease in computer modeling.

UMTA Cycles - simple speed versus time traces used to evaluate buses. The two cycles used differ only by the addition of 4 seconds of added cruise time.

NYC Cycle - a low speed versus time trace generated during traffic studies in NYC. This cycle has higher acceleration (4.0 mph per second) and deceleration rates (5.1 mph per second) than the 3.3 mph per second of the FTP.

Speed versus time plots of these traces are given in Appendix B. Their key features are summarized below. For comparison the Federal Urban and Highway Cycles are also given below.

Cycle	Length Miles	Average Speed MPH	Top Speed MPH	Stops per mile	% Time Idle	Cycle Time
AA-1	5.49	11.3	33.2	4.55	20.8%	29.2 min.
U of F	5.36	10.9	34.2	2.43	29.7	29.5 min.
UMTA slow	0.13	9.6	25.0	7.56	41.3%	0.8 min.
UMTA fast	0.16	10.8	25.0	6.26	38.2%	0.9 min.
NYC	1.18	7.1	27.7	9.33	42.1%	10.0 min.
Urban	7.45	19.7	56.7	2.42	19.5%	22.9 min.
Highway	10.24	48.2	59.9	0.10	0.5%	12.8 min.

The bag sample times for the AA-1 and U/F cycles were chosen to permit further evaluation of the driving cycles and prevent overfilling of the CVS sample bags. The values are:

	Bag 1	Bag 2	Bag 3
AA-1	1.23 miles 6.5 min	1.01 miles 8 min	3.15 miles 14.5 min
U of F	1.85 miles 10 min	2.52 miles 13 min	0.99 miles 6.3 min.

An electric hybrid vehicle can store electrical energy in one cycle and expend it in another. To properly evaluate an electric hybrid vehicle's emissions and fuel economy there must be no net change in vehicle's battery state of charge (energy storage) over the driving cycle chosen. In addition, tests must be conducted with the batteries at a representative level of charge since the vehicle's charge/discharge efficiency, fuel economy, and performance are dependent on the level of energy storage.

A previous EPA test program had shown the difficulty in quickly performing cold start tests of an electric hybrid vehicle while simultaneously properly maintaining the battery state of charge. Since a limited amount of facility time and personnel were available, only hot tests were planned. In addition, to eliminate warm-up effects on emissions, the engine and tires were warmed up prior to emission tests. This engine warm up was accomplished without charging the batteries. The tires were warmed up by motoring the vehicle with the dynamometer. No hot start tests were attempted. The engine was running prior to the start of each cycle. The above considerations should not bias the results greatly since it is anticipated that cold starting would represent only a small portion of a bus' daily duty cycle and, once started, the bus would continuously repeat its duty cycle.

The specific gravity and voltage of each battery were measured before and after each emission test. Those results were used to determine the vehicle's battery state-of-charge prior to each test and the net change in charge.

Prior to testing, the batteries were charged by using the bus alternator. The batteries were charged until they would accept energy only at a very low rate even when the maximum safe alternator output voltage was used.

Results

The exhaust emissions data are summarized in Table 1 for each of the driving cycles. No Federal emission standards exist for this type of vehicle or for these types of driving cycle. Detailed results for these tests and the steady state tests appear in Appendix B.

The results in Table 1 are uncorrected for net energy storage or expenditure during the test cycle. However, the battery conditions, as measured by specific gravity and voltage did not change appreciably during testing. (See Appendix B, Tables B-4 and B-5).

At the conclusion of testing the batteries were discharged by driving the vehicle for 30 minutes at 30 mph. Attempts were made to partially map the fuel/battery energy relationships by charging the batteries and measuring the fuel consumed. (See Appendix B Tables B-4 and B-5). It was hoped that this would allow the vehicle charge efficiency to be determined as a function of battery state of charge. At the battery charge levels at which emission testing was performed, the data shows a large fuel consumption with little change in battery charge. Straight forward application of these results to the AA-1 and U of F cycles would have lead to an unrealistic decrease in fuel economy for the AA-1 cycle and an unrealistic gain in fuel economy for the U of F cycle.

Other results tend to show that the effects of battery energy storage on the vehicle fuel economy were minimal. Again referring to Tables B-4 and B-5, the batteries were brought from a discharged state of 85.11 volts at 1.164 specific gravity to 87.30 volts at 1.224 specific gravity. This consumed 1.69 gallons of Diesel fuel. This change in battery energy storage was considerably greater than that experienced during any test cycle. This implies the effects on fuel economy, due to the small changes in battery conditions during testing, should be minimal.

Therefore, because of the conflicting data, it was not possible to correct the fuel economy results for the small changes in battery state of charge.

Similar problems were encountered during previous tests of a hybrid vehicle (Report 75-14). These difficulties were overcome only by the use of additional test equipment and a considerably larger test program. Accurately investigating and accounting for these effects on the bus would require a much broader and more extensive testing program. Therefore, it appears that hybrids cannot be effectively tested with existing equipment.

Table 1 - Mass Emissions

Cycle	# of Tests	grams per mile (grams per kilometer) HC*	CO	CO_2	NOx	Fuel Economy (fuel consumption)	Total Battery Change Over Tests: Battery Voltage	Any Cell Specific Gravity
AA-1	3	7.07	5.00	1200	11.59	8.4 miles/gal	-.98	-.0116
		(4.39)	(3.11)	(746)	(7.20)	(28.0 litres/100 km)		
U of F	3	6.34	4.29	1207	12.10	8.3 miles/gal	.40	.0114
		(3.94)	(2.67)	(750)	(7.52)	(28.2 litres/100 km)		
U of F**	4	3.39	1.99	885	11.89	11.4 miles/gal	-.96	-.0145
		(2.11)	(1.24)	(550)	(7.39)	(20.7 litres/100 km)		
UMTA slow	1	8.72	5.70	1743	19.08	5.8 miles/gal		-.0039
		(5.42)	(3.54)	(1083)	(11.86)	(40.6 litres/100 km)		
UMTA fast	1	7.32	5.03	1450	15.45	6.9 miles/gal		-.0039
		(4.55)	(3.13)	(901)	(9.60)	(34.1 litres/100 km)		
NYC	3	12.36	8.92	1864	17.24	5.4 miles/gal		-.0059
		(7.68)	(5.54)	(1158)	(10.71)	(43.9 litres/100 km)		

* HC values given are for heated flame ionization detector

** Test series consists of electric (engine off), hybrid, electric (engine off), hybrid mode of operation. Emissions and fuel economy are adjusted for total miles driven. This includes cycles with engine off. Bag 2 values for test 78-1811 assumed to be same as test 78-2811.

The effects on emissions of the above load changes would probably be minimal for the AA-1 cycle and the U of F cycle. Referring to the steady state values of Table B-3, it appears that except at idle, the emissions do not vary appreciably with a small change in engine load.

EPA has previously tested several buses using the AA-1 route and a version of the Federal Heavy Engine Certification procedure adapted for a chassis dynamometer. Compared to these vehicles the hybrid bus results were encouraging (i.e. no better or worse). However, none of these vehicles would be an ideal choice for fuel economy comparison since they are either much larger or do not use a diesel engine. Mercedes Benz markets a small (13 to 19 passenger) Diesel bus. Their fleet users achieve fuel economies of between 8 and 13 mpg. However, these results are for a slightly smaller bus over unknown duty cycles.

The relatively good fuel economy for the bus while driving the U of F cycle in the electric (engine off) hybrid mode may not be as good as it would appear. Measurement of fuel consumption with a fuel meter showed fuel consumptions 6% to 20% higher than the CVS results for the electric/hybrid test. The 20% discrepancy occurred on bags 1 and 3 of test 78-2810. This did not occur on the replicate test, 78-2811 or on bag 2 of test 78-2810. Therefore, both emissions and fuel economy may be in error. The scheduling problems and heavy testing load prevented additional tests from being performed which could have investigated this problem further. However, no additional reasons have been found to invalidate the results, so they are reported herein.

Problems were encountered in testing. The vehicle has excellent low speed acceleration and is able to follow the fastest scheduled accelerations below 20 mph. After this point, there is a decrease in the vehicle acceleration rate and the vehicle cannot follow all driving cycles (see driving cycles in Appendix C). The controller did cause some difficulty in following the driving cycle. Since it works in discrete increments, it was sometimes difficult to hold an intermediate speed over a portion of the driving cycle. In addition one controller relay was malfunctioning and there was therefore a large jump in power at times. The high charging currents required for the AA-1 and U of F cycles caused many of the special catalytic battery caps to blow off. The vehicle is not equipped with power steering and is very difficult to manuever, however, this created only minimal problems for the dynamometer tests.

In previous tests of diesel fueled vehicles (cars and buses), the ratio of the hydrocarbon values for the heated FID to the CVS ranged from 1.01 to 1.8 for most transient test cycles. For this vehicle there was a marked change in this pattern. The ratio was between 2.5 and 3.5 for all transient tests. For steady state tests the values ranged from 1.6 to 3.2. This implies either that the combustion process relating to HC formation is considerably different for this vehicle, or, since the engine was designed for stationary power plant usage, the engine's basic control of HC is poor during transient cycles.

Conclusions

As a hybrid vehicle, the bus functioned well with minimal problems for a prototype vehicle. The vehicle fuel economies are comparable to other buses. For the hot tests, using the AA-1 route, the vehicle's emissions for HC, CO, and NOx were 7.07, 5.00, and 11.59 grams per mile respectively. Vehicle fuel economy was 8.4 miles/gallon. The vehicle showed potential for fuel economy improvements by operating it as an electric/hybrid vehicle. However, there were additional fuel economy results which indicated little or no change. Lack of facility time prevented this problem from being explored further.

The change in the ratio of HC measured by heated FID to CVS values is noteworthy. Previously, for most vehicles test results showed the ratio to be from 1.1 to 1.6. However for tests of this vehicle, it varied from 2.6 to 3.5.

The emissions and fuel economy test results for hybrid vehicles are difficult to measure due to the capability of the vehicle to store electrical energy in one cycle and discharge in another. The change in charge/discharge efficiency, fuel economy, and performance with vehicle state-of-charge further complicates testing. Therefore, the hybrid results must be considered suspect until accurate methods exist for determining the energy levels in a battery.

Appendix A
Test Vehicle Description

University of Florida - DOT Urban Transit Vehicle

Electric Propulsion Unit

Prime Mover	37.3 kW (50 hp), series would electric motor, with two fields - Tork Link Corp.
Alternator	3 phase A.C., 30 kW, 40 V RMS line to line, 1800 RPM, modified Onan Corp model 30-DDA-15R with 2 independent outputs
Rectifiers	Two SCR bridge type, 400 V-370 AMP Westinghouse model G.E. 1987d
Batteries	Two 21 cell Gould Electric Vehicle type 63E-W1, 630 amp hr (6 hr rate), 42 V, weight 1850 lbs each.
Controller	Contactor with relays. Provides 7 driving modes plus one for dynamic breaking

Engine

Manufacturer	John Deere, Series 300, Model 4219D
Type	4 stroke, Diesel cycle, OHV, inline, 4 cylinder
Bore x Stroke	102 mm x 110 mm (4.02 in x 4.33 in)
Displacement	3590 cc (219 cu. in.)
Compression Ratio	16.3:1
Power @ rpm	44.7 kW (60 hp) @ 1800 rpm
Fuel Metering	Fuel injection
Fuel Requirement	Diesel No. 2

Drive Train

Transmission	None, direct drive by electric motor (Diesel engine with alternator is used to charge battery)
Axle Ratio	6.8:1

Appendix A (cont.)

Chassis

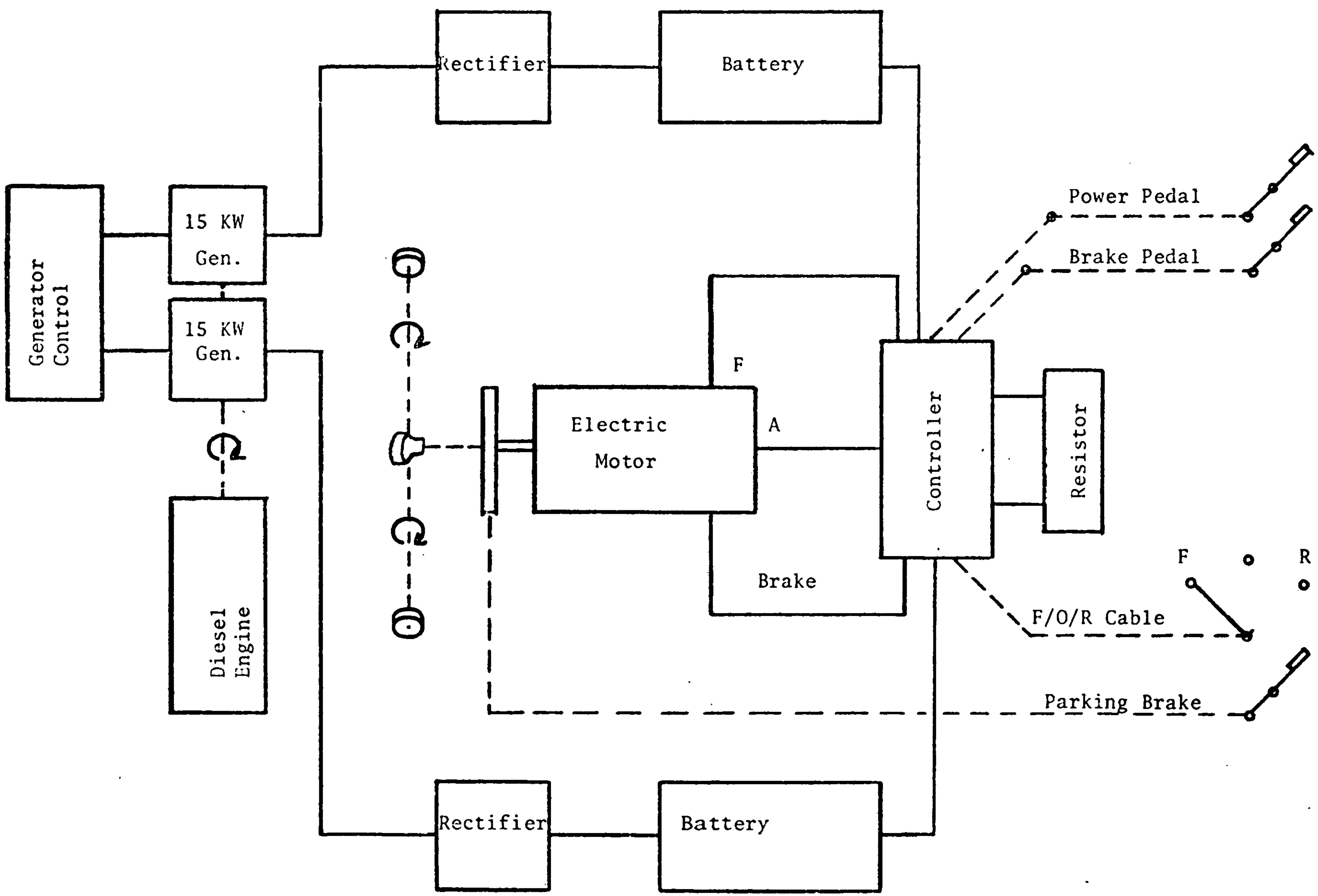
Basic Chassis	Re-engineered model 20 Electrobus, mfg. by Tork Link
Size	7.493 meters (24 ft. 7 in.) long 2.337 meters (92 in.) high 2.565 meters (101 in.) wide
Type	Rear engine, rear drive.
Tire Size	8.25 x 15, 14 ply rating, Michelin steel belted radials
Curb Weight	6895 kgm (15,200 lbs)
Passenger Capacity	15 including driver due to experimental seating arrangement. Vehicle designed for 20 with standard seating arrangement.

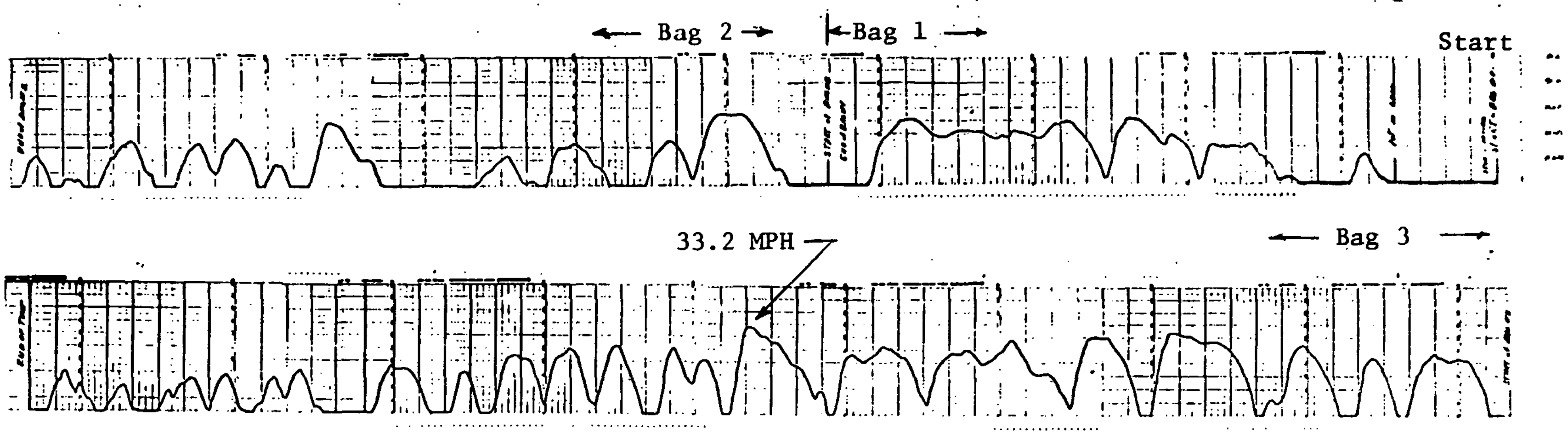
Emission Control System

Basic Type	None, diesel engine operated at 1800 rpm at all times, it is an open chamber Diesel
Durability Accumulated on System	2000 miles (estimated)

FIGURE 1 -

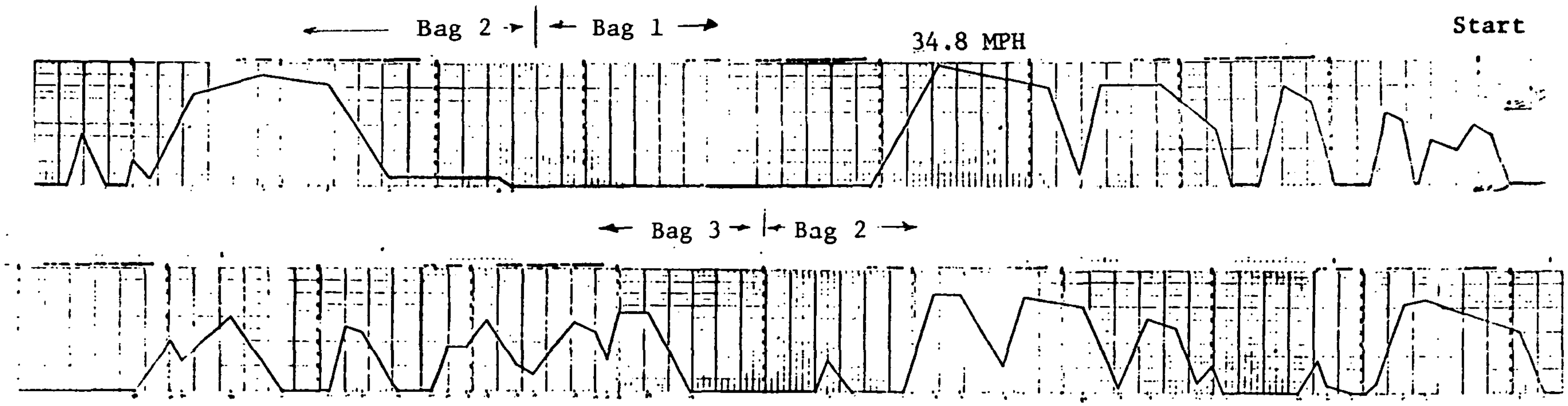
HYBRID SYSTEM SCHEMATIC





END

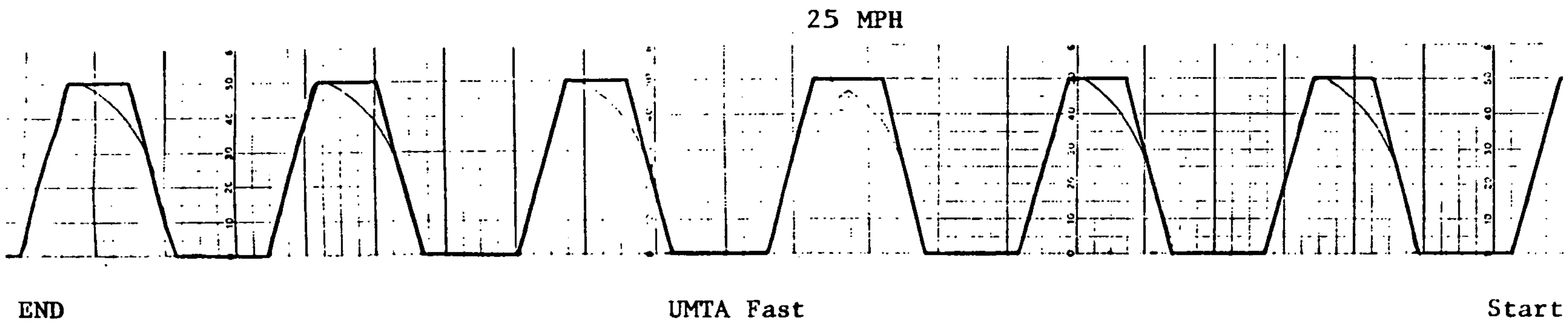
Ann Arbor Bus Route



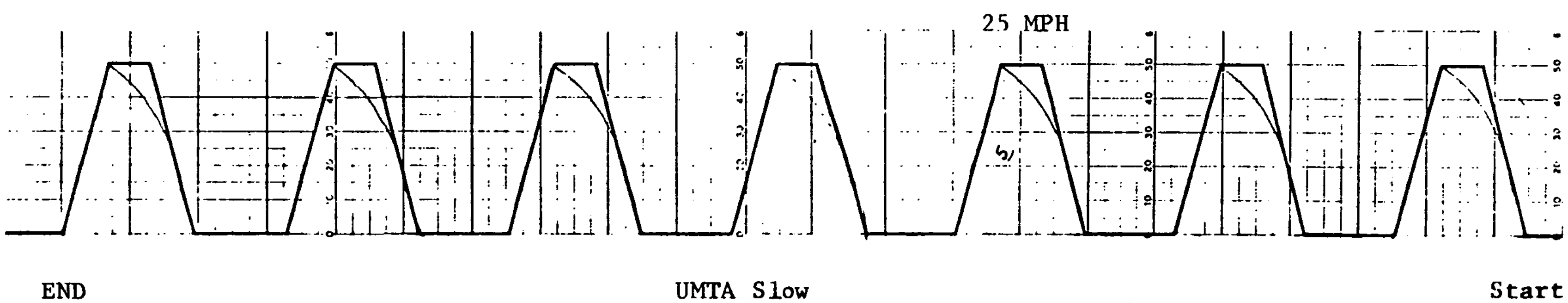
END

University of Florida Cycle

Appendix B - Bus Test Cycles

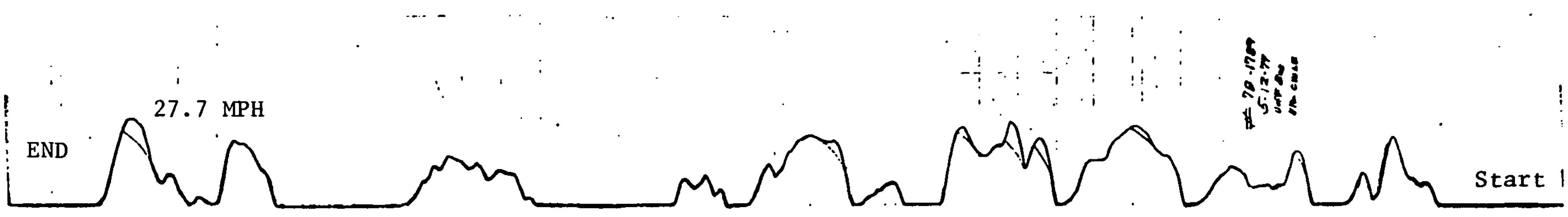


UMTA Fast



UMTA Slow

UMTA Cycles



NYC Cycle

Appendix B (cont.) - Bus Test Cycles

Table B-1
Ann Arbor Bus Route
Mass Emissions - grams per mile

	Bag 1						Bag 2						Bag 3					
Test No.	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG
78-1786	2.33	8.03	5.85	1130	11.03	8.9	3.68	12.28	8.69	1656	15.52	6.1	1.99	6.51	4.64	978	9.25	10.3
78-1787	2.73	8.82	6.21	1104	10.08	9.1	3.96	11.89	7.98	1722	16.00	5.8	1.86	6.17	3.77	1049	9.32	9.6
78-1788	2.15	6.99	4.67	1214	12.57	8.3	3.37	9.92	5.96	1944	20.64	5.2	2.51	5.81	3.51	1081	11.06	9.3

Ann Arbor Bus Route
Total Mass Emissions - grams per mile

Test No.	HC	HFID	CO	CO_2	NOx	MPG
78-1786	2.38	7.94	5.67	1140	10.83	8.8
78-1787	2.45	6.42	5.10	1187	10.74	8.5
78-1788	2.59	6.85	4.23	1273	13.19	7.9

Table B-2
University of Florida Bus Route
Mass Emissions - Grams per mile

Test No.	Bag 1						Bag 2						Bag 3					
	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG
78-1790	1.93	6.71	4.14	1371	14.37	7.4	1.65	4.66	2.72	943	9.97	10.7	2.66	8.03	4.94	1589	16.31	6.3
78-1791	2.35	6.23	4.54	1201	11.99	8.4	2.48	6.27	3.90	1288	12.95	8.2	2.94	7.85	6.06	1451	14.69	6.9
78-1792	2.45	6.45	4.55	1222	12.32	8.2	2.36	6.10	4.51	1048	9.40	9.6	2.79	7.55	5.67	1272	11.00	7.9

University of Florida Bus Route
Total Mass Emissions - grams per mile

Test No.	HC	HFID	CO	CO_2	NOx	MPG
78-1790	1.93	5.99	3.62	1210	12.66	8.3
78-1791	2.52	5.54	4.52	1260	12.94	8.0
78-1792	2.47	6.49	4.73	1150	10.71	8.7

University of Florida Bus Route
Electric/Hybrid Mode of Operation
Mass Emissions - grams per mile

Test No.	Bag 1						Bag 2						Bag 3					
	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG	HC	HFID	CO	CO_2	NOx	MPG
78-2810*	1.73	9.61	3.34	1586	20.97	6.4/4,9	1.98	6.17	3.15	1679	22.17	6.0/5.6	2.70	8.06	3.95	1868	24.87	5.4/4.1
78-2811*	2.97	6.96	5.68	1886	25.71	5.3/5.0							4.01	8.06	6.23	2268	32.78	4.4/4.0

University of Florida Bus Route
Electric/Hybrid Mode of Operation
Total Mass Emissions - grams per mile

Test No.	HC	HFID	CO	CO_2	NOx	MPG
78-2810	2.03	6.80	3.37	1682	22.44	6.0

Mass emissions are not adjusted to include mileage for cycle in electric mode.

Table B-3
Mass Emissions - grams per mile

Test Type	Test No.	HC	HFID	CO	CO_2	NOx	MPG
UMTA slow	78-1793	2.99	8.72	5.70	1743	19.08	5.8
UMTA fast	78-1793	2.52	7.32	5.03	1450	15.45	6.9
NYC	78-1789	4.12	12.89	9.07	1991	19.15	5.0
NYC	78-1789	4.35	12.27	8.80	1818	16.67	5.5
NYC	78-1789	4.09	11.95	8.91	1786	15.94	5.6
Steady State Idle*	78-1804	52.65	146.54	89.36	4696	237.12	0.49
Steady State 25.5 mph	78-1804	1.76	3.48	3.59	498	12.70	20.0
Steady State 25.7 mph	78-1805	2.07	3.38	2.12	496	19.61	20.0
Steady State 33.0 mph	78-1805	1.53	2.38	1.06	502	25.10	20.0
Steady State 41.8 mph	78-1805	1.06	3.36	1.83	553	7.54	18.2

*Values are gms/hr and gal/hr.

Table B-4
Vehicle Battery State of Charge Summary

Date		Avg. Cell Volts	Total Volts	Avg. Specific Gravity
5/10	Before A^2	2.1114	88.68	1.2420
5/11	Before U/F	2.0877	87.70	1.2305
5/12	Before NYC	2.0974	88.10	1.2419
5/12	14 cells before NYC	2.0977		1.2417
5/12	14 cells before UMTA	2.1011		1.2358
5/13	Before Steady State	2.0832	87.50	1.2281
5/13	14 cells before Steady State			1.2280
5/13	14 cells before discharge			1.2338
5/13	4 cells after discharge			1.1745
5/14	Before charge	2.0265	85.11	1.1636
5/16	After charge	2.0759	97.19	1.2049
5/23	14 cells before charge	2.0664	86.67	1.2054
5/27	14 cells after charge	2.0788	87.30	1.2243
6/14	14 cells only before charge	2.0659	86.75	1.2170
6/15	14 cells only after charge			1.2176
6/17	Before U/F	2.1008	88.24	1.2389
6/20	After U/F	2.0807	87.28	1.2244

Table B-5
Vehicle Battery Change Charge Summary

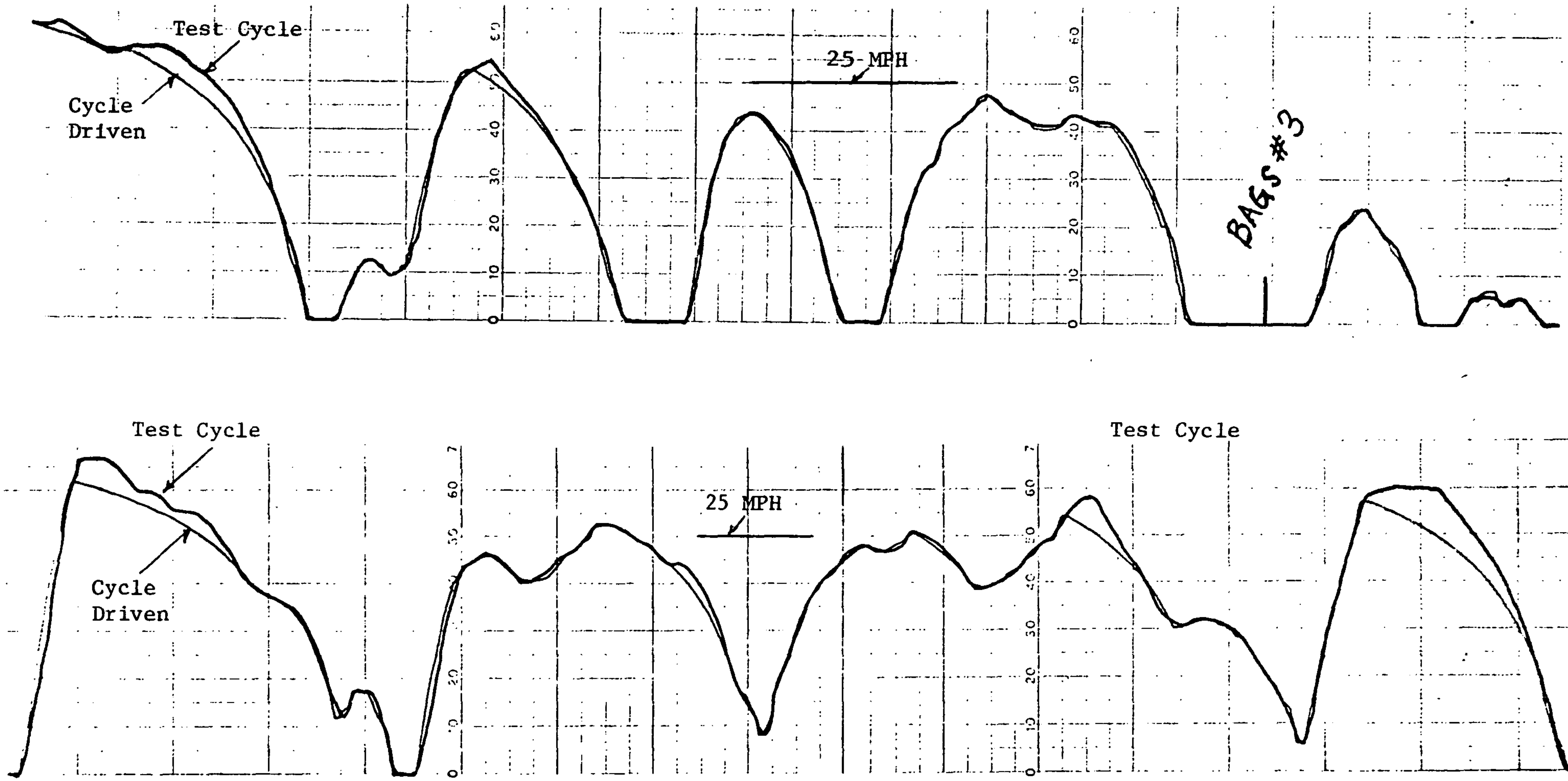
Date	Test Number	Avg. Cell Volts	Total Volts	Avg. Specific Gravity
5/10	A^2 78-1786, 1787, 1788	-.0237	-.98	-.0116
5/11	U/F 78-1790, 1791, 1792	0.0097	0.40	0.0114
5/12	NYC 78-1789	0.0034		-.0059
5/12	UMTA 78-1793 (slow & fast)	-.0180		-.0078
5/13	Steady State			0.0058
5/14	Charge 1.04 gallons	0.0494	2.08	0.0414
5/23	Charge 0.65 gallons	0.0124	0.63	0.0189
6/15	Charge 1.02 gallons			0.0006

Table B-6
Ann Arbor Bus Route - grams per mile

	HC	CO	CO_2	NOx	MPG
20 passenger gasoline	19.16	282.37	1288	19.64	5.0
45 passenger diesel	6.2	14.0		31.5	4.6
53 passenger steam bus Rankine cycle	3.3	7.0		8.9	1.0

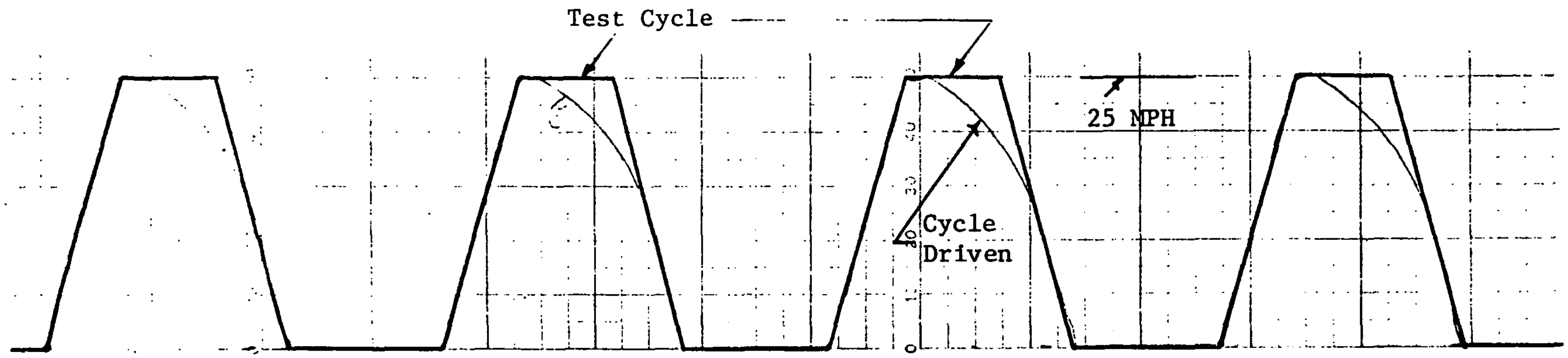
13 Mode Heavy Duty
grams per brake horsepower hours

	HC	CO	NOx	HC + NOx
25 passenger Rankine cycle	2.1	20.0	2.0	
29 passenger gasoline	8.1	53.4	12.4	
45 passenger diesel	1.2	7.4	8.4	
53 passenger Rankine cycle	0.4	2.3	2.7	
77 Cal. Std.		25.0		5

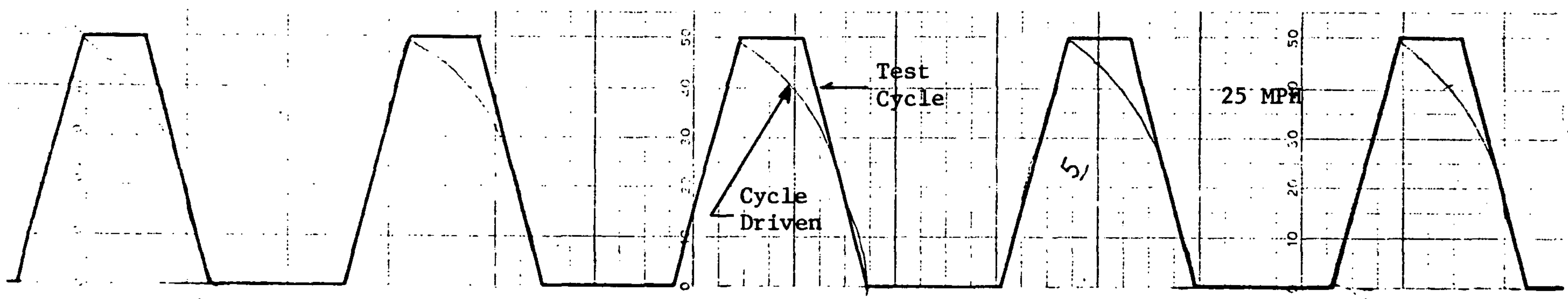


Ann Arbor Bus Route

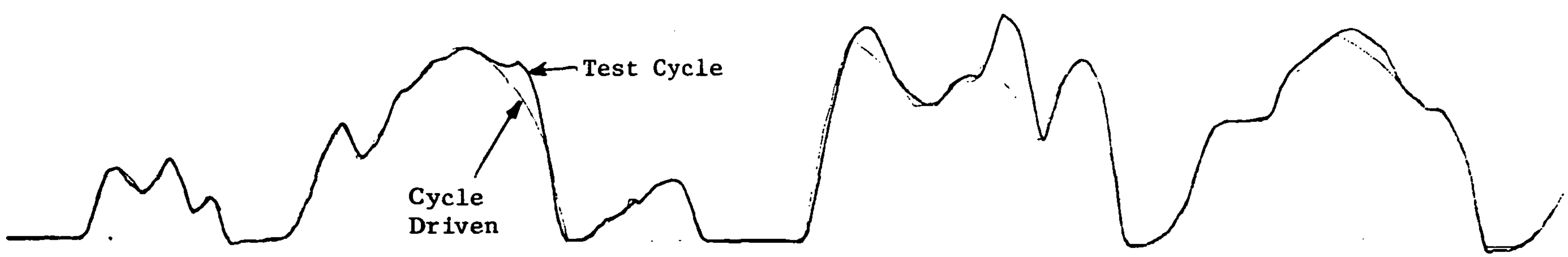
Appendix C - Driving Traces



UMTA Fast

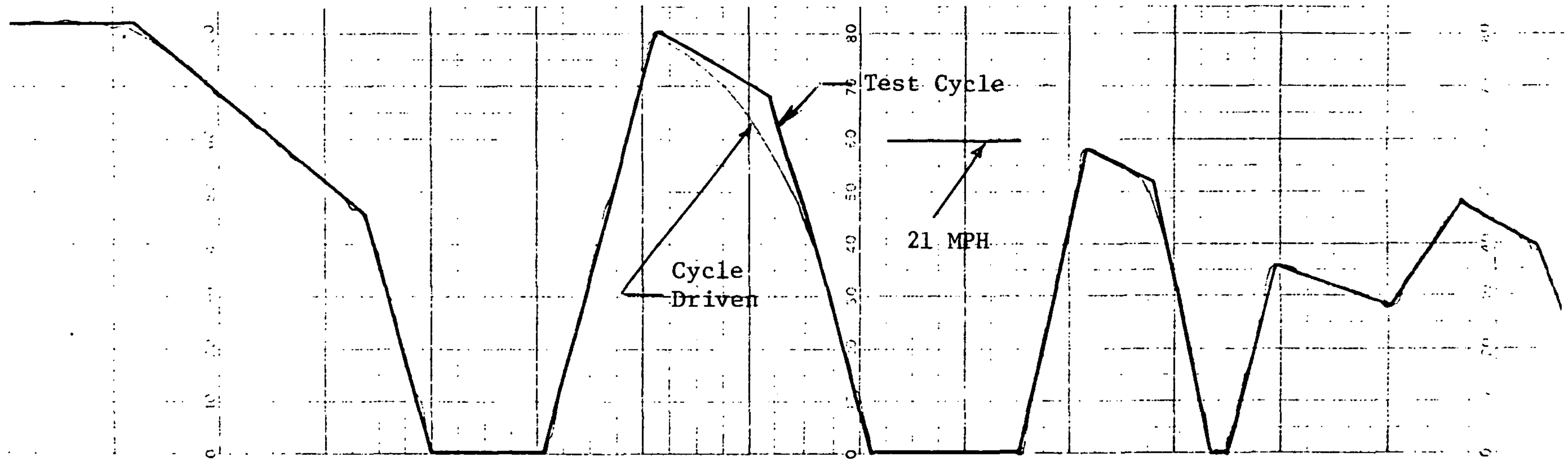


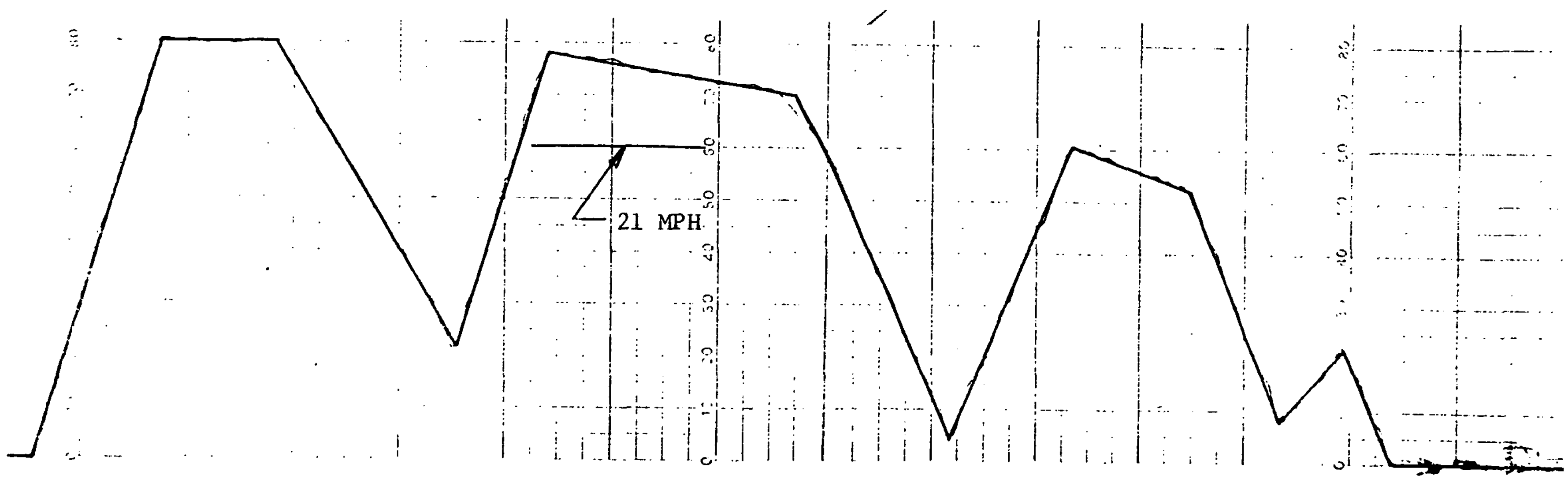
UMTA Slow



NYC Cycle

Appendix C - Driving Cycles (cont.)





University of Florida

Appendix C (cont.)