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RESULTS OF BASELINE TESTS OF THE LUCAS LIMOUSINE

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Prepared for
ERDA Electric and Hybrid Highway Vehicle Systems Program
Division of Transportation Energy Conservation

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16. Abstract

The Lucas Limousine, an electric vehicle manufactured by Lucas Industries, Ltd., of Birmingham, England, was tested at the DANA Corporation Test Track between September 24, 1976 and September 30, 1976. The tests are part of an ERDA project to assess the state-of-the-art of electric vehicles. This report includes the performance test results on the Lucas vehicle. The Lucas Limousine is a converted General Motors Bedford CF van, modified to carry the electric drive system and battery packs. It is classified as a luxury executive personnel carrier, capable of accommodating seven passengers plus a driver. It is powered by a 216 volt d.c. series wound motor that has a rating of 50 bhp and 200 ft-lb torque. The braking system of the vehicle is a Girling servo-assisted hydraulic system, that is supplemented by a regenerative motor-braking system. The controller is a Lucas developed SCR chopper type which changes the ratio of open to closed times of the SCRs to vary the average voltage across the motor. Except for repeating the test runs the prescribed number of times, the tests were run in accordance with the SAE J227a Electric Vehicle Test Procedure. All tests were made without the regenerative braking system and were conducted at the gross vehicle weight of 7700 pounds (3500 kg.). The range of the vehicle when driven at a steady speed was as follows: 30 mph - 102.2 miles; 40 mph - 76.1 miles; and 50 mph - 57.1 miles. Over a 30-mph stop and go driving cycle (J227a - schedule C) the vehicle went 48.4 miles. The vehicle was able to accelerate to 30 mph in about 15 seconds and has a gradeability limit of 16.5 percent. As determined by coast down tests the road power and road energy consumption for the vehicle were 2.92 kilowatts and 0.146 kWh/mi, respectively, at 20 mph. At 40 mph the road power requirement was 11.12 kilowatts and the road energy requirement was 0.278 kWh/mi. The maximum energy economy measured 0.45 kilowatt hours per mile at 30 mph and increased to 0.76 kilowatt hours per mile at 50 mph. Over the 30 mph stop and go driving cycle the energy economy was 0.92 kilowatt hours per mile.

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SUMMARY

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The Lucas Limousine is a converted General Motors Bedford CF van, modified to carry the electric drive system and battery packs. It is classified as a luxury executive personnel carrier, capable of accommodating seven passengers plus a driver. It is powered by a 216 volt d. c. series wound motor that has a rating of 50 bhp and 200 ft-lb torque. The braking system of the vehicle is a Girling servo-assisted hydraulic system, that is supplemented by a regenerative motor-braking system. The controller is a Lucas developed SCR chopper type which changes the ratio of open to closed times of the SCRs to vary the average voltage across the motor.

Except for repeating the test runs the prescribed number of times, the tests were run in accordance with the SAE J227a Electric Vehicle Test Procedure. All tests were made without the regenerative braking system and were conducted at the gross vehicle weight of 7700 pounds (3500 kg.).

The range of the vehicle when driven at a steady speed was as follows:

30 mph - 102. 2 miles
40 mph - 76. 1 miles
50 mph - 57. 1 miles

Over a 30-mph stop and go driving cycle (J227a - schedule C) the vehicle went 48. 4 miles. The vehicle was able to accelerate to 30 mph in about 15 seconds and has a gradeability limit of 16. 5 percent. As determined by coast down tests the road power and road energy consumption for the vehicle were 2. 92 kilowatts and 0. 146 kWh/mi respectively at 20 mph. At 40 mph the road power requirement was 11. 12 kilowatts and the road energy requirement was 0. 278 kWh/mi. The maximum energy economy measured 0. 45 kilowatt hours per mile at 30 mph and increased to 0. 76 kilowatt hours per mile at 50 mph. Over the 30 mph stop and go driving cycle the energy economy was 0. 92 kilowatt hours per mile.

INTRODUCTION

This report describes performance tests conducted on the Lucas Limousine, manufactured by Lucas Industries, Ltd., of Birmingham, England. A photograph of the vehicle is shown in figure 1. These tests are part of an ERDA project to assess the state-of-the-art of electric vehicles. This assessment will be used 1) to help formulate standards and specifications for government purchase of electric vehicles, 2) to determine areas where technology improvements are needed and 3) as a benchmark for measuring progress.

STAR category 44

Figure 1. - Lucas Limousine

OBJECTIVE

The objective of the track tests on the Lucas Limousine was to determine performance characteristics of the vehicle. These performance characteristics include range at steady speed, range while the vehicle is driven over a prescribed stop and go driving cycle ("C cycle"), maximum acceleration characteristics, top speed, gradeability, vehicle energy consumption and vehicle energy economy.

TEST PROCEDURE

The tests described in this report were performed at the DANA Corporation Test Track, a 3-lane, 1-3/4 mile concrete track located at Ottawa Lake, Michigan.

Range Tests: Two types of range tests, described in the SAE J227a, were performed on the Lucas Limousine, constant speed tests and stop-and-go driving in accordance with a specified driving schedule (schedule C). The constant speed tests were carried out at selected test speeds of 30, 40 and 50 mph which were held constant within ±5 percent. The tests were terminated when the vehicle speed fell below 95 percent of the chosen test speed. The 30 mph test was run once and the 40 and 50 mph tests were each run twice.

The stop-and-go-driving cycle tests shown in figure 2 consist of an acceleration phase to a specified speed in a specified time period, followed by a cruise period at this speed, followed by coast, braking, and idle periods. The range is measured at the end of the cycle preceding the cycle in which the vehicle either ceases to meet the requirements of the selected driving schedule or reaches some other vehicle performance limitation specified by the vehicle manufacturer. The Lucas Limousine was tested to schedule "C".

Acceleration Test: This test determines the maximum acceleration of the vehicle on a level road with the battery at full charge, 40 and 80 percent discharged. Two runs in opposite directions were conducted at each of these three battery states-of-charge.

Gradeability: Gradeability is defined by the SAE as the maximum grade on which the vehicle can just move forward and gradeability at speed is the maximum vehicle speed which can be maintained on roads having different grades. The maximum grade capability of the vehicle was determined from tractive force tests by towing a second vehicle with the test vehicle at approximately 2 mph. The vehicles were connected by a 3000 lb load cell. Knowing the weight of the vehicle, the maximum grade was calculated from

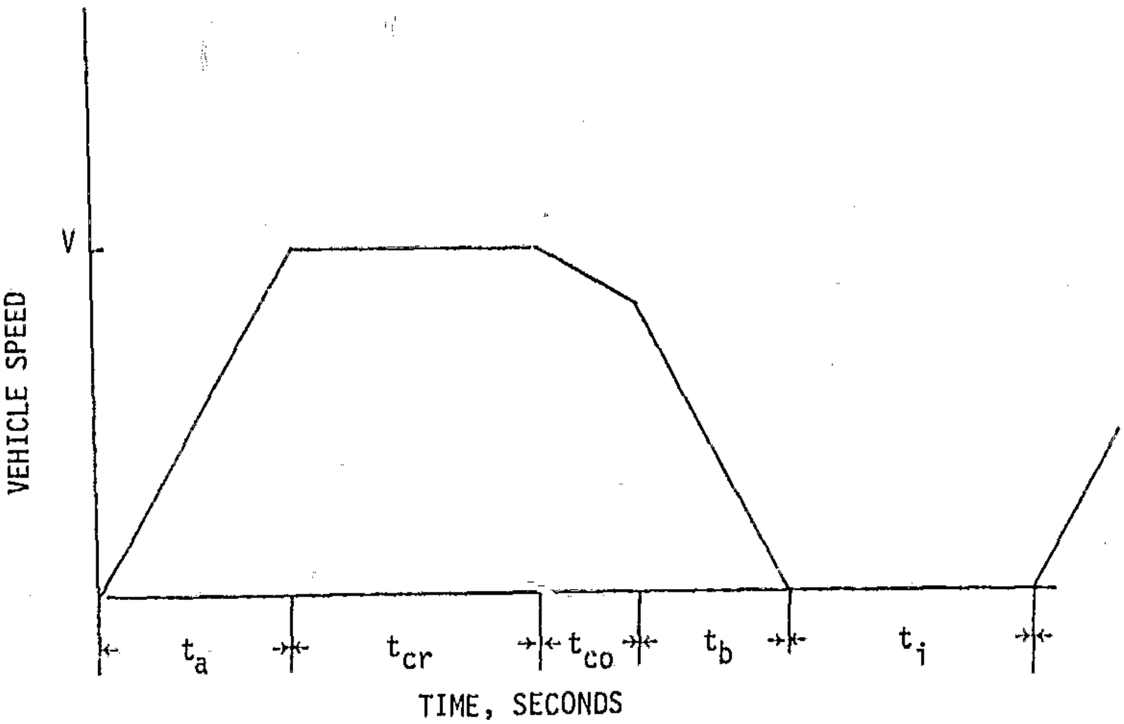
$$\text{Percent gradeability limit} = 100 \tan\left(\sin^{-1} \frac{P}{W}\right)$$

where

P = tractive force in pounds

W = gross vehicle weight in pounds

The maximum vehicle speed on a specific grade was calculated from maximum acceleration performance of the vehicle.



TEST PARAMETER	S.A.E. SCHEDULE			
	A	B	C	D
MAX. SPEED, V, MPH	10	20	30	45
ACCEL. TIME, t_a, SEC	4	19	18	28
CRUISE TIME, t_{cr}	0	19	20	50
COAST TIME, t_{co}	2	4	8	10
BRAKE TIME, t_b	3	5	9	9
IDLE TIME, t_i	30	25	25	25

Figure 2. - S.A.E. J227a - Driving Cycle Schedules

Percent gradeability at speed $V = 100 \tan (\sin^{-1} 0.0455 \bar{a}_n)$

where $\bar{a}_n$ is the average acceleration during time period t_{n-1} to t_n where vehicle speed increased from V_{n-1} to V_n. Therefore

$$\bar{a}_n = \frac{V_n - V_{n-1}}{t_n - t_{n-1}}$$

and the average speed at acceleration $\bar{a}_n$ is defined as

$$\bar{V}_n = \frac{V_n + V_{n-1}}{2}$$

Road Energy Consumption: The power and the energy consumption of the vehicle at various speeds needed to overcome the aerodynamic and rolling resistance were determined from coast down tests. The road power required is reported as kilowatts and the energy consumption is reported as kilowatt-hours per mile. The vehicle was allowed to coast from top speed to a complete stop. The coast down test results together with the equations below were used to calculate the power, P_n, and energy, E_n, requirements.

$$P_n \text{ kilowatts} = 4.54 \times 10^{-5} W \frac{\left(V^2_{n-1} - V^2_n\right)}{\left(t_n - t_{n-1}\right)}$$

where W is the weight of the vehicle in pounds and t_n and t_{n-1} are the times in seconds required for the vehicle to reach speeds of V_n and V_{n-1} in miles per hour. The power thus calculated was reported at an average speed $\bar{V}$ calculated from

$$\bar{V}_n = \frac{V_n + V_{n-1}}{2}$$

The energy consumption, calculated as kilowatt hours per mile, was obtained from the equation below.

$$E_n \text{ kilowatt hours per mile} = 9.07 \times 10^{-5} W \frac{\left(V_{n-1} - V_n\right)}{\left(t_n - t_{n-1}\right)}$$

where the units are as presented above and reported at an average speed $\bar{V}$.

Energy Economy: Energy economy was determined from the amount of energy required to recharge the batteries after a test. A residential A. C. kilowatt-hour meter was used to measure charger input energy. Energy economy was determined by dividing the A. C. energy required for recharging the battery by the range achieved in the prescribed driving mode.

INSTRUMENTATION

The instrumentation package mounted within the vehicle include

(a) Two Honeywell 195 Electronik - two channel strip chart recorders, weighing about 30 pounds each. These are easy to calibrate, hold calibration well, and have high input impedance; used for recording battery current and voltage, vehicle speed and distance.

(b) Curtis Current Integrator SHR-C3; weighing about 10 pounds; used to measure charge and discharge battery capacity through a 500amp/100 mv shunt.

(c) Tripp Lite 500 watt DC/AC inverter, weighing about 20 pounds; used to supply AC power to strip charts and current integrator.

(d) One or two 12-volt SLI batteries; 70 A-H weighing about 50 pounds each; used to power DC/AC inverter and supply 12-volt power where needed.

(e) Stop watch, Wakmann Breitling number 917; used in SAE J227a stop/start cycle tests.

(f) Keithley Model 163 Digital Voltmeter weighing about 5 pounds; used to facilitate battery voltage monitoring during test runs.

(g) Nucleus Corp. Model NC-7 Precision Speedometer (5th wheel), with Electronic Pulser Model ERP-X1 for distance measurements, Pulse Totalizer Model NC-PTE, and Expanded Scale Speedometer, Model ESS/E and Programmable digital attenuator; the weight of the 5th wheel is approximately 30 pounds with the dash-mounted instruments weighing about 20 pounds.

(h) Hewlett-Packard Model 6920B Meter Calibrator, 0. 2 percent accuracy on DC output, usable range 0. 01 to 1000 volts.

All instruments are calibrated after installation in the test vehicle, and are recalibrated at the track between tests.

This instrument package has demonstrated itself to be reliable and versatile for the measurements required.

Figures 3, 4, and 5 show the typical instrumentation installation in the Lucas vehicle.

Figure 3 shows an overall view of the Lucas vehicle with the "5th wheel" attached to a rear-mounted bracket. Figure 4 is a photograph taken inside the vehicle showing some of the recording apparatus. The two 2-channel recorders and the current integrator receive power from the DC to AC invertor shown in the photograph.

Figure 5, taken from the drivers seat, shows 5th wheel components to the left of the driver, on top of the dash. The two larger units mounted "piggyback" are the digital distance integrator (on the bottom) and the analog speed indicator. The driver uses the expanded scale portion of the speed indicator to hold the vehicle speed steady on a fixed value when required.

AC energy to the charger was measured by a General Electric Type 1-50-A Model AR272 single phase residential Watthour meter.

Figure 3. - Rear View of Lucas Limousine Showing 5th Wheel Attachment.

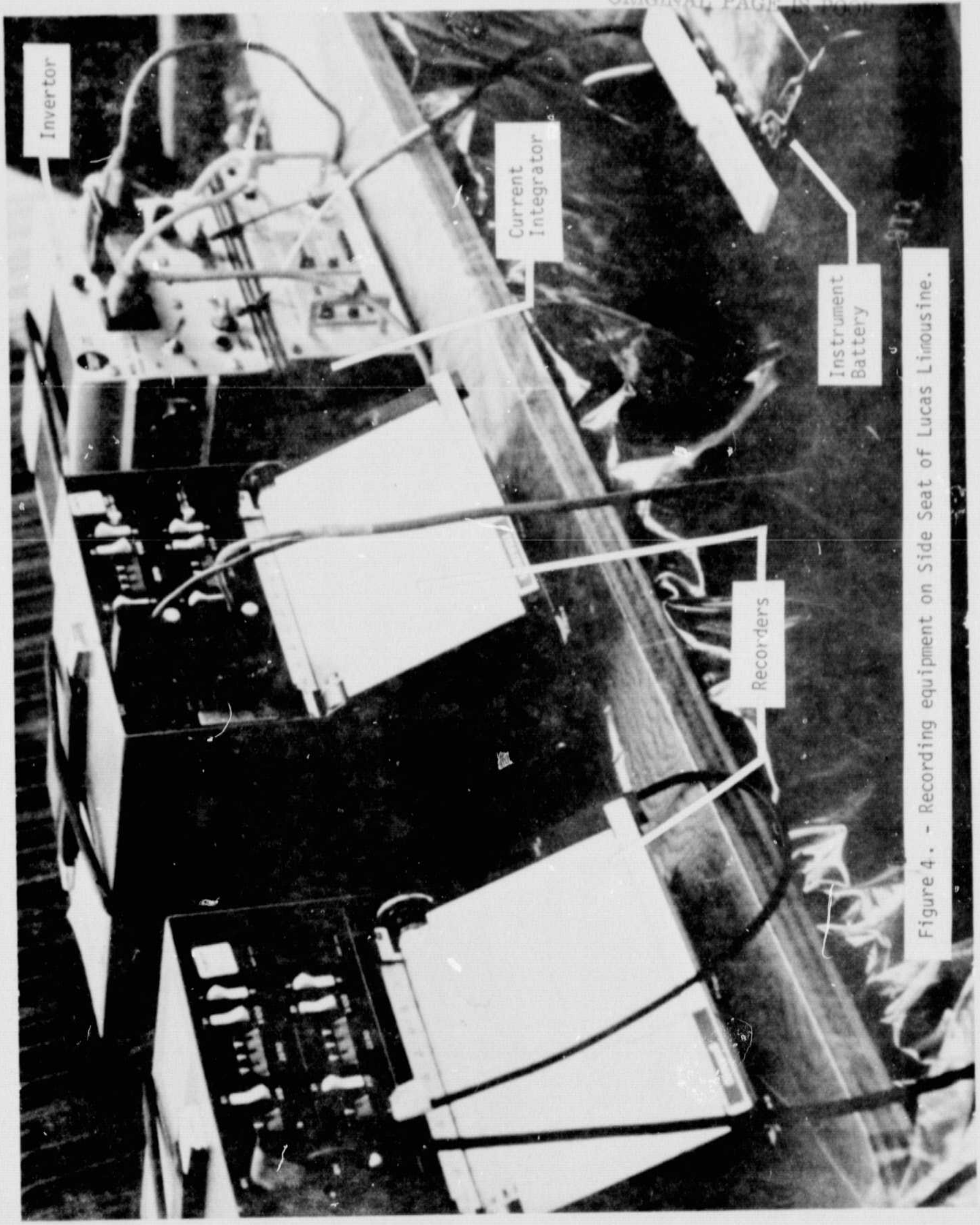


Figure 4. - Recording equipment on Side Seat of Lucas Limousine.

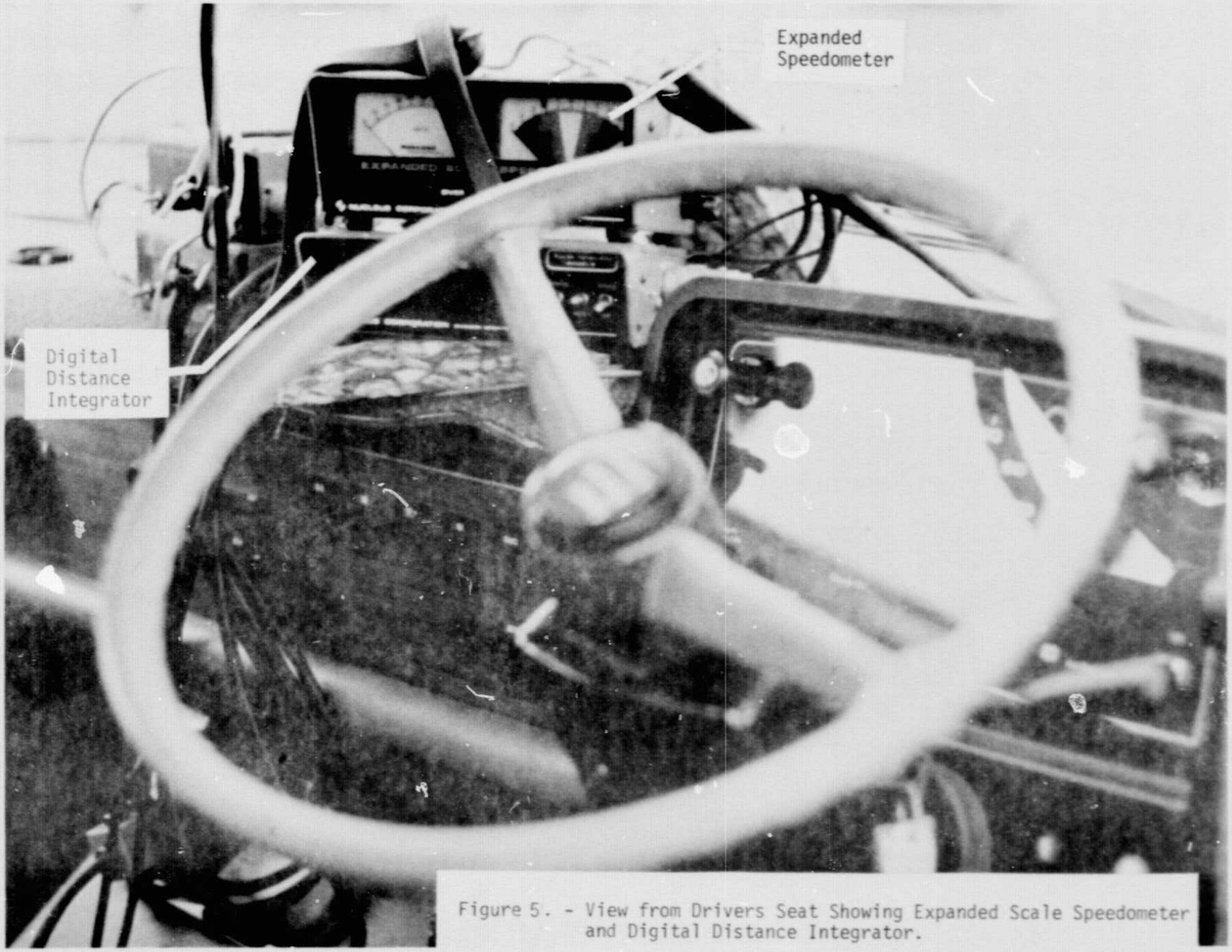


Figure 5. - View from Drivers Seat Showing Expanded Scale Speedometer and Digital Distance Integrator.

TEST RESULTS

The Lucas Limousine was tested at the DANA Corporation Test Track between September 24, 1976, and September 30, 1976. The vehicle was available only during this limited period, and battery changing was not possible. The testing was therefore confined to one specific test per day. These included three different steady speed range tests, one cycle test (Schedule C), a repeat of two of the range tests, and the miscellaneous tests of acceleration, coast down, and tractive force.

Vehicle Description: The Lucas Limousine is described by the manufacturer as a "luxury executive personnel carrier." The vehicle is a converted Bedford van, and accommodates seven passengers plus a driver. The front passenger seat is on a locking swivel base and allows the occupant to sit facing the other passengers. Luggage and storage space is provided, thereby giving a total payload capability of 1584 pounds (720 KG).

The vehicle is powered by a 50 bhp d. c. motor. A two-stage chain reduction drives the rear wheels through a conventional differential gear and fully floating half shafts.

The SCR chopper type controller is mounted at the front of the vehicle.

Specifications:

Vehicle Serial Number - None

Size and Weight

- Length . . . . 168 in.
- Width . . . . 79 1/2 in.
- Height . . . . 86 in.
- Road Clearance . . . . 6 1/2 in.
- Projected Frontal Area . . . . 28.5 ft^2 (approx.)
- Curb Weight . . . . 6116 lb. (2780 KG)
- Gross Vehicle Weight . . . . 7700 lb. (3500 KG)
- Payload . . . . 1584 lb. (720 KG)

Wheels

- Tires - 205 x 14 steel braced radial
- Tire Pressure
  - Front - 65 psi
  - Rear - 75 psi
- Rolling radius - 13.5 in.
- Wheel base - 106 in.
- Wheel track
  - Front - 64.75 in.
  - Rear - 66.25 in.

Battery Charger

- Type - Lucas (off board)
- Input: 240v single phase
- Weight - 264 lb (120 KG) approx.

Batteries
- Traction - (light-weight lead-acid)
- Manufacturer - Lucas Industries
- Type - EV-4
- Normal Rating - 130 AH (approx.)
- Weight - 1980 lb (900 KG)

Accessory
- Type - Lucas P 250 (type CP11)
- Capacity - 66AH
- Weight - 43 lb (19.5 KG)

Propulsion Motor
- Type - 216 V d. c. Series
- Rating - 50 bhp (200 ft-lb torque)
- Weight - 308 lb (140 KG)

Controller
- Lucas SCR Chopper operating at approximately 200 cycles per second.

Braking
- Girling servo-assisted hydraulic system supplemented by an optional regenerative motor-braking system

Axle
- Front - independent, coilspring suspension
- Rear - modified leafspring suspension, low-loss wheel bearings
- Ratio - primary reduction of 2.385:1 is in a Morse Hy-Vo chain reduction. Secondary reduction of 2.81:1 is in the rear axle housing
- Drive - fully floating half shafts of unequal length from a conventional differential
- Heater - none

Results:

Meteorology: Over the entire week of testing the wind speed was variable from 0 mph to a maximum of 10 mph with an average daily speed of 4.4 mph. The ambient temperature varied from 55° to 69° with a daily average of 63.8° F.

Range at Steady Speeds: Results of the range tests at steady speed are shown in table I. The range tests were run at 30, 40, and 50 mph. In order to determine repeatability the 40 and 50 mph tests were run twice. The final range in mileage for both repeat tests was within 3.5 percent. The other range and cycle tests were not repeated because of the limited available time.

Range During Cycle Tests: Results of the cycle test with the vehicle operated over a definite driving pattern are also shown in table I. The 30 mph Schedule C of SAE J227a was selected for this test. The vehicle completed 128 full cycles at a range of 48.4 miles.

Braking Tests: Braking tests were not conducted on the Lucas Vehicle because of the limited length of time the vehicle was available.

Acceleration Tests: Tests were conducted on the Lucas Limousine to determine the maximum acceleration with the battery fully charged, 40 percent discharged and 80 percent discharged. The results of the tests are shown in the curve of figure 6 and are tabulated in table II. The vehicle accelerated the

TABLE I - LUCAS LIMOUSINE RANGE TESTS

Test	Range, Miles	Number of Cycles	kWh/Mile
Range-at-steady-speed			
30 mph	102.2	--	0.45
40 mph	*76.1	--	*0.64
50 mph	*57.1	--	*0.76
Driving Cycle Range Schedule C, 30 mph	48.4	128	0.92

* Average of 2 Runs

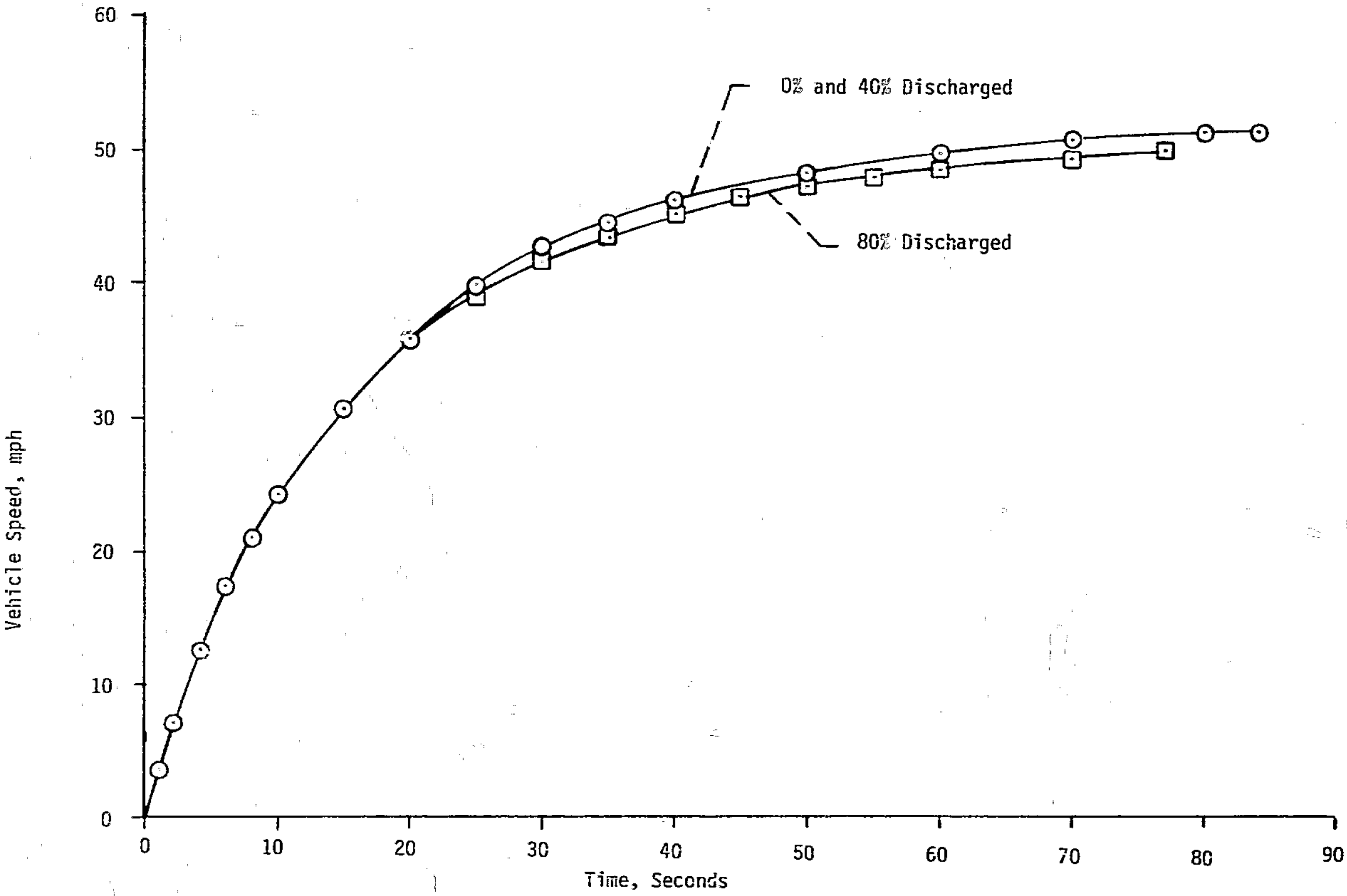


Figure 6 - Acceleration Characteristics of Lucas Limousine.

TABLE II - ACCELERATION CHARACTERISTICS OF LUCAS LIMOUSINE

Time, sec	Vehicle speed, mph	
	0 &40 percent discharged	80 percent discharged
1	3.5	3.5
2	7.0	7.0
4	12.5	12.5
6	16.9	16.9
8	21.0	21.0
10	24.3	24.3
15	30.5	30.5
20	36.0	36.0
25	39.7	39.0
30	42.6	41.5
35	44.4	43.5
40	46.0	45.0
45	----	46.5
50	48.2	48.3
55	----	48.0
60	49.8	48.5
70	50.8	49.4
77	----	50.0
80	51.5	
84	51.5	

same with the battery 40 percent discharged as with the battery fully charged. Some decrease in acceleration occurred when the batteries became 80 percent discharged. Maximum acceleration as a function of vehicle speed is shown in figure 7 and table III.

Gradeability - The curve in figure 8 shows the maximum grade that the Lucas Limousine can negotiate as a function of the vehicle speed. The data are also listed in table IV. As can be seen, the state-of-charge of the battery does not greatly affect the gradeability of the vehicle. Tractive force tests were conducted with the batteries fully charged and 80 percent discharged to determine the vehicles gradeability limit. The tractive force varied between 1240 pounds and 1275 pounds whether the battery was fully charged or up to 80 percent discharged, indicating a maximum gradeability of the vehicle of 16.5 percent. This percentage confirmed the predicted gradeability of the manufacturer.

Road Energy Consumption - The road energy of the vehicle was determined from coast down tests. The vehicle is allowed to coast from a top speed down to a complete stop. The results of the tests are plotted in figure 9 and listed in table V. From the coast down data the road power and road energy requirements are calculated. Road power and road energy requirements are presented in figures 10 and 11, respectively. The data are also listed in tables VI and VII. At a vehicle speed of 20 mph the road power requirement is 2.92 kilowatts and the road energy requirement is 0.146 kWh/mi. At a speed of 40 mph the road power requirement increases to 11.12 kilowatts and the road energy requirement increases to 0.278 kWh/mi.

For the coast-down tests it was not possible to isolate or disconnect the motor from the powertrain. The data has not been corrected for motor friction and windage losses as required by SAE J227a because motor data is not available at this time.

Energy Economy - For the steady speed range tests the energy economy as a function of vehicle speed is plotted in figure 12 and tabulated in table VIII. The maximum economy measured is 0.45 kilowatt hours per mile at a vehicle speed of 30 mph. For the 30 mph driving cycle test the energy economy was 0.92 kilowatt hours per mile.

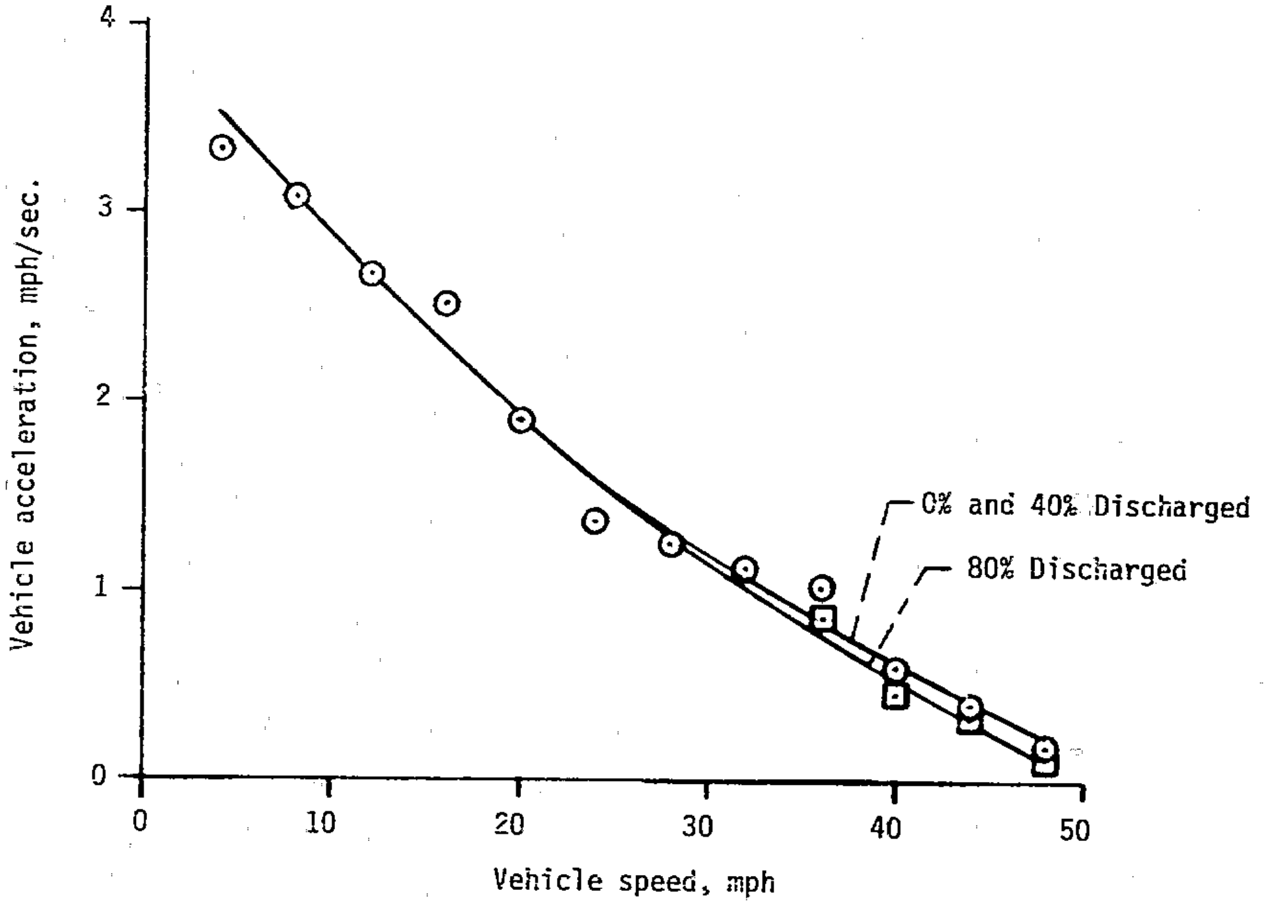


Figure 7. - Vehicle Maximum Acceleration as a Function of Vehicle Speed for Lucas Limousine.

TABLE III - VEHICLE MAXIMUM ACCELERATION AS A FUNCTION OF VEHICLE SPEED FOR LUCAS LIMOUSINE

Vehicle speed, mph	Acceleration, mph/sec	
	0 & 40 percent discharged	80 percent discharged
4	3.3	3.3
8	3.1	3.1
12	2.7	2.7
16	2.5	2.5
20	1.9	1.9
24	1.4	1.4
28	1.3	1.3
32	1.1	1.1
36	1.0	.9
40	.6	.5
44	.4	.3
48	.2	.1

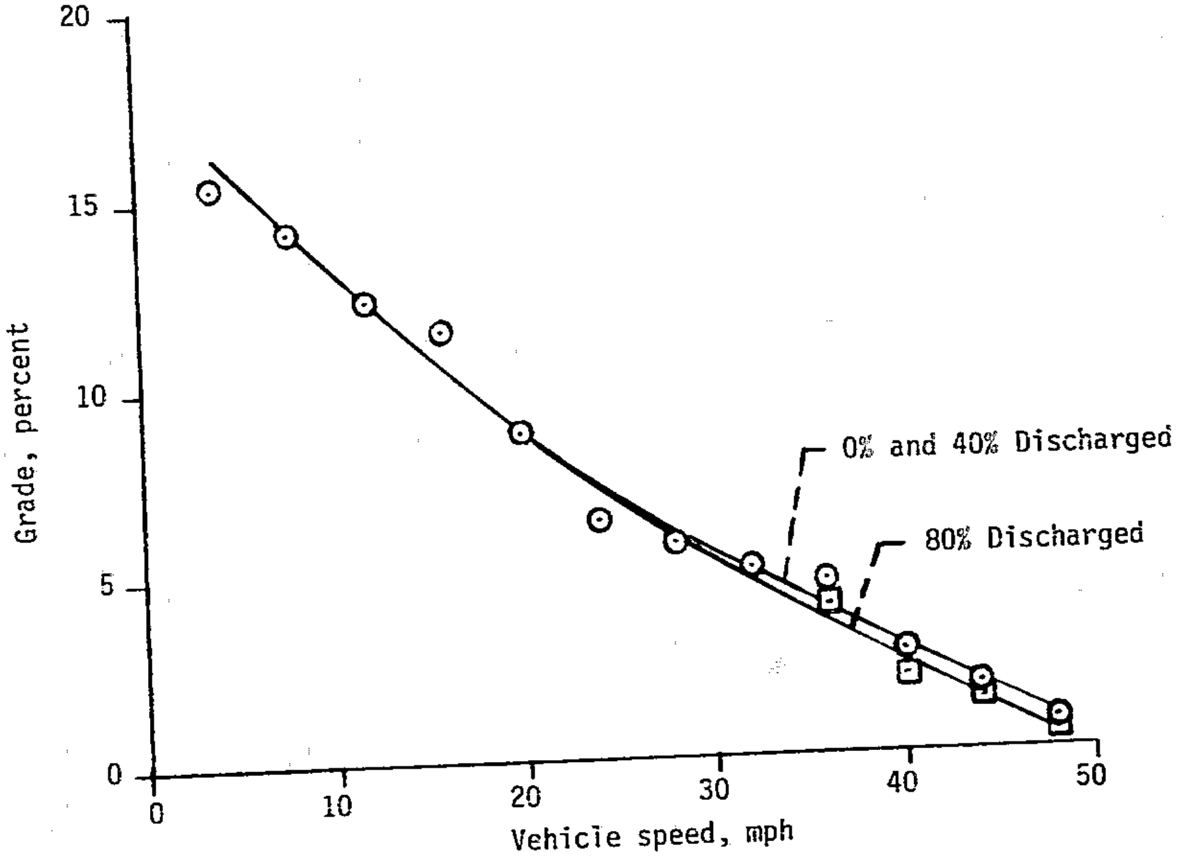


Figure 8. - Gradeability of Lucas Limousine.

TABLE IV - GRADEABILITY OF LUCAS LIMOSINE AS DETERMINED BY MAXIMUM ACCELERATION TESTS

Vehicle speed, mph	Gradeability, percent	
	0(. 40 percent discharged	80 percent discharged
2*	16.5*	16.5*
4	15.3	15.3
8	14.1	14.1
12	12.2	12.2
16	11.4	11.4
20	8.7	8.7
24	6.3	6.3
28	5.7	5.7
32	5.0	5.0
36	4.6	4.0
40	2.7	2.1
44	1.8	1.4
48	0.8	0.5

* Determined by tractive force tests.

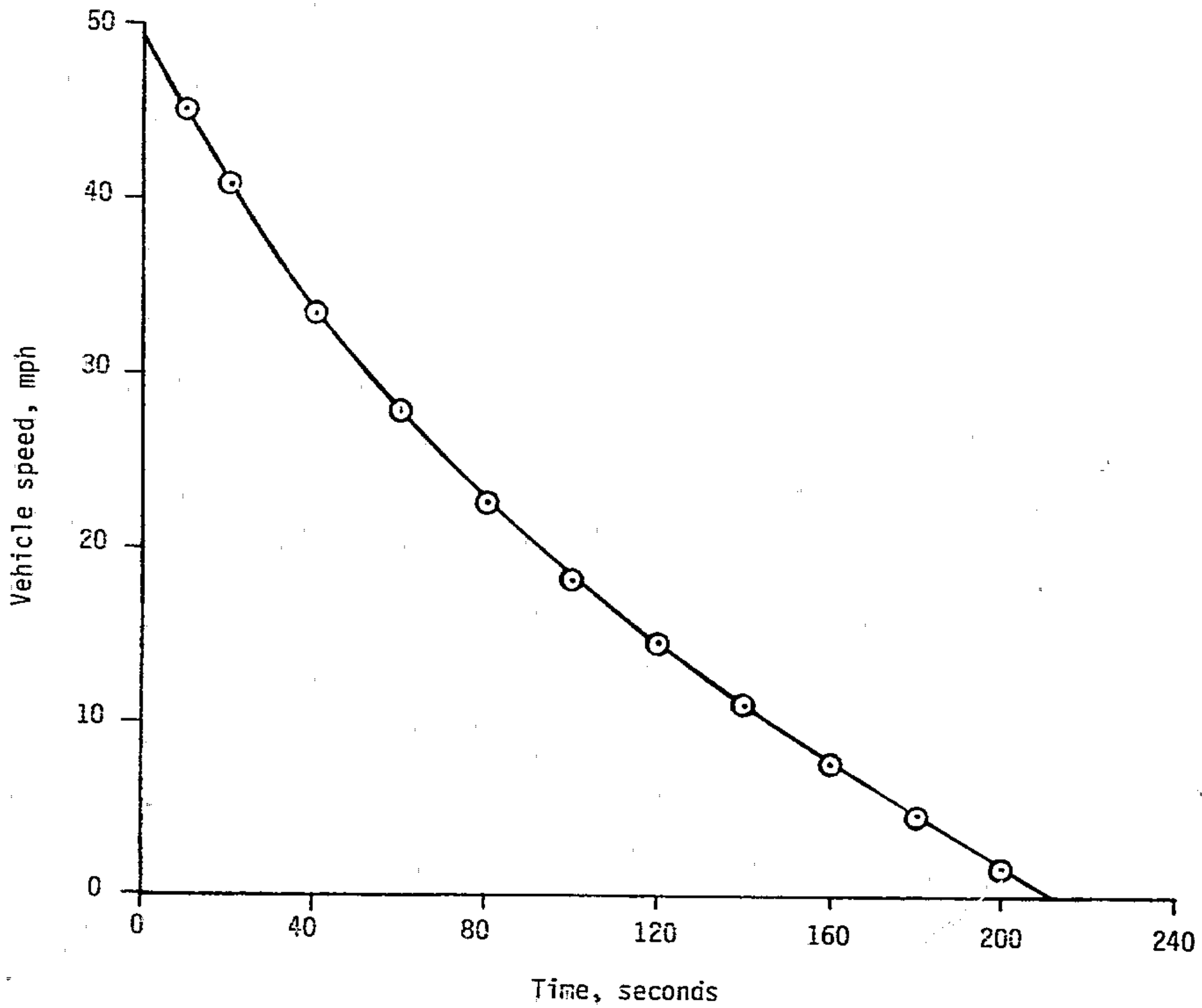


Figure 9 - Vehicle Speed as a Function of Time During Coasting for Lucas Limousine.

TABLE V - VEHICLE SPEED AS A FUNCTION OF TIME DURING COASTING FOR LUCAS LIMOUSINE

Time, sec	*Vehicle velocity, mph
1	48.9
2	48.3
4	47.5
6	46.6
8	45.5
15	42.6
20	40.8
30	37.0
40	33.5
50	30.4
60	27.9
80	22.7
100	18.2
120	14.7
140	11.1
160	7.7
180	4.7
200	1.6
210	0

* Average of 2 runs.

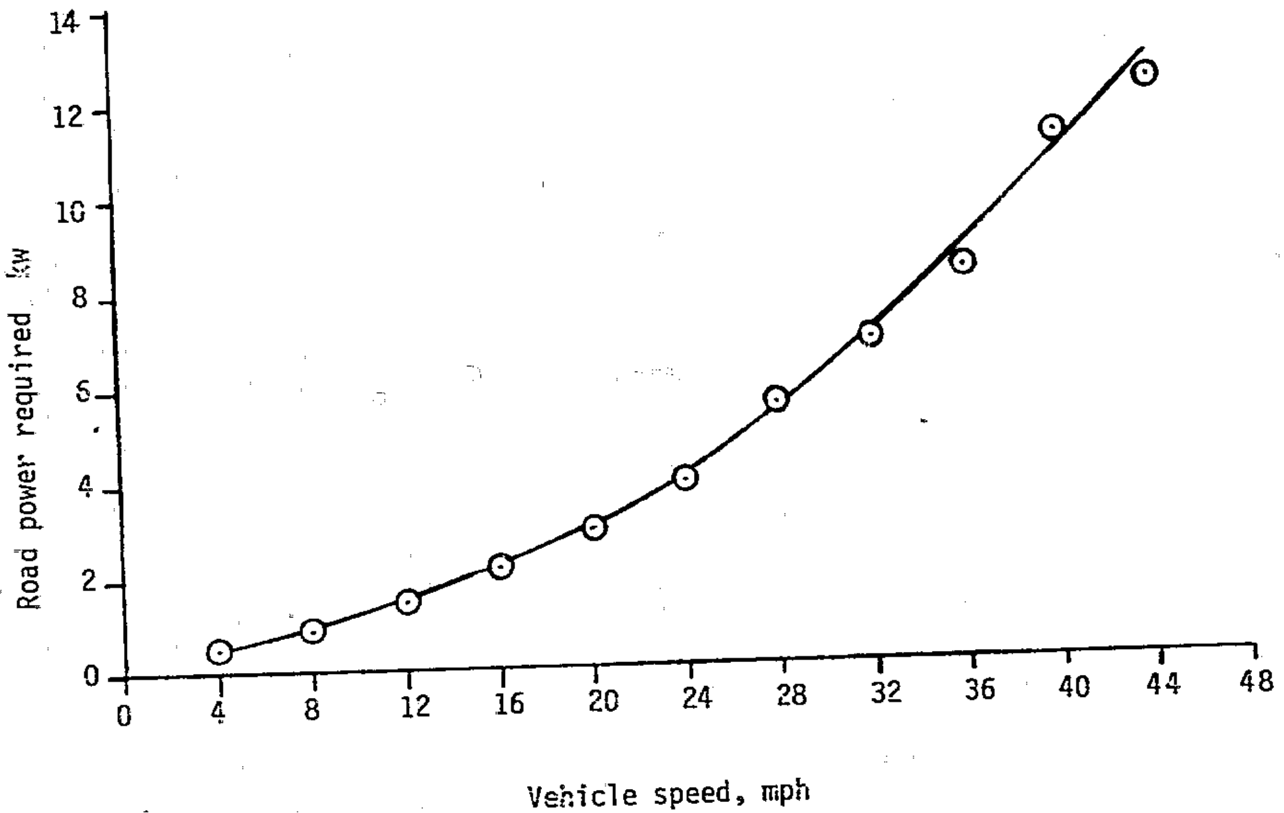


Figure 10 - Road Power Required as a Function of SPeed for Lucas Limousine.

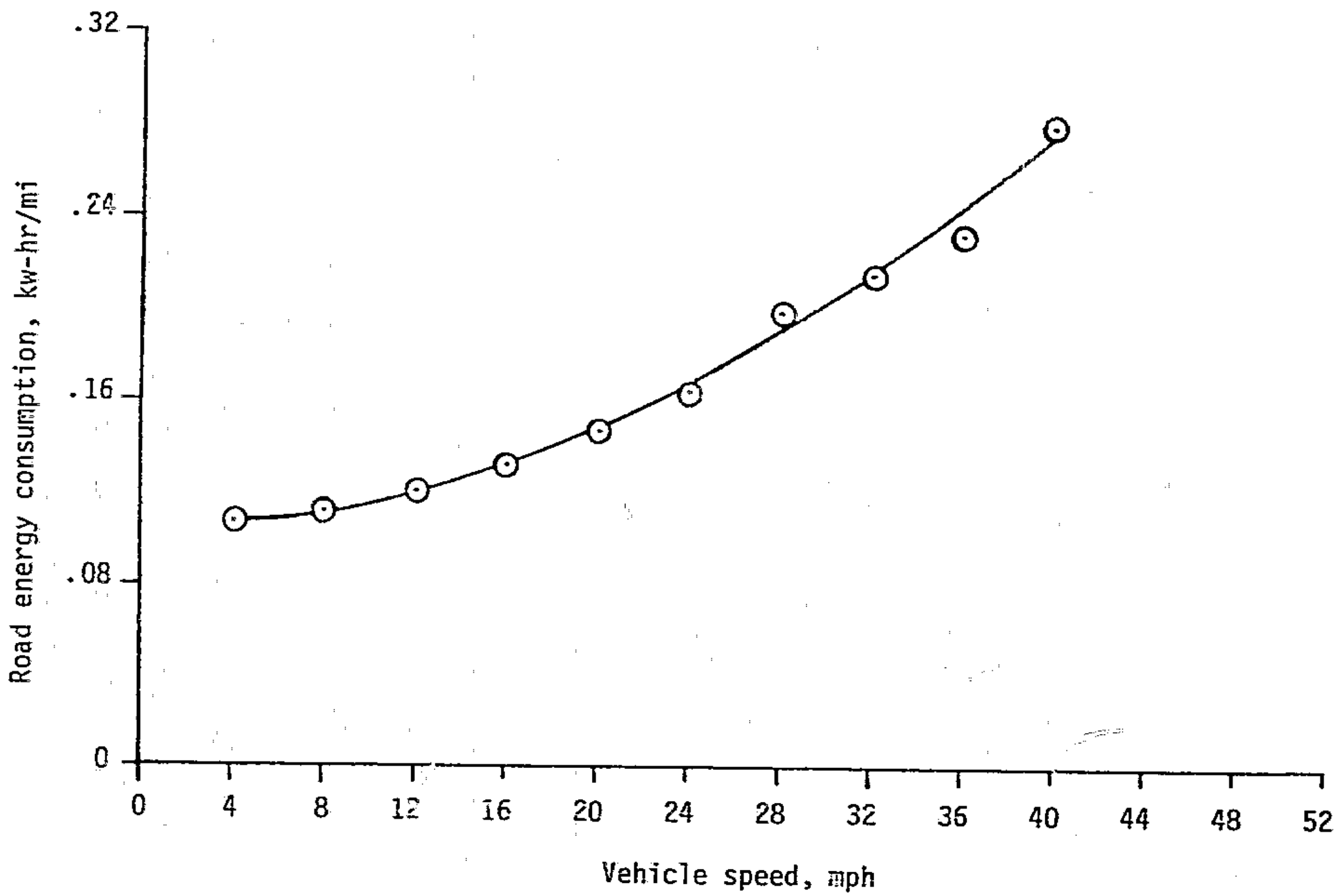


Figure 11. - Road Energy Consumption as a Function of Vehicle Speed for Lucas Limousine.

TABLE VI - ROAD POWER REQUIRED AS A FUNCTION OF SPEED FOR LUCAS LIMOUSINE

Vehicle speed, mph	Road power required, kw
4	0.5
8	.9
12	1.5
16	2.1
20	2.9
28	5.5
32	6.8
36	8.3
40	11.1
44	12.2

TABLE VII - ROAD ENERGY CONSUMPTION AS A FUNCTION OF VEHICLE SPEED FOR LUCAS LIMOUSINE

Vehicle speed, mph	Road energy consumption, kWh/mi
4	0.107
8	.111
12	.121
16	.132
20	.146
24	.163
28	.198
32	.214
36	.232
40	.2[illegible]3

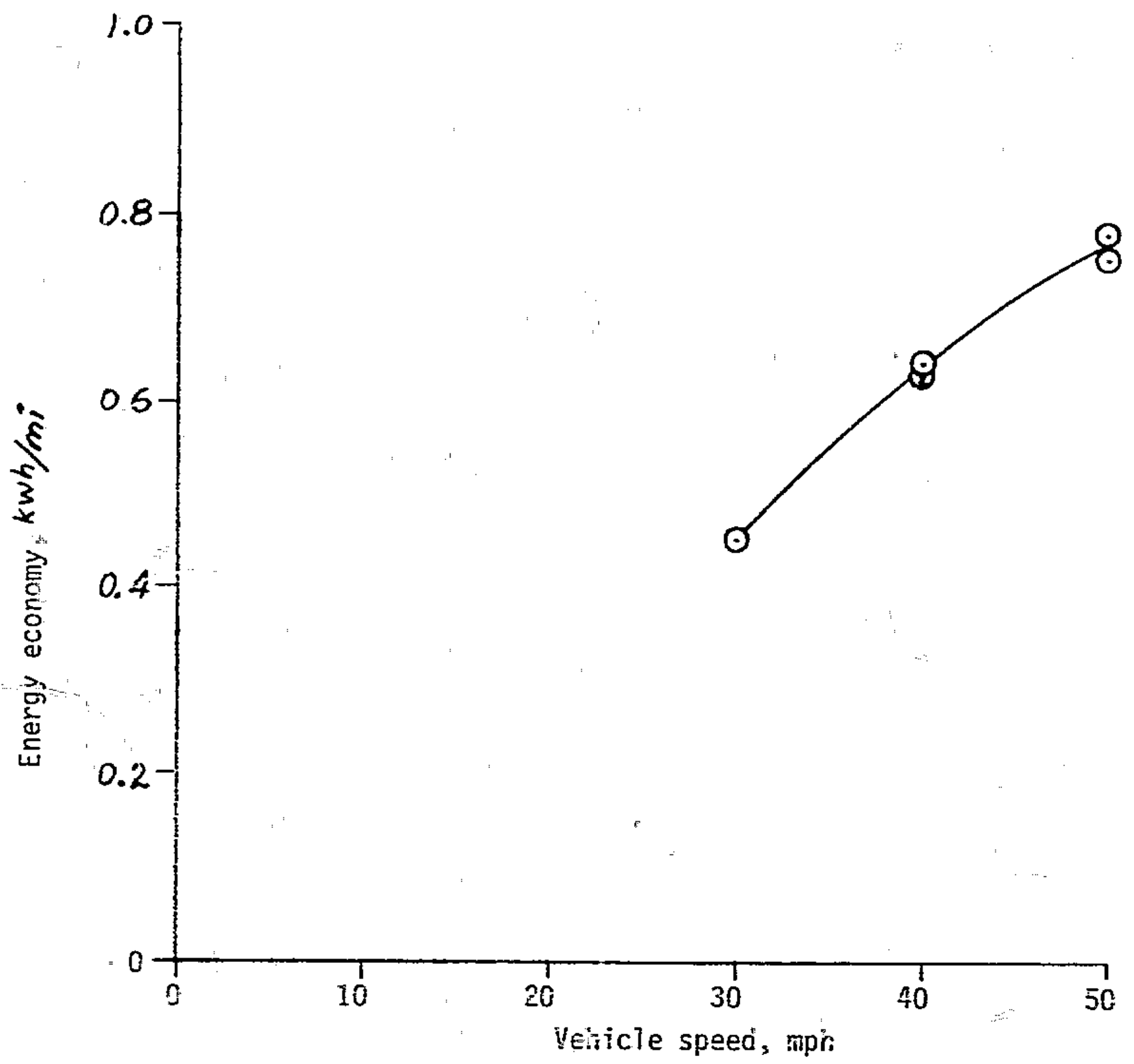


Figure 12. - Energy Economy as a Function of Vehicle Speed for Lucas Limousine.

TABLE VIII - ENERGY ECONOMY AS A FUNCTION OF VEHICLE SPEED FOR LUCAS LIMOUSINE

Vehicle speed, mph	Energy economy, kWh/mi.
30	0.45
40	* .64
50	* .76

* Average of 2 runs.