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National Aeronautics and
Space Administration

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SUMMARY

The NASA John H. Glenn Research Center initiated baseline testing of the EV Global E-Bike with ultracapacitors as a way to reduce pollution in urban areas, reduce fossil fuel consumption and reduce operating costs for transportation systems. The E-Bike provides an inexpensive approach to advance the state of the art in hybrid technology in a practical application. The project transfers space technology to terrestrial use via non-traditional partners, and provides power system data valuable for future space applications. The work was done under the Hybrid Power Management (HPM) Program, which includes the Hybrid Electric Transit Bus (HETB). The E-Bike is a state of the art, ground up, hybrid electric bicycle. Unique features of the vehicle's power system include the use of an efficient, 400 watt, electric hub motor, and a 7-speed derailleur system that permits operation as fully electric, fully pedal, or a combination of the two. Other innovative features, such as regenerative braking through ultracapacitor energy storage, are planned. Regenerative braking recovers much of the kinetic energy of the vehicle during deceleration. The E-bike has been tested with the standard battery energy storage system, an ultracapacitor energy storage system, and a combination battery and ultracapacitor energy storage system. A description of the E-bike, the results of performance testing and future vehicle development plans is the subject of this report. The report concludes that the E-Bike provides excellent performance, and that the implementation of ultracapacitors in the power system can provide significant performance improvements.

INTRODUCTION

The NASA Glenn Research Center initiated baseline testing of the EV Global E-Bike as an excellent opportunity to transfer technology from the aerospace and military industries to a commercial venture. The project is seen as a way to reduce pollution in urban areas, reduce fossil fuel consumption and reduce operating costs for transportation systems. The E-Bike provides an inexpensive approach to advance the state of the art in hybrid technology in a practical application. The project transfers space technology to terrestrial use via non-traditional partners, and provides power system data valuable for future space applications.

The NASA Glenn Research Center provides overall project coordination and is responsible for testing the vehicle. This includes instrumenting the vehicle and developing instrumentation and control programs. Wherever practical, off-the-shelf components have been integrated into the test configuration.

TEST OBJECTIVES

Testing of the vehicle was performed at the NASA Glenn Research Center. Of particular interest are the following characteristics: range, vehicle speed, acceleration time, and performance over stop-and-go driving schedules. The performance of the various vehicle components, especially the motor, controller, energy storage system, and charger are also of interest.

TEST VEHICLE DESCRIPTION

The E-Bike is a state of the art, ground up, hybrid electric bicycle. The vehicle is shown in Fig. 1 and described in detail in Appendix A. The E-Bike is a parallel hybrid vehicle as shown in Fig. 2. As a parallel hybrid vehicle, power is provided to the drive wheel from an internal electric hub motor, or through the pedals via a 7-speed derailleur, or a combination of the two.

The standard energy storage system consists of two 12 volt, 12-amp hour sealed lead acid, deep discharge batteries to store electrical energy. The battery charger is built into the battery pack. The charger is rated at 24 volts, 3 amps DC. The complete battery pack including the charger is shown in Fig. 3. The battery pack is quickly removed from the vehicle if so desired. This permits the quick installation of another battery pack, as well as charging of the battery pack outside of the vehicle.

The ultracapacitor energy storage system tested is rated at 400 Farads. One of the ultracapacitors is shown in Fig. 4. This state-of-the-art technology not only has much longer life than conventional batteries, but also provides much higher current capacity than batteries. Ultracapacitors are maintenance free, and have excellent low temperature characteristics.

The electric traction motor shown in Fig. 5 is a 400-Watt DC brushed electric hub motor. This is a direct drive system with no drive train losses. A pulse width modulated motor controller allows for efficient speed control over a wide speed range. The motor controller includes cruise control to maintain constant speed.

The vehicle incorporates Department of Transportation specified safety features including lights, mirror, and horn.

Fig. 1 – EV Global E-Bike

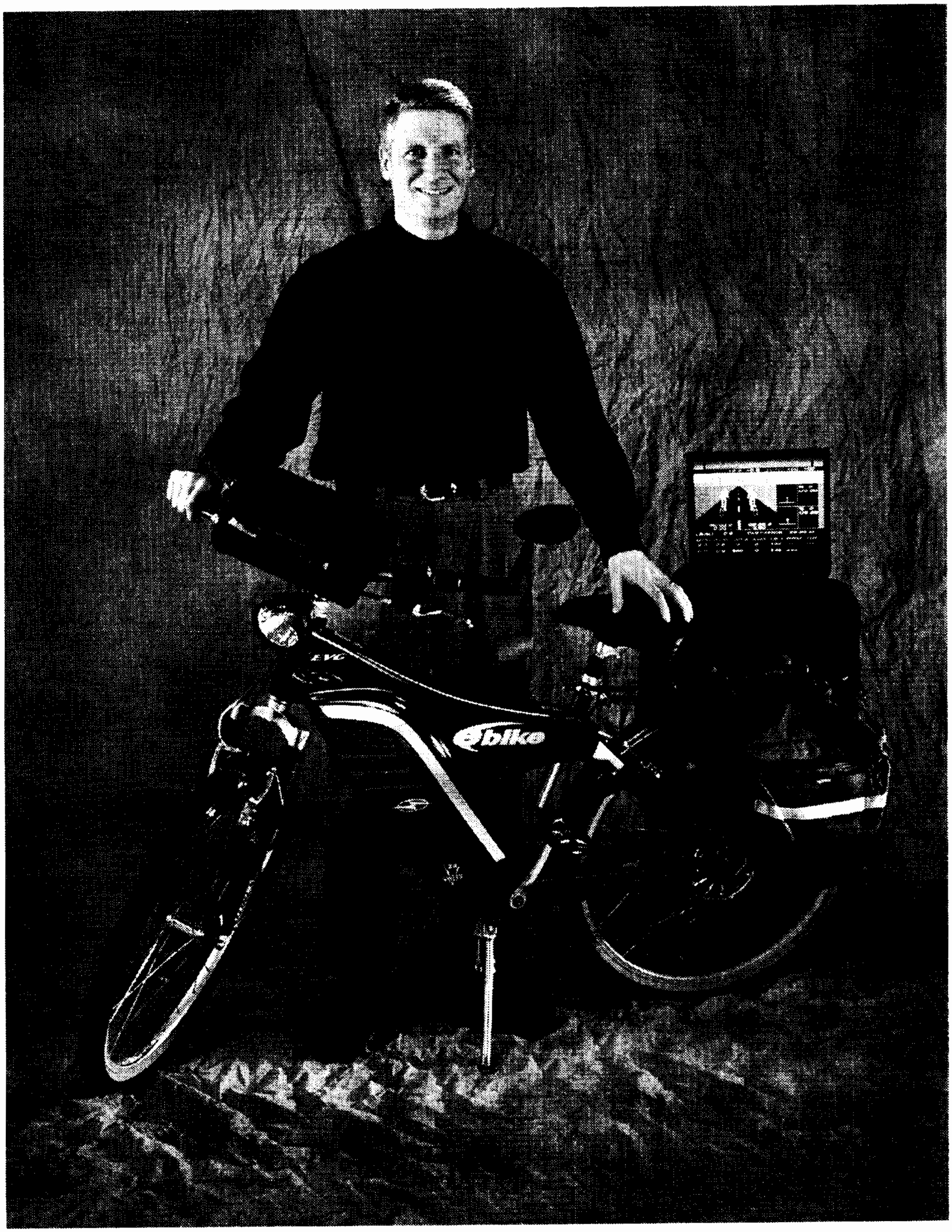
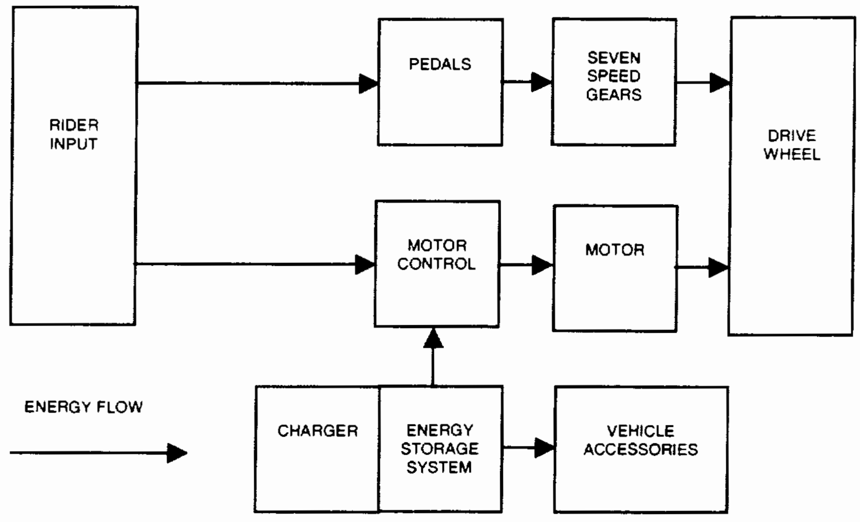


Fig. 2 – E-Bike Schematic Diagram



PARALLEL HYBRID SCHEMATIC DIAGRAM

Fig. 3 – Battery Pack

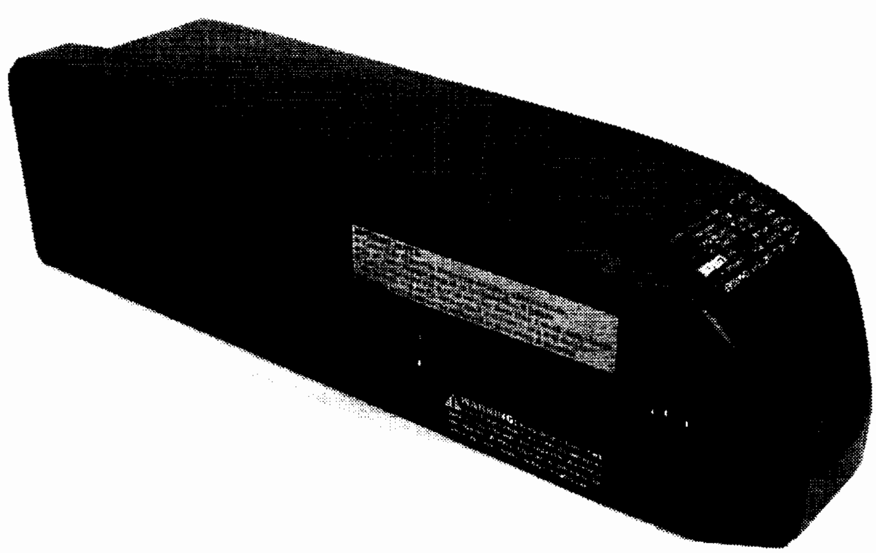


Fig. 4 – Ultracapacitor

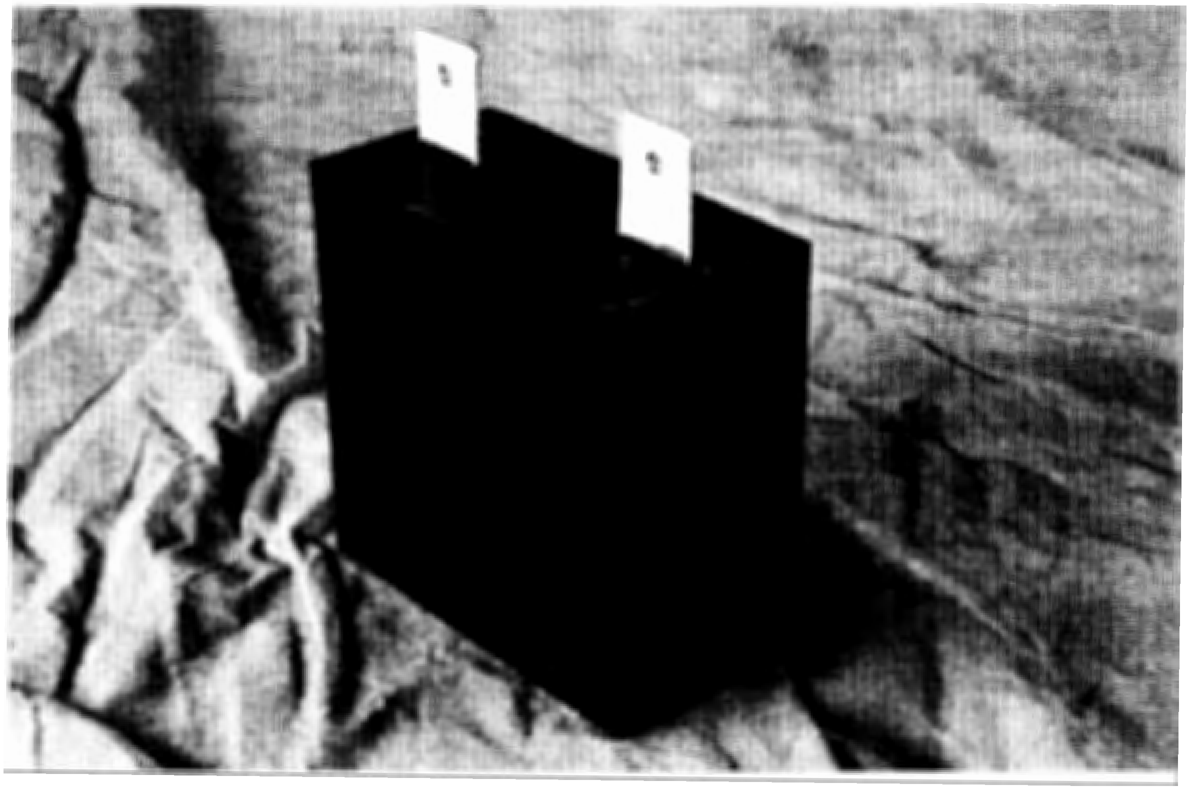
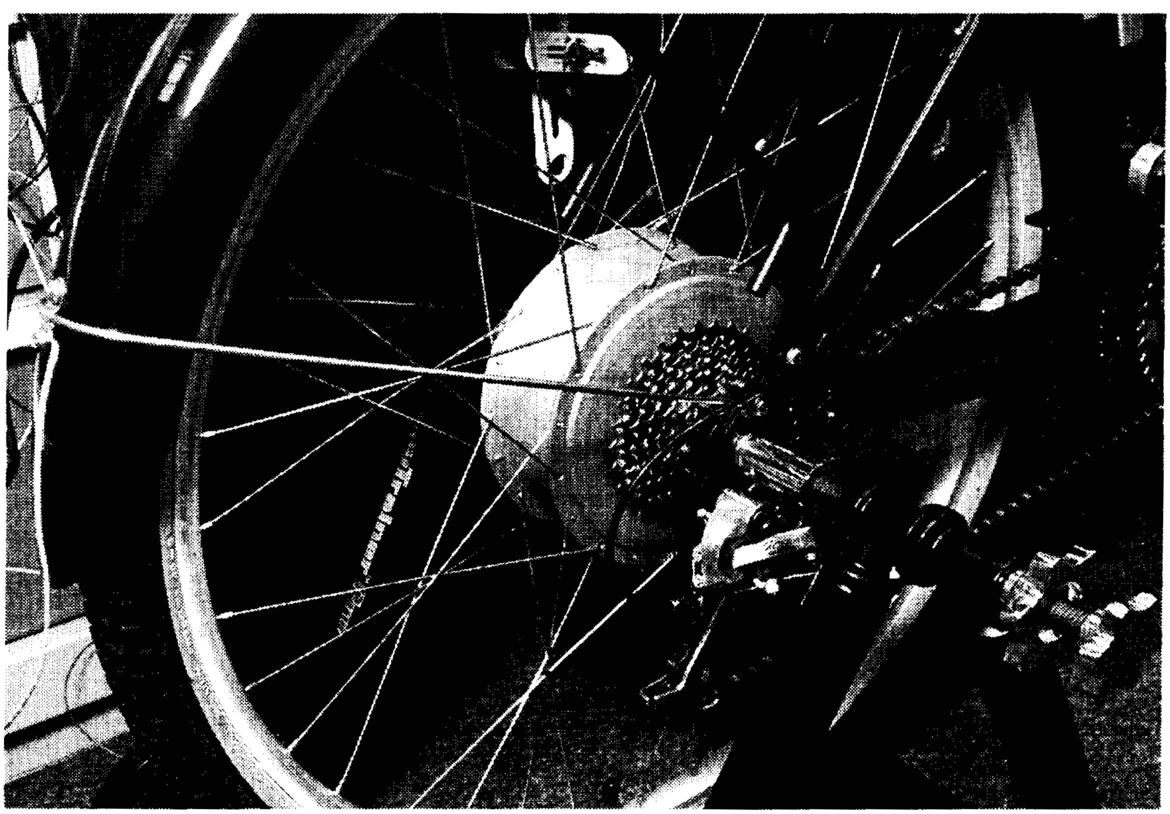


Fig. 5 – Hub Motor



INSTRUMENTATION

The E-Bike was instrumented to measure vehicle speed, distance, and load. These data were sent to an off-board digital data acquisition system, sampled continuously and stored on a desktop PC. Additional channels measured the battery voltage and current, as well as the following temperatures: traction motor, motor controller, energy storage, and the ambient temperature. These data were sent to an off-board digital data acquisition system and stored on a laptop PC. Power for the data acquisition system, was derived from the Building 86 utility system. The instrumentation configuration is described in Appendix B.

TEST PROCEDURES

The tests described in this report were conducted on a dynamometer at the NASA Glenn Research Center in Cleveland, Ohio. A description of the dynamometer is given in Appendix C. The tests were conducted in accordance with the test matrix provided in Appendix D.

TEST RESULTS

Vehicle Performance

Ten tests were conducted to determine vehicle performance, per Table 1:

Table 1 – Performance Tests Conducted on the E-Bike

Test Number	*Grade (%)*	*Vehicle Mode*	*Top Vehicle Speed*	*Energy Source*	*Test Mode*
1	+0	Normal	Maximum	Battery	Acceleration test.
2	+4	Normal	Maximum	Battery	Acceleration test.
3	+8	Normal	Maximum	Battery	Acceleration test.
4	+0	Normal	Maximum	Capacitor	Acceleration/range test.
5	+4	Normal	Maximum	Capacitor	Acceleration/range test.
6	+8	Normal	Maximum	Capacitor	Acceleration/range test.
7	+0	Economy	5 mph	Capacitor	Range test.
8	+0	Normal	Maximum	Bat & Cap	Acceleration test.
9	+4	Normal	Maximum	Bat & Cap	Acceleration test.
10	+8	Normal	Maximum	Bat & Cap	Acceleration test.

A similar set of plots have been included in Appendix E for each of the vehicle tests:

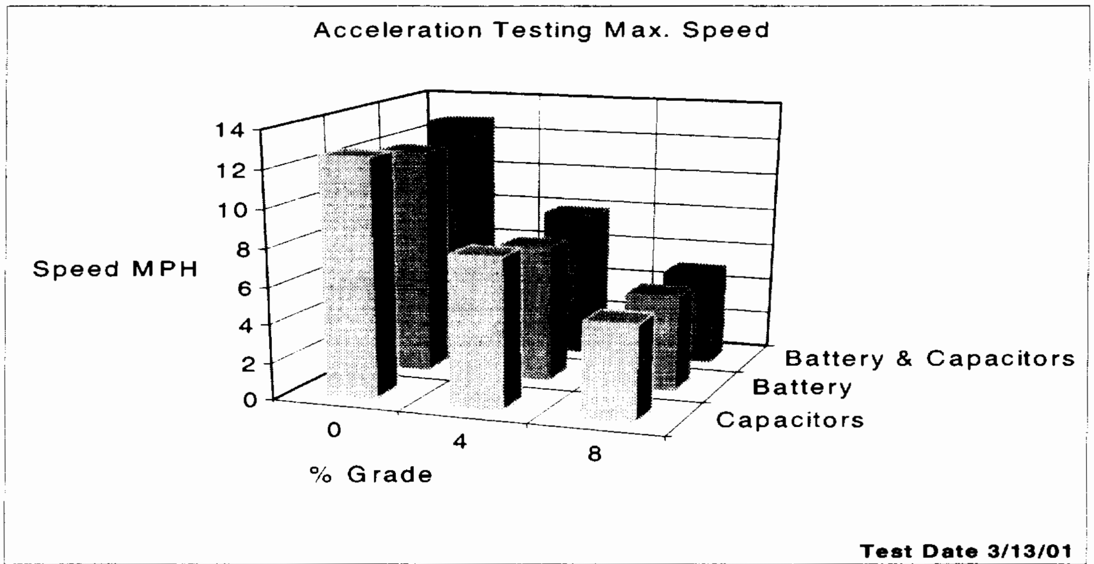
a. Vehicle speed and vehicle power vs. elapsed time.
b. Vehicle battery voltage, current, and power vs. elapsed time.
c. Component temperatures vs. elapsed time.

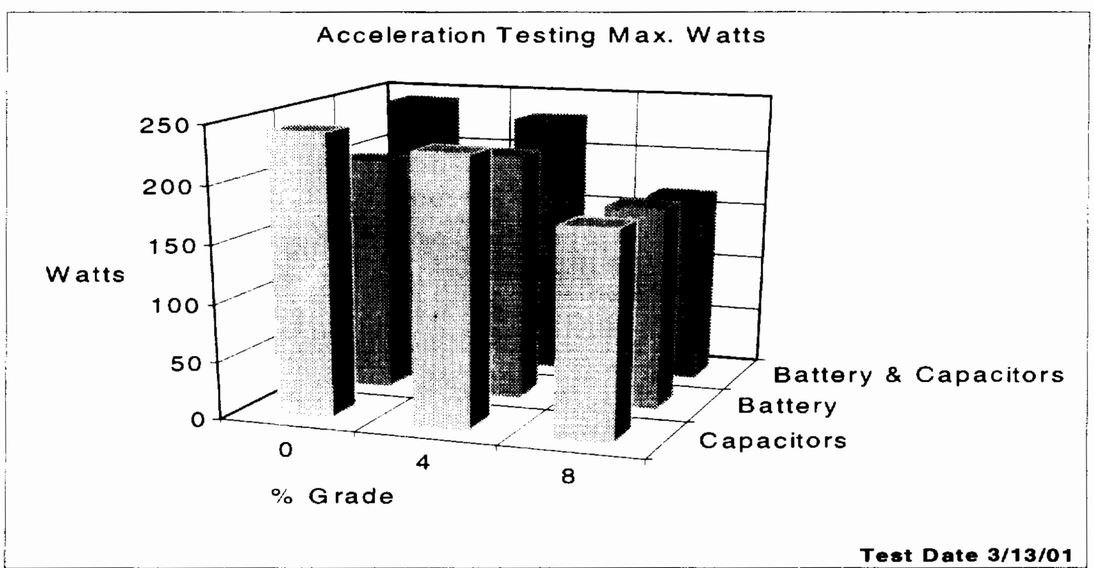
A summary of the test results is shown in Table 2 at the end of this section.

Maximum Speed

The maximum speed of the vehicle was measured to be 11.94 mph with no grade under full power with battery energy storage. The maximum speed was measured to be 12.56 mph with no grade under full power with ultracapacitor energy storage. The maximum speed was measured to be 12.76 mph with no grade under full power with a combination of battery and ultracapacitor energy storage. Figure 6 indicates the maximum speeds achieved with the various energy storage systems, as well as the various powers that were obtained.

Fig. 6 – Maximum Speed for Various Grades





Acceleration

The average acceleration, a_n, of the vehicle is computed as a change in vehicle speed as a function of time.

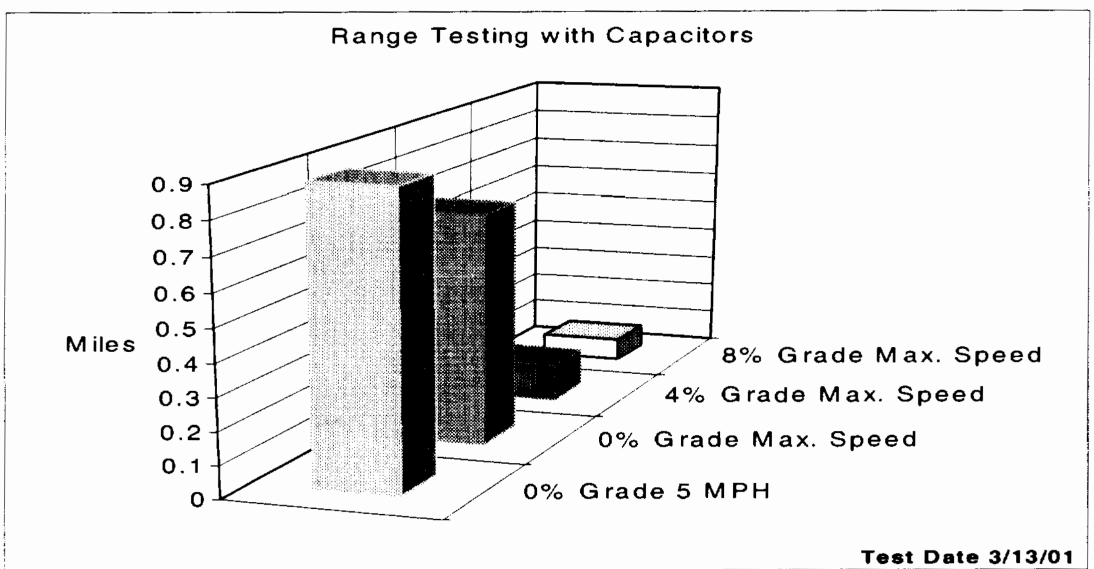
$$a_n = \frac{v_n - v_{n-1}}{t_n - t_{n-1}}$$

Acceleration times are given in Table 2.

Range

The range of the vehicle was determined from the dynamometer tests under full electric operation with ultracapacitor energy storage. This yields a range of 0.89 miles for no grade in the economy mode with an initial speed of 5 mph.

Fig. 7 – Range with Various Speeds and Grades



Summary

An overall summary of the vehicle testing is shown in Table 2.

Table 2 – Summary of Test Results for the EV Global E-Bike with Ultracapacitors

Parameter	Configuration	Test Conditions	Test Results	Remarks
Acceleration Times				
5 mph	Battery Capacitor Battery & Capacitor	0% Grade, Normal Mode	1.10 sec 0.97 sec 0.97 sec	
10 mph	Battery Capacitor Battery & Capacitor	0% Grade, Normal Mode	7.50 sec 6.38 sec 6.07 sec	
12 mph	Battery Capacitor Battery & Capacitor	0% Grade, Normal Mode	18.12 sec 11.50 sec 10.42 sec	
5 mph	Battery Capacitor Battery & Capacitor	4% Grade, Normal Mode	1.16 sec 1.16 sec 0.58 sec	
7.24 mph	Battery Capacitor Battery & Capacitor	4% Grade, Normal Mode	12.03 sec 9.87 sec 10.60 sec	
5 mph	Battery Capacitor Battery & Capacitor	8% Grade, Normal Mode	1.29 sec 0.43 sec 0.71 sec	
Top Speed	Battery Capacitor Battery & Capacitor	0% Grade, Normal Mode	11.94 mph 12.56 mph 12.76 mph	
Range				
5 mph	Capacitor	0% Grade, Economy Mode	0.89 miles 13.77 min	
Maximum Speed	Capacitor	0% Grade, Normal Mode	0.71 miles 4.11 min	12.56 mph maximum speed.

CONCLUDING REMARKS

The EV Global E-Bike as tested and described in this report with the standard battery pack is a commercially available vehicle that is fully prepared for the mass market. The E-Bike was also tested successfully with ultracapacitor energy storage, and a combination of battery and ultracapacitor energy storage. The vehicle, nor the energy storage systems, exhibited any problems under the rigorous test conditions that it was exposed to. The performance of the vehicle proved to be excellent.

The vehicle acceleration tests were very revealing. The acceleration tests were performed with battery energy storage, ultracapacitor energy storage, and a combination of battery and ultracapacitor energy storage. The acceleration performance to 5 mph and 10 mph in the three modes of operation was roughly the same with no grade. The acceleration performance to 12 mph was greatly improved with the ultracapacitor alone or the combination battery and ultracapacitor. The acceleration performance of the vehicle with a 4% grade and an 8% grade with ultracapacitor energy storage, either by itself or in combination with the battery, was far superior to that of the battery alone. The ultracapacitor is capable of supplying the high power required to accelerate the vehicle more quickly. The addition of the ultracapacitor to the battery conserves the battery since it does not need to provide the high current required for acceleration, thus extending its life.

The top speed of the vehicle with no grade and full throttle with the standard battery pack was 11.94 mph. The top speed with the ultracapacitor alone improved to 12.56 mph. The highest top speed was achieved with a combination of battery and ultracapacitor at 12.76 mph.

The range performance of the vehicle with the standard battery energy storage is extraordinary. The range of 34.8 miles achieved at an initial speed of 5 mph with no grade is almost twice the advertised range of 20 miles. The vehicle operated for 5.7 hours under these conditions. The range achieved with ultracapacitor energy storage alone at the same conditions was 0.89 miles. The vehicle operated for 13.77 minutes under these conditions.

The test results with a combination of battery and capacitor energy storage were very impressive. The ultracapacitor provides the high currents required for high acceleration, while conserving the battery. The top speed is the greatest with the battery and ultracapacitor combination.

The baseline testing of the E-Bike with the standard battery pack was the first step in the testing process. The baseline testing of the E-Bike with ultracapacitor energy storage was the second step. Future plans for the E-Bike calls for the testing of the vehicle with regenerative braking. Ultracapacitors will be used for regenerative braking, because of their superiority to batteries in accepting high braking currents, allowing for less usage of the mechanical brakes. A photovoltaic charging station will be assembled and tested, to permit the effective use of the E-Bike in remote locations with no dependence upon the utilities.

The E-Bike provides an inexpensive approach to advance the state of the art in hybrid technology in a practical application. The project transfers space technology to terrestrial use via non-traditional partners, and provides power system data valuable for future space applications.

REFERENCES

1. "Baseline Testing of the EV Global E-Bike", NASA Technical Memorandum 2001-210569, January 2001.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle Manufacturer	EV Global Motors Company Los Angeles, CA
2.0 Vehicle	E-Bike Touring Model
3.0 Vehicle Configuration	Parallel Hybrid
4.0 Traction Motor	
4.1 Traction Motor Configuration	DC brushed
4.2 Traction Motor Power	400 watts
4.3 Traction Motor Cooling	Air cooled
5.0 Drivetrain	
5.1 Traction Motor Drivetrain	Direct Drive
5.2 Pedal Drivetrain	
5.1.1 Transmission Type	7-speed Shimano derailleur
5.1.2 Front Chain Ring	33 teeth
5.1.3 Rear Cluster	14, 16, 18, 20, 22, 24, 28 teeth
5.1.4 Gear Ratio	0.42, 0.48, 0.55, 0.61, 0.67, 0.73, 0.85
5.1.5 Crankarm	6.7 in (170 mm)
5.1.6 Chain	½ x 3/32 x 110 L
6.0 Vehicle Dimensions	
6.1 Wheel Base	41.8 in (1062.3 mm)
6.2 Frame Size (center to top)	16.5 in (419 cm)
6.3 Head Tube	6.4 in (163 mm)
6.4 Headset Stack Height	1.30 in (33 mm)
6.5 Headset Dimensions	25.4 mm x 34 mm x 30 mm w/seal
6.6 Fork Steerer Tube	1-1/8 in
6.7 Fork Travel	65 mm
6.8 Stem 1	40 degrees, 110 mm extension
6.9 Stem 2	28.6 mm x 25.4 mm x 150 mm with quill
6.10 Handlebar Width	620 mm
6.11 Handlebar Rise	30 mm, 10 degrees
6.12 Handlebar Handle	200 mm
6.13 Seat Post	350 mm x 27.2 mm O.D.
6.14 Seat Post Spacer	100 mm x 27.3 I.D. x 34.9 mm O.D.
6.15 Tires	26 x 1.95 in
6.16 Rims	26 x 1.5 in, 14G x 36H, double wall
6.17 Spokes	
6.17.1 Front	266 mm, 14G stainless with brass nipples
6.17.2 Rear	219 mm, 14G stainless with brass nipples
6.18 Bottom Bracket	127 mm cartridge

6.19 Base Curb Weight	67 lb
6.20 Total Weight (as tested)	267 lb

7.0 Energy Storage

7.1 Battery Pack

7.1.1	Configuration	Two in series with integral charger
7.1.2	Battery Type	Deep discharge, sealed lead acid
7.1.3	Battery Energy Rating	12 amp hours each
7.1.4	Battery Voltage Rating	12 volts each
7.1.5	Charger Input	115 volts ac, 60 Hz, 2 amps
7.1.6	Charger Output	24 volts dc, 3 amps
7.1.7	Dimensions	15 in x 4 in x 4 in
7.1.8	Weight	22.3 lb

7.2 Capacitors

7.2.1	Configuration	Bank of 8 ultracapacitors (4 legs of 2 ultracapacitors in series)
7.2.2	Capacitance	50 F each, 400 F total
7.2.3	Energy Rating	8.1 kJ each, 64.8 kJ total
7.2.4	Voltage Rating	18 V each, 36 V for each series leg
7.2.5	Dimensions	3.25 in x 6 in x 7 in
7.2.6	Weight	10.8 lb each, 80 lb total

APPENDIX B

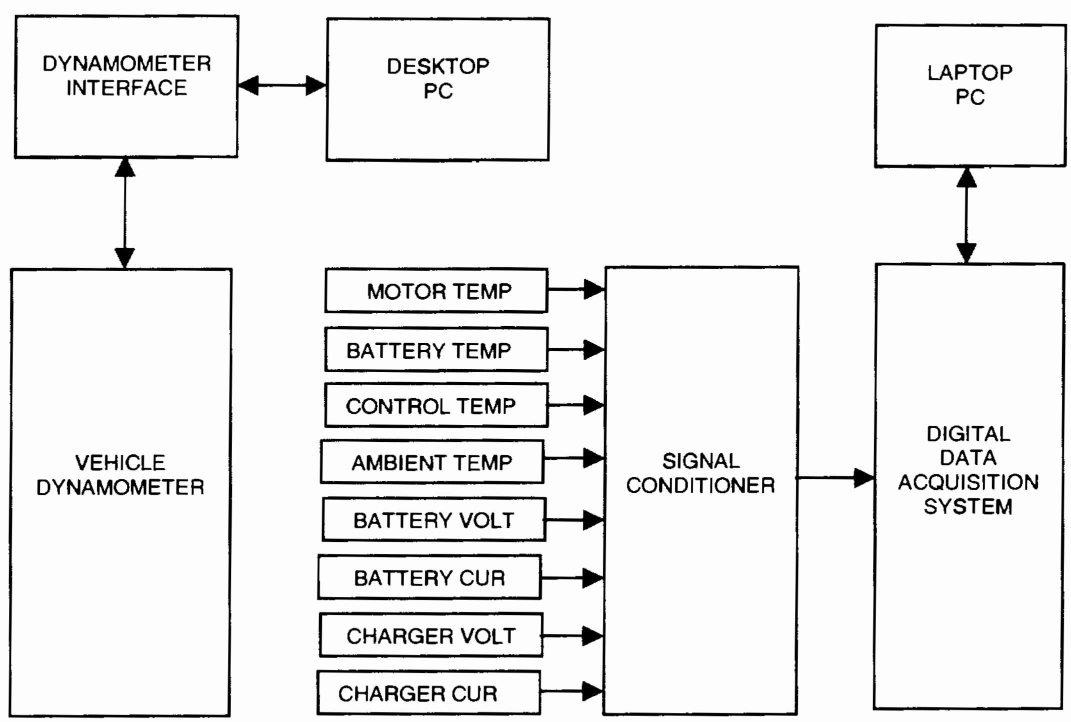
DESCRIPTION OF THE INSTRUMENTATION SYSTEM

A block diagram of the instrumentation system is shown in Fig. B-1.

The vehicle dynamometer has an integral instrumentation system that monitors vehicle speed, distance, and power. These data are sampled at 3 Hz and transmitted to the desktop PC via a serial interface. The PC logs the dynamometer data.

All other measurements were obtained with a Hewlett Packard data acquisition system, sampling at 100 Hz. Type K thermocouples were used for all temperature measurements. Hall effect transducers were used for all current measurements. These data are transmitted to the laptop PC via a serial interface. The PC logs the data.

Fig. B-1



VEHICLE INSTRUMENTATION SYSTEM

APPENDIX C

DESCRIPTION OF VEHICLE DYNAMOMETER

The vehicle dynamometer used to conduct the tests described in this report is the CompuTrainer Pro Challenge PC1 Model 8001. It is a high performance, microprocessor controlled, indoor dynamometer designed for bicycle use. The electronic load generator is capable of creating resistance loads from 50 to 1500 watts to simulate road grades to 15%. The dynamometer is shown in Fig. 5.

Tests documented in this report were conducted with the dynamometer programmed to meet the test matrix requirements.

APPENDIX D

DESCRIPTION OF TEST CYCLES

Testing of the vehicle was based on the test matrix shown in table D-1.

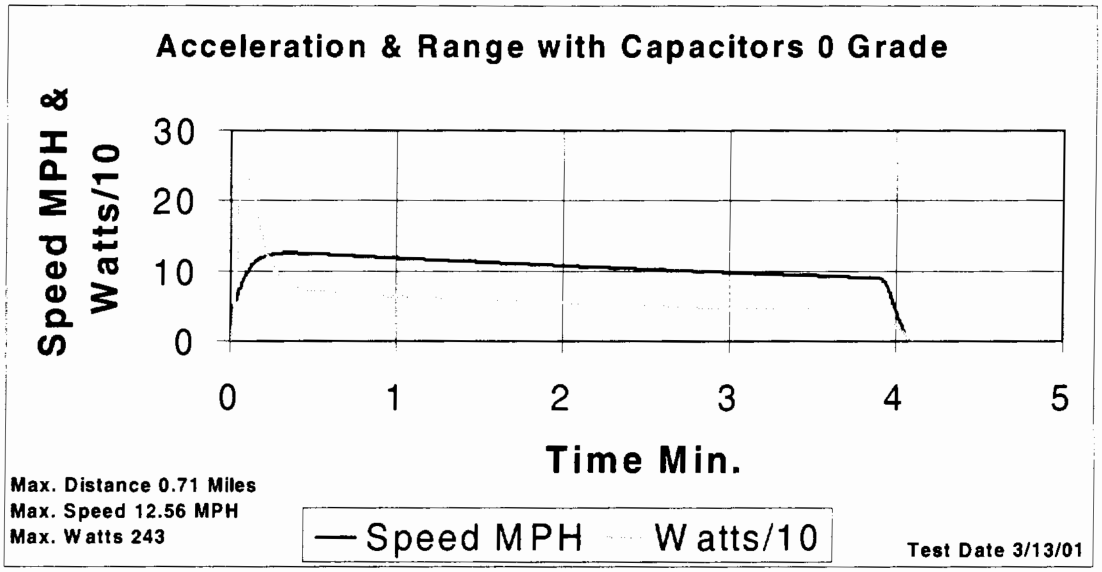
Table D-1 EV Global E-Bike Test Matrix

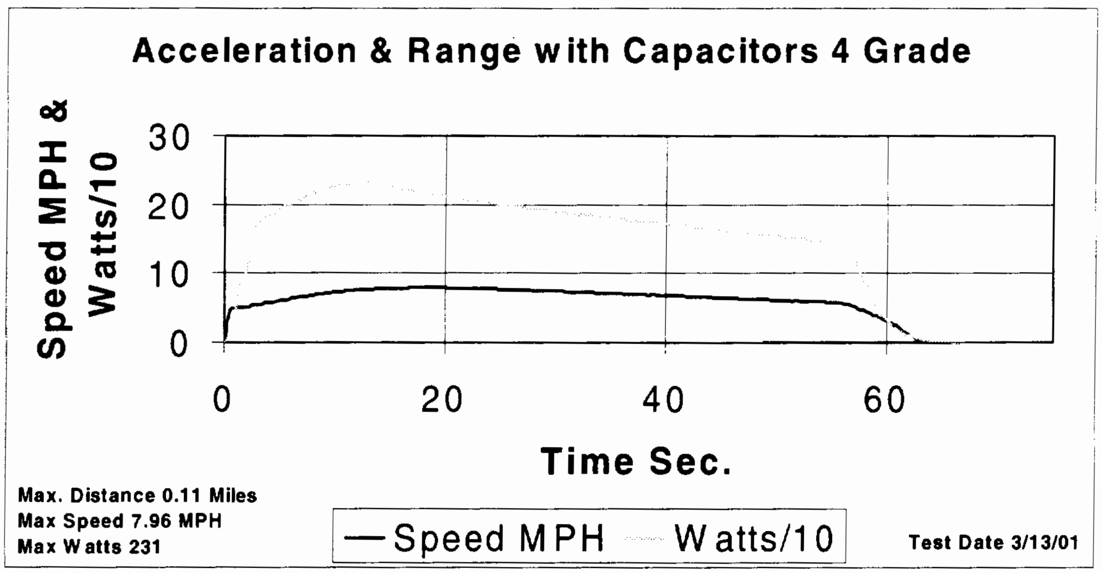
PARAMETER	CONDITIONS
Acceleration	To maximum speed at 0%, 4%, and 8% grades in the normal mode with battery energy storage, ultracapacitor energy storage, and combination battery and ultracapacitor energy storage.
Range	To maximum speed at 0% grade in the normal mode of operation with ultracapacitor energy storage. To 5 mph in the economy mode of operation with ultracapacitor energy storage.
Top Speed	To maximum speed at 0% grade in the normal mode of operation with battery energy storage, ultracapacitor energy storage, and combination battery and ultracapacitor energy storage.

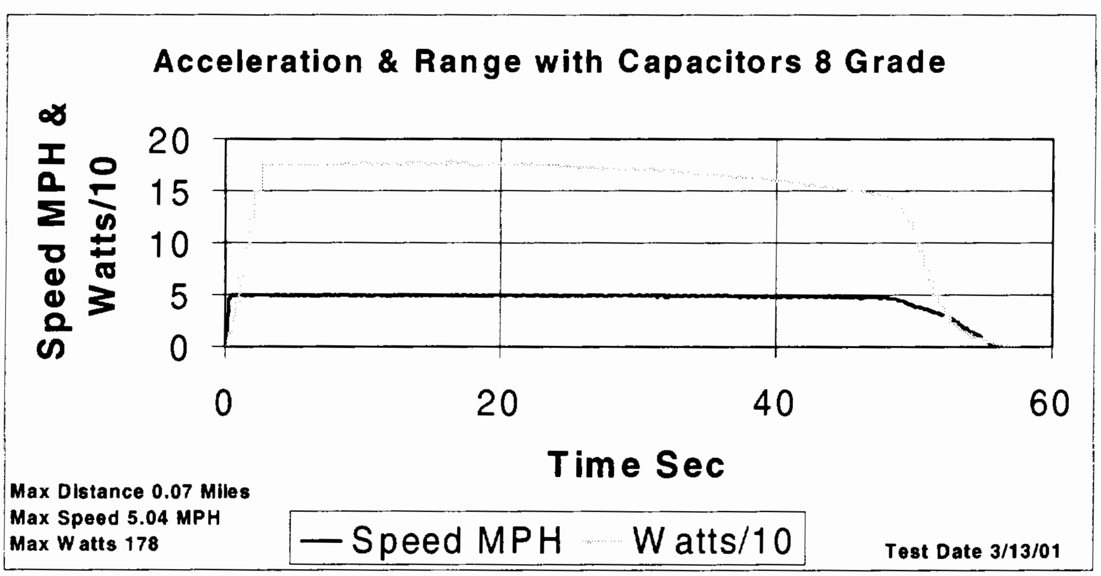
APPENDIX E

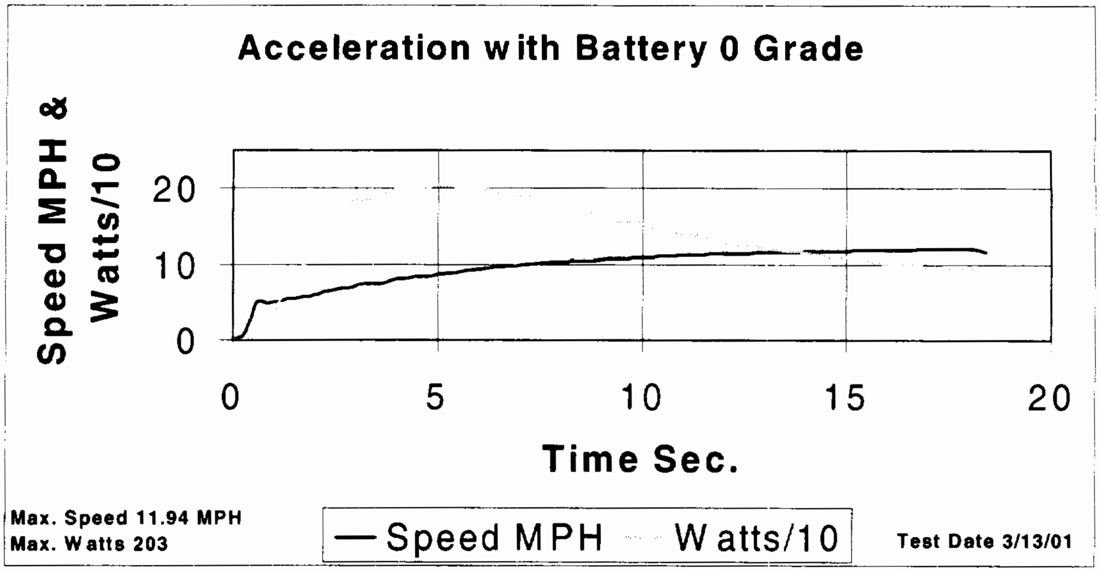
VEHICLE PERFORMANCE TEST RESULTS

A complete set of plots of the test results are included here. Table 1 identifies the tests that were conducted.

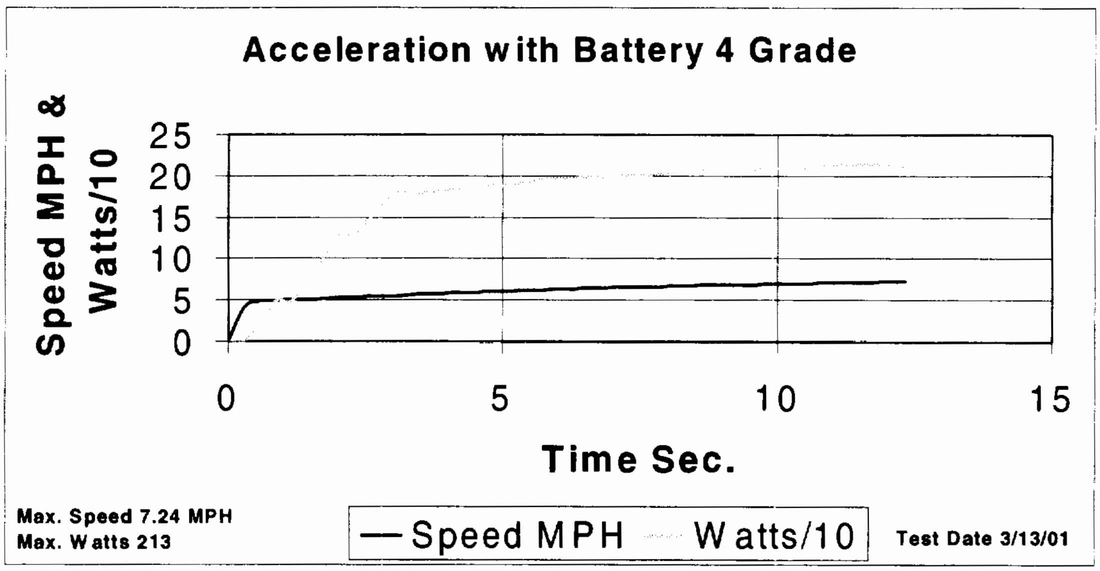

Acceleration & Range with Capacitors 0 Grade
Speed MPH & Watts/10
30
20
10
0
0
1
2
3
4
5
Time Min.
Max. Distance 0.71 Miles
Max. Speed 12.56 MPH
Max. Watts 243
Speed MPH
Watts/10
Test Date 3/13/01


Acceleration & Range with Capacitors 4 Grade
Speed MPH & Watts/10
30
20
10
0
0
20
40
60
Time Sec.
Max. Distance 0.11 Miles
Max Speed 7.96 MPH
Max Watts 231
Speed MPH
Watts/10
Test Date 3/13/01

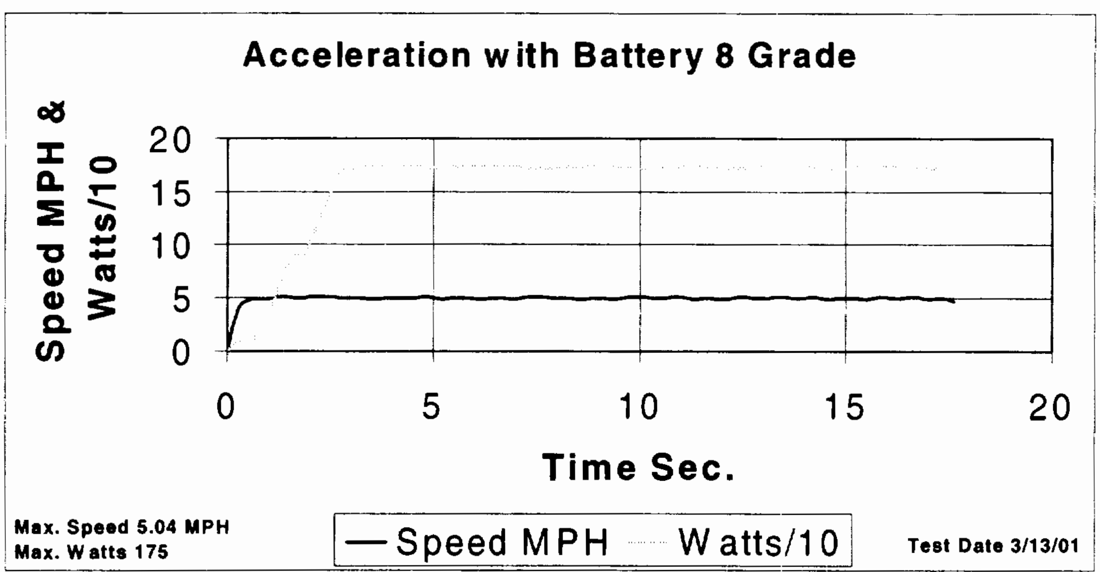

Acceleration & Range with Capacitors 8 Grade
Speed MPH & Watts/10
20
15
10
5
0
0
20
40
60
Time Sec
Max Distance 0.07 Miles
Max Speed 5.04 MPH
Max Watts 178
Speed MPH
Watts/10
Test Date 3/13/01



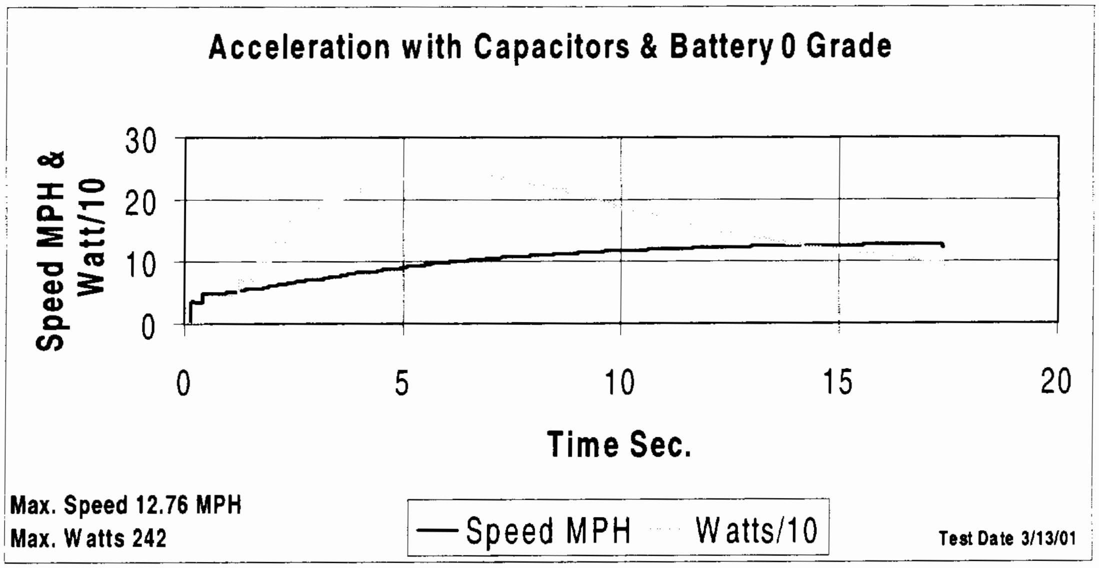
Acceleration with Battery 0 Grade
Speed MPH & Watts/10
0
10
20
0
5
10
15
20
Time Sec.
Max. Speed 11.94 MPH
Max. Watts 203
Speed MPH
Watts/10
Test Date 3/13/01



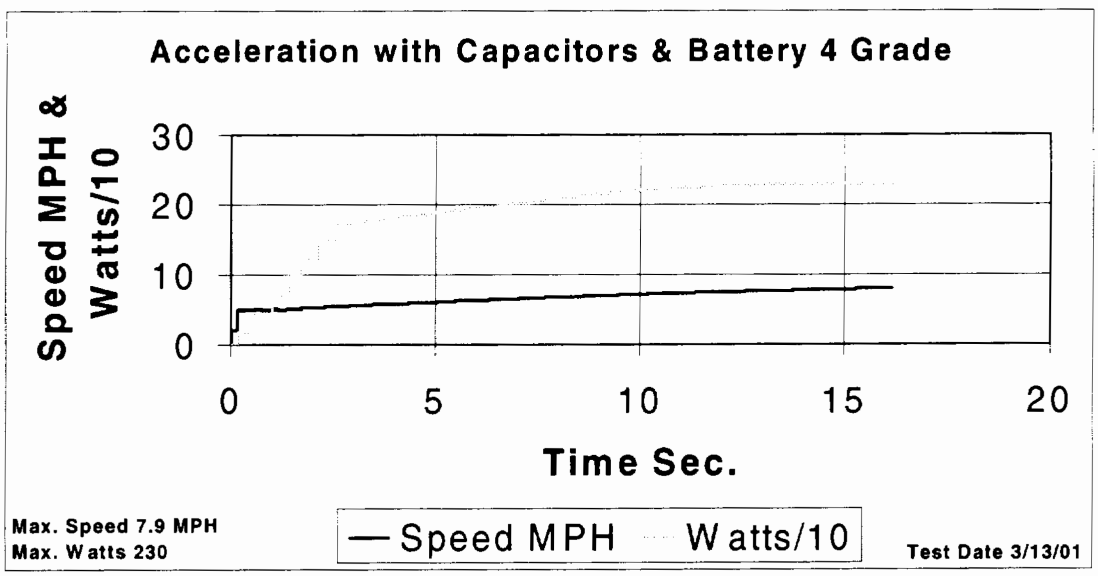
Acceleration with Battery 4 Grade
Speed MPH & Watts/10
0
5
10
15
20
25
0
5
10
15
Time Sec.
Max. Speed 7.24 MPH
Max. Watts 213
Speed MPH
Watts/10
Test Date 3/13/01



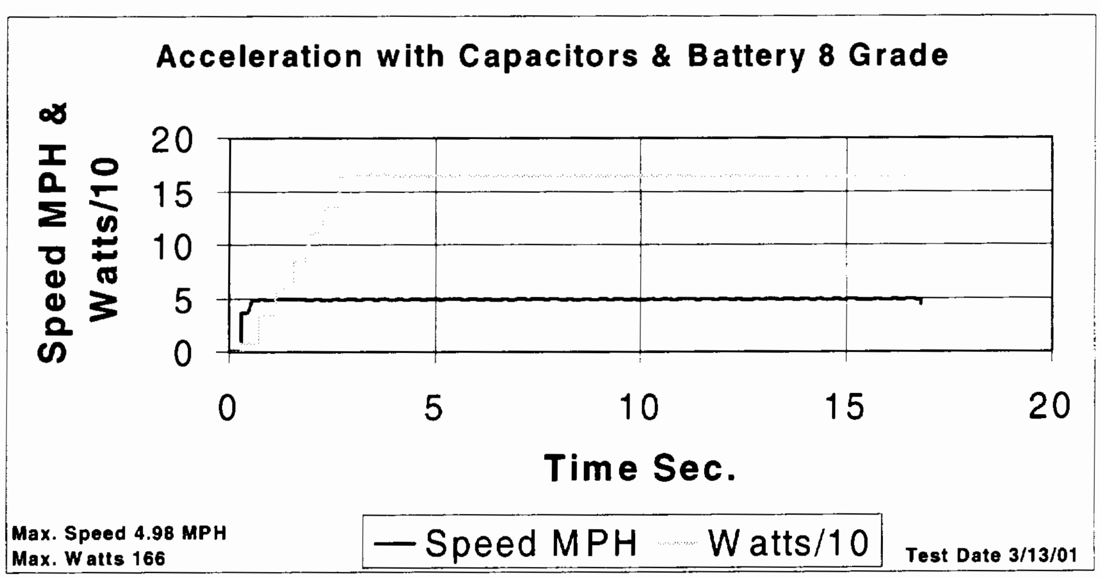
Acceleration with Battery 8 Grade
Speed MPH & Watts/10
0
5
10
15
20
0
5
10
15
20
Time Sec.
Max. Speed 5.04 MPH
Max. Watts 175
Speed MPH
Watts/10
Test Date 3/13/01



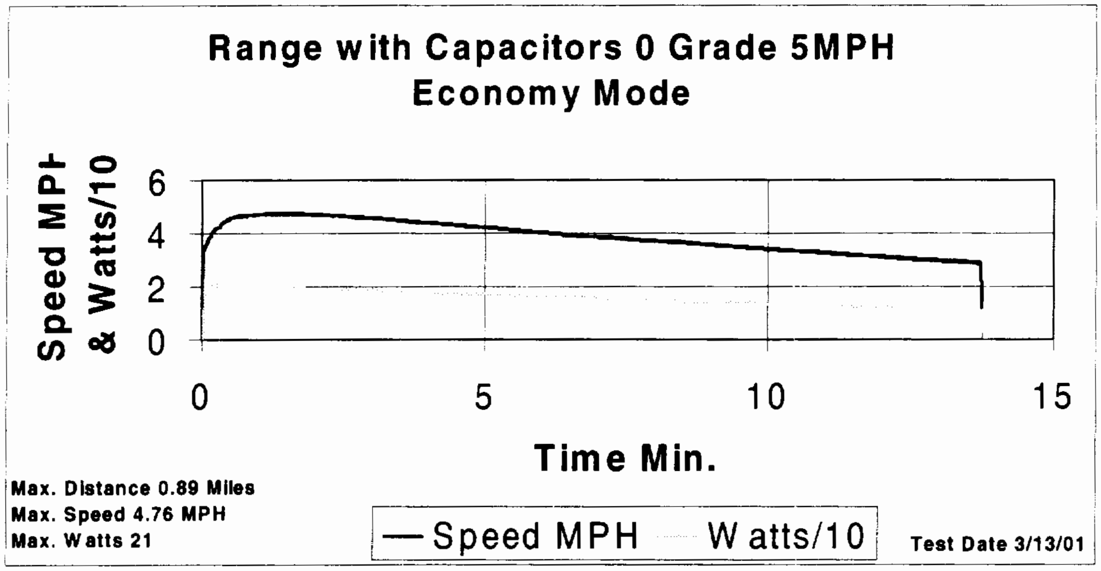
Acceleration with Capacitors & Battery 0 Grade
Speed MPH & Watt/10
30
20
10
0
0
5
10
15
20
Time Sec.
Max. Speed 12.76 MPH
Max. Watts 242
Speed MPH
Watts/10
Test Date 3/13/01



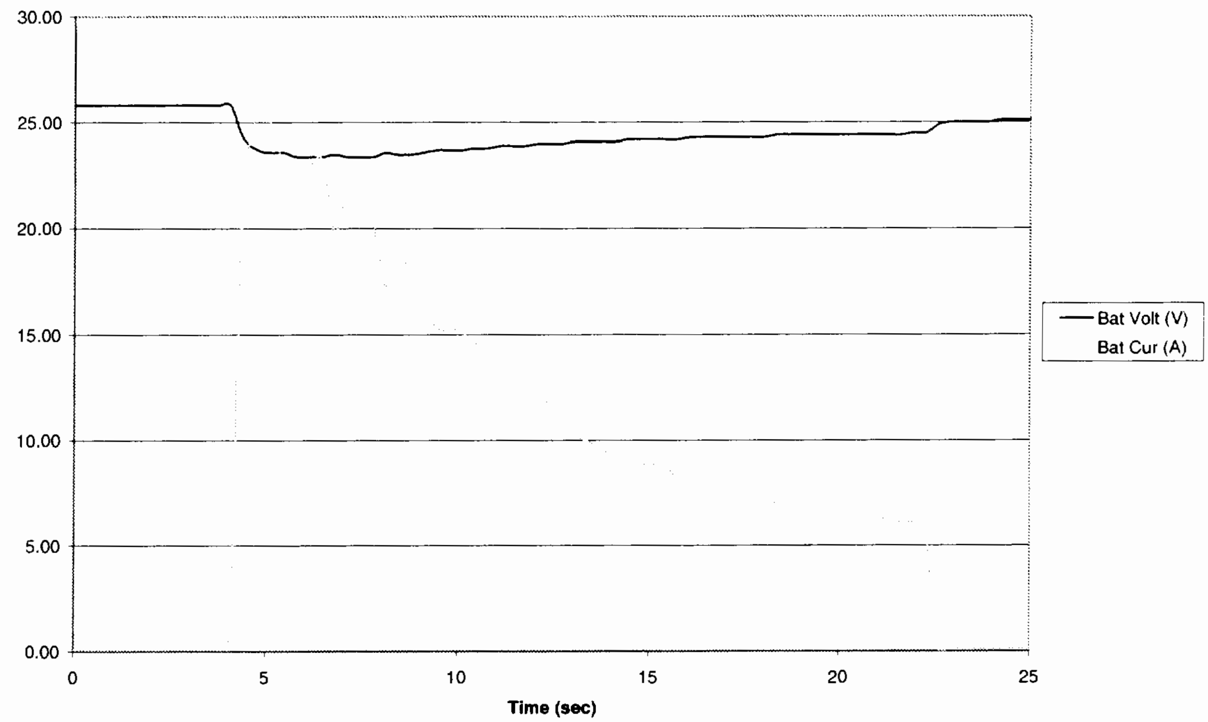
Acceleration with Capacitors & Battery 4 Grade
Speed MPH & Watts/10
30
20
10
0
0
5
10
15
20
Time Sec.
Max. Speed 7.9 MPH
Max. Watts 230
Speed MPH
Watts/10
Test Date 3/13/01



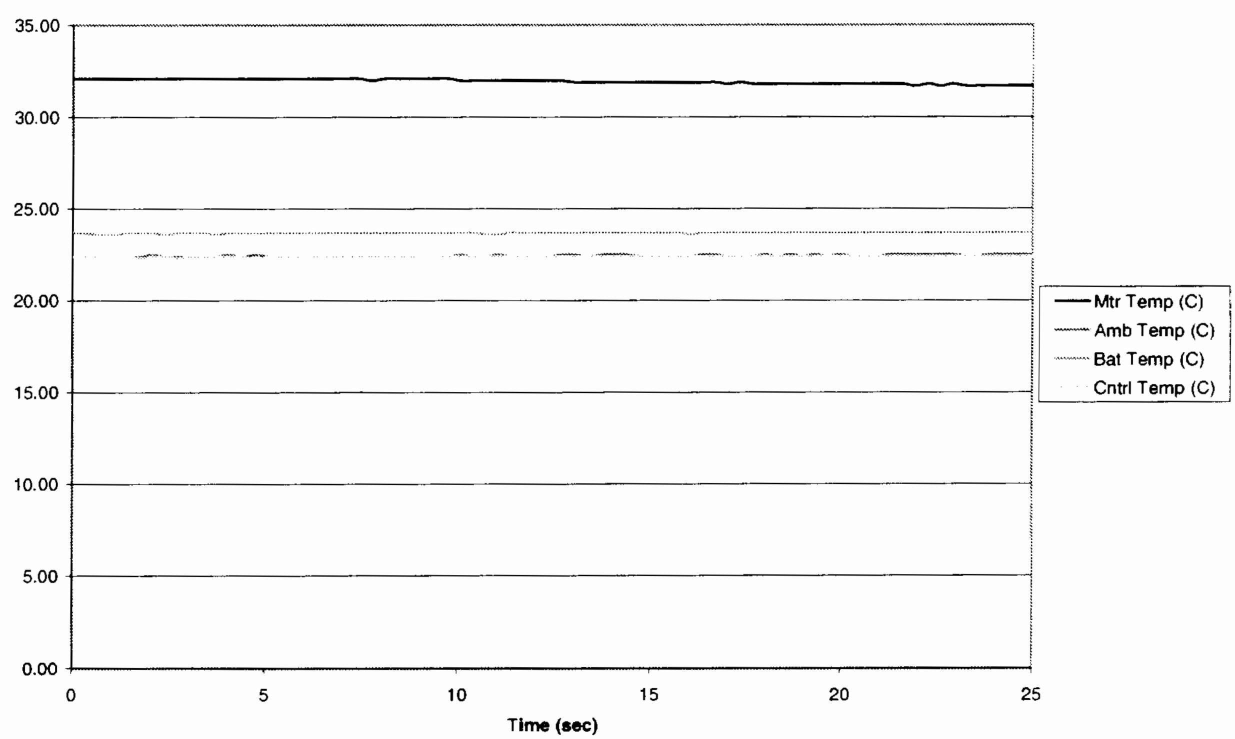
Acceleration with Capacitors & Battery 8 Grade
Speed MPH & Watts/10
20
15
10
5
0
0
5
10
15
20
Time Sec.
Max. Speed 4.98 MPH
Max. Watts 166
Speed MPH
Watts/10
Test Date 3/13/01


Range with Capacitors 0 Grade 5MPH
Economy Mode
Speed MPH & Watts/10
6
4
2
0
0
5
10
15
Time Min.
Max. Distance 0.89 Miles
Max. Speed 4.76 MPH
Max. Watts 21
Speed MPH
Watts/10
Test Date 3/13/01

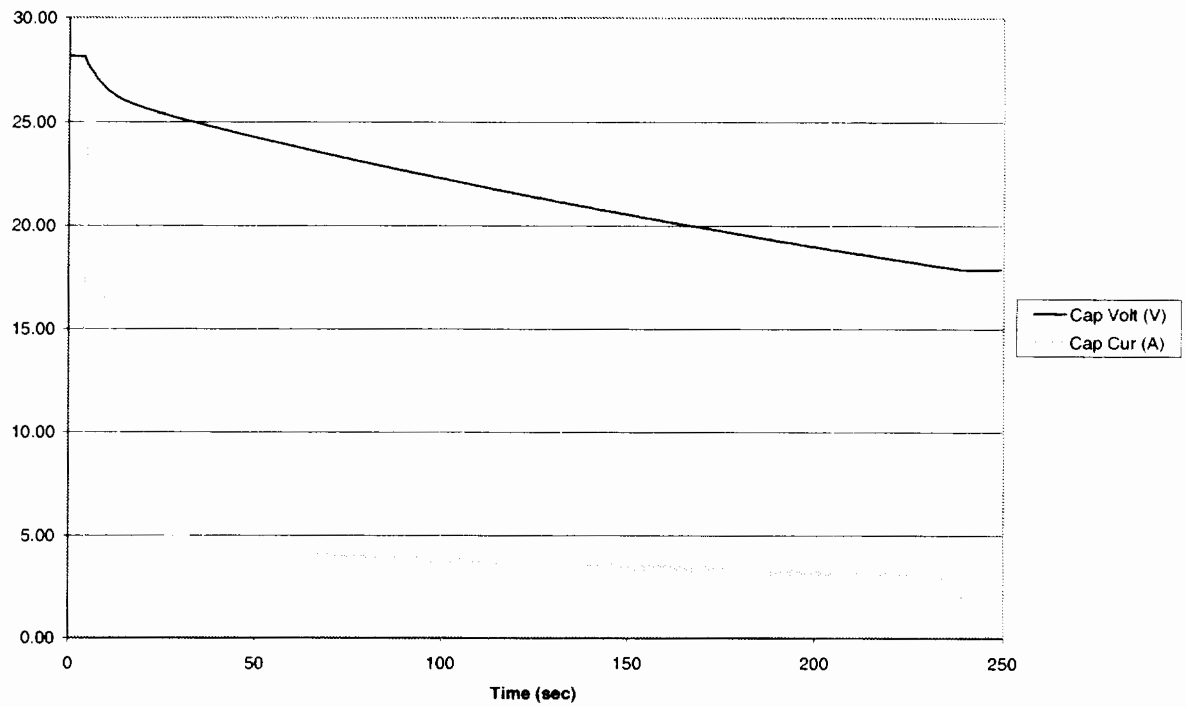
Acceleration Test, Battery, 0% Grade, Maximum Initial Speed, Normal Mode



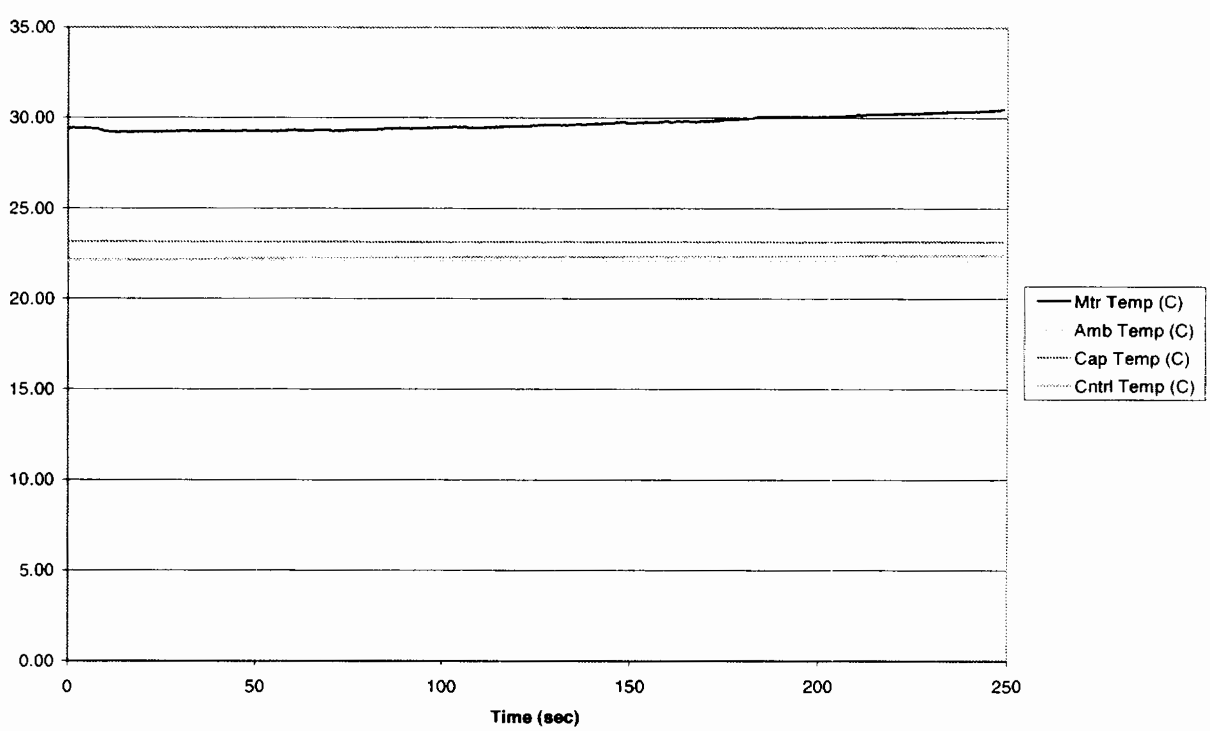
Acceleration Test, Battery, 0% Grade, Maximum Initial Speed, Normal Mode



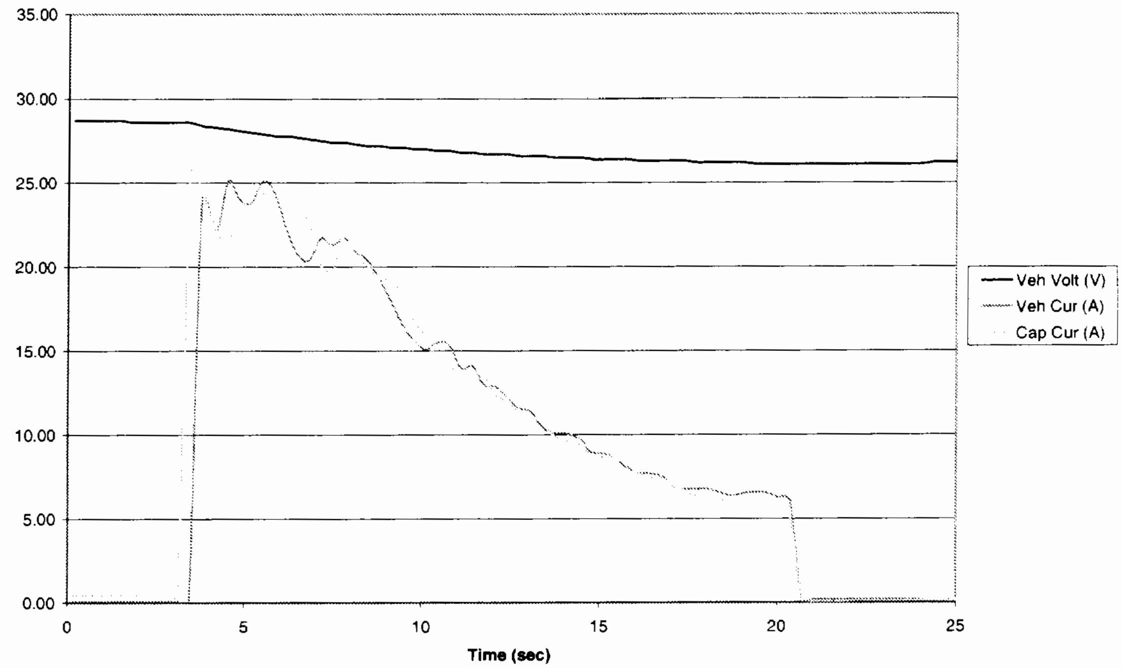
Acceleration & Range Test, Capacitor, 0% Grade, Maximum Initial Speed, Normal Mode



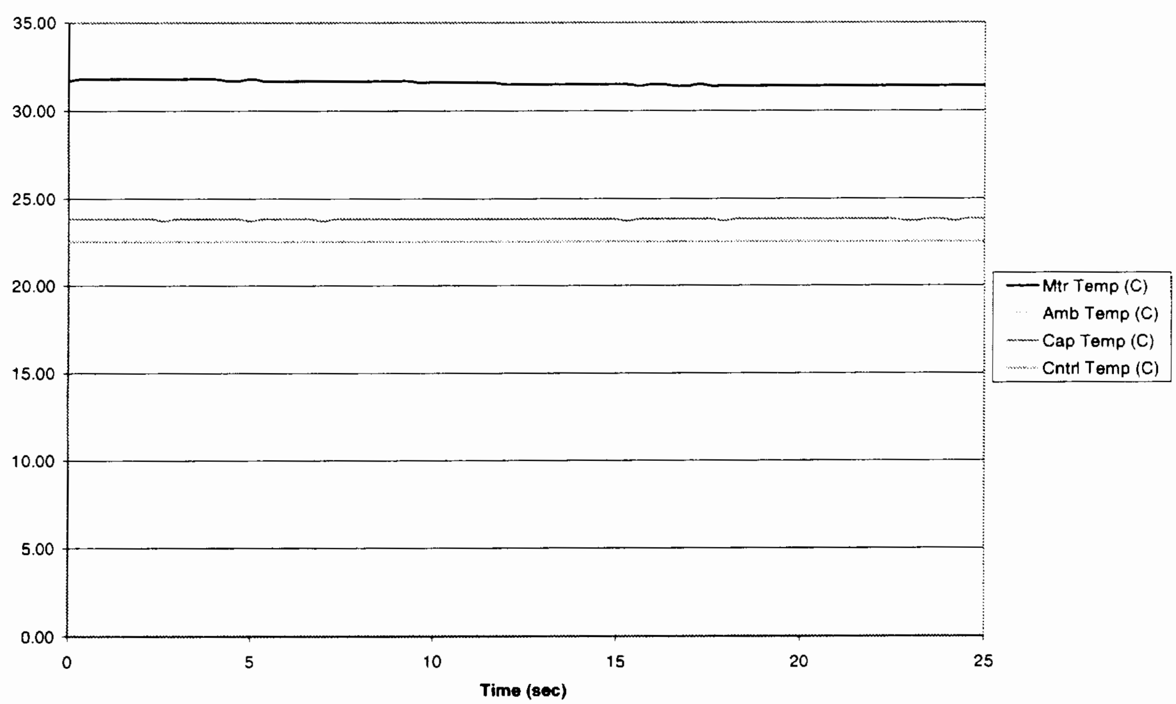
Acceleration & Range Test, Capacitor, 0% Grade, Maximum Initial Speed, Normal Mode



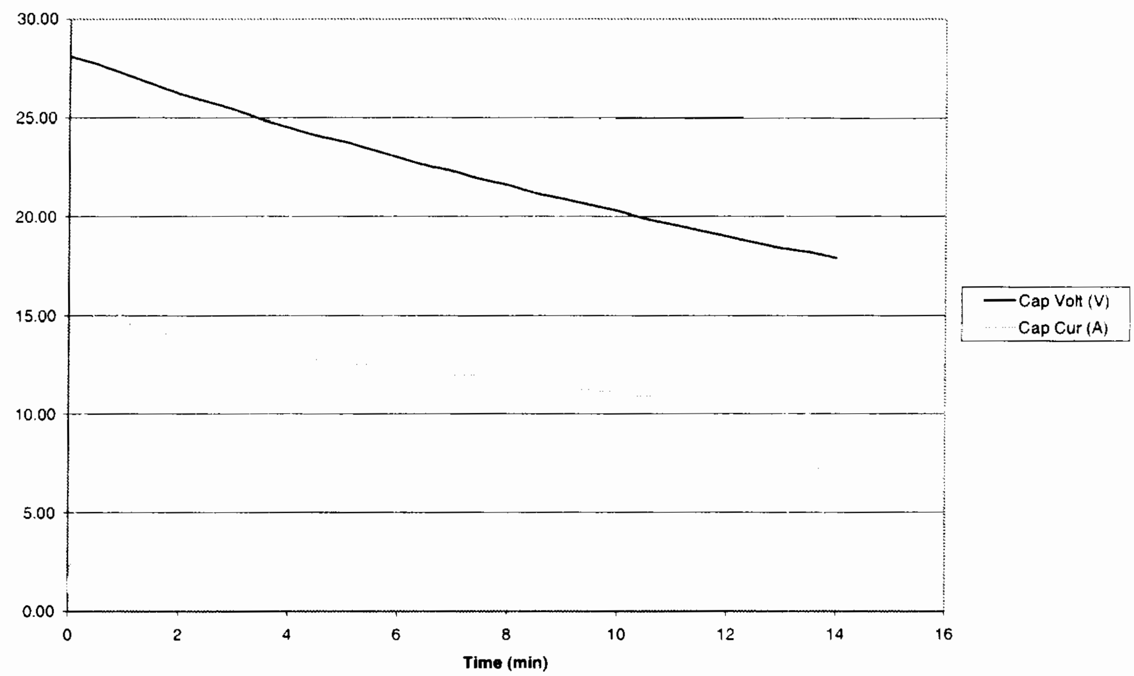
Acceleration Test, Battery & Capacitor, 0% Grade, Maximum Initial Speed



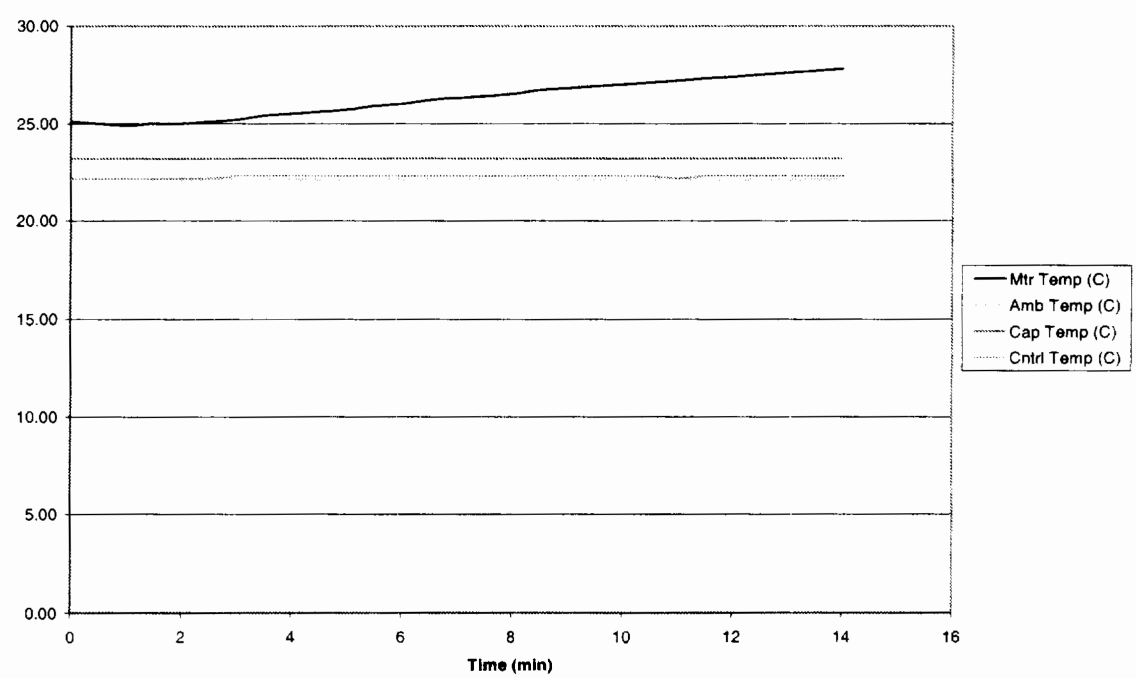
Acceleration Test, Battery and Capacitor, 0% Grade, Maximum Initial Speed



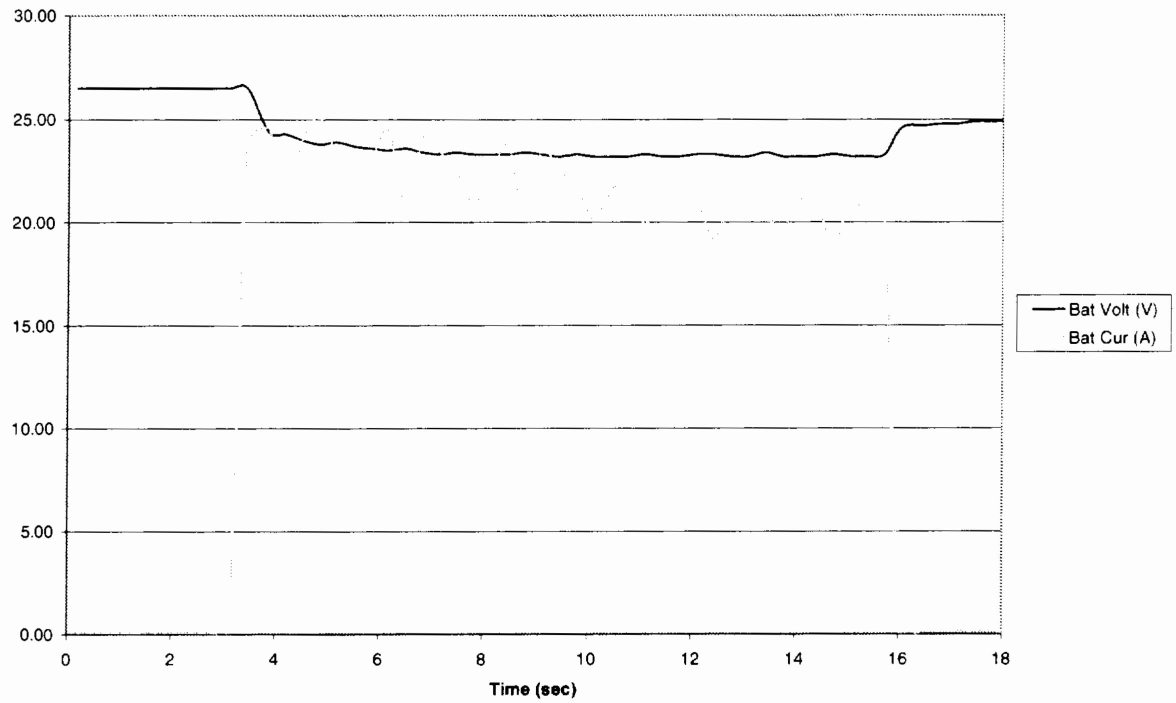
Range Test, Capacitor, 0% Grade, 5 mph Initial Speed, Economy Mode



Range Test, Capacitor, 0% Grade, 5 mph Initial Speed, Economy Mode



Acceleration Test, Battery, 4% Grade, Maximum Initial Speed, Normal Mode



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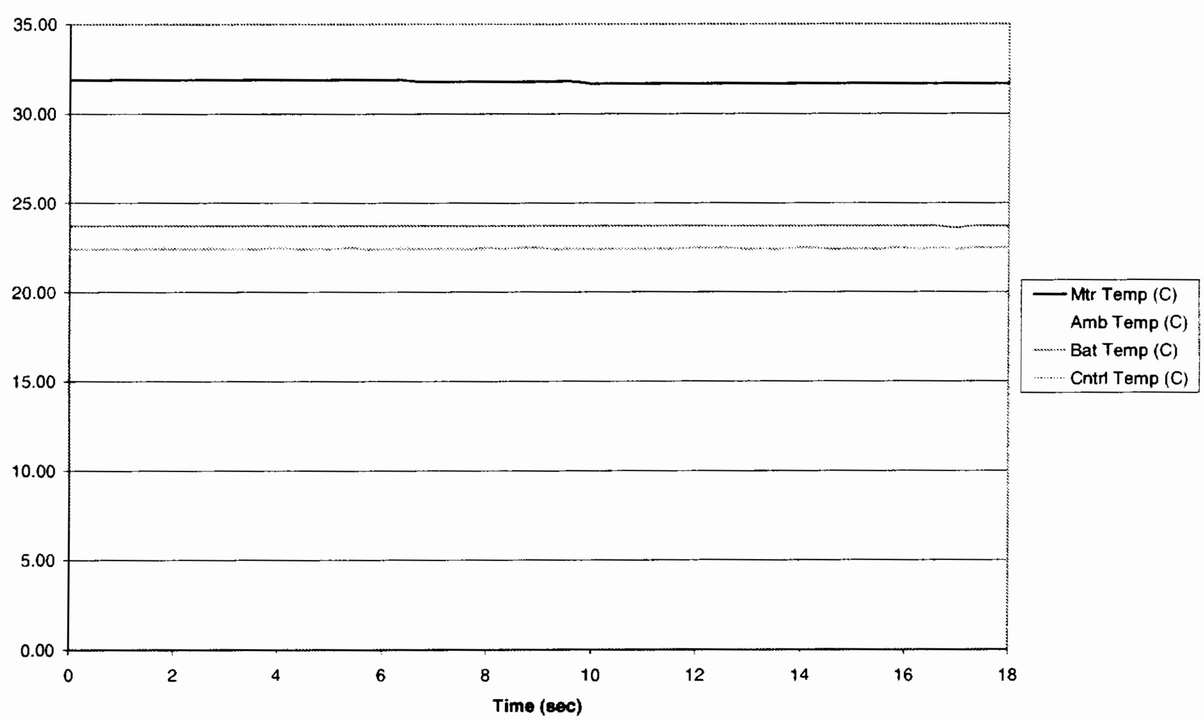
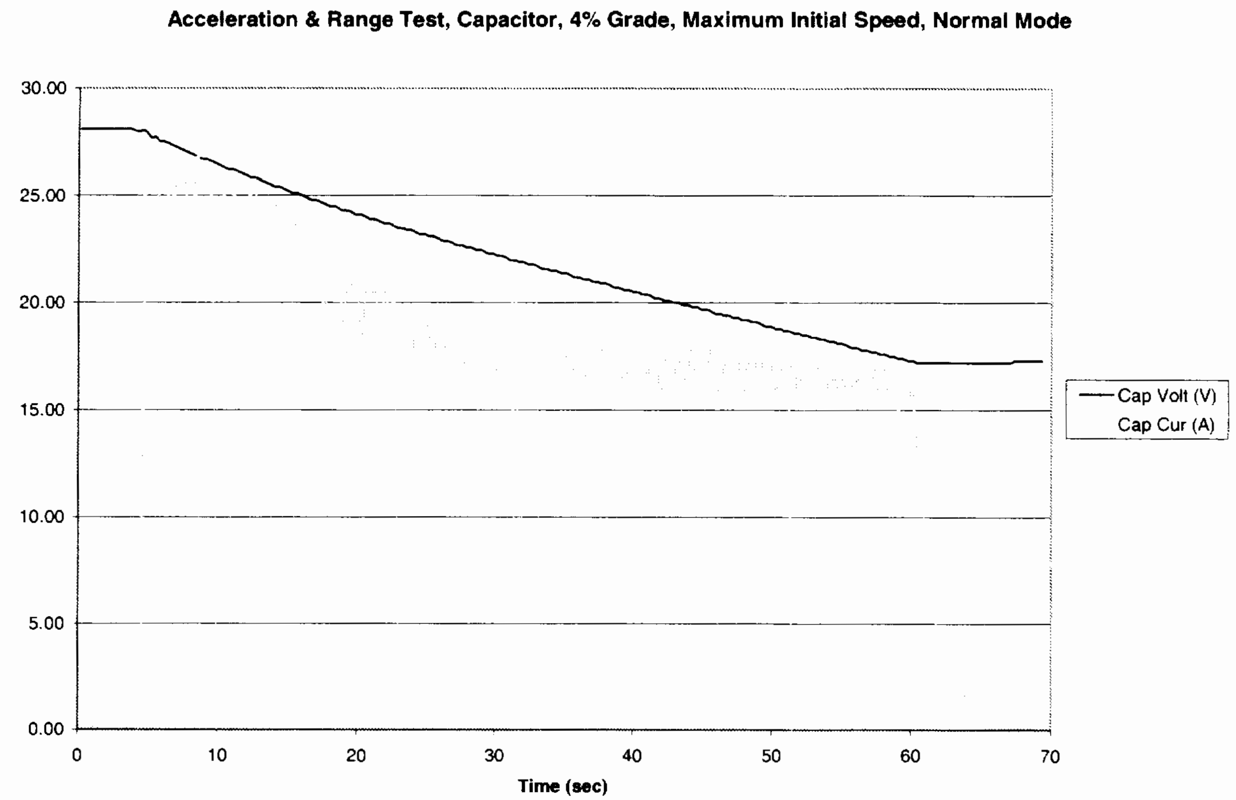
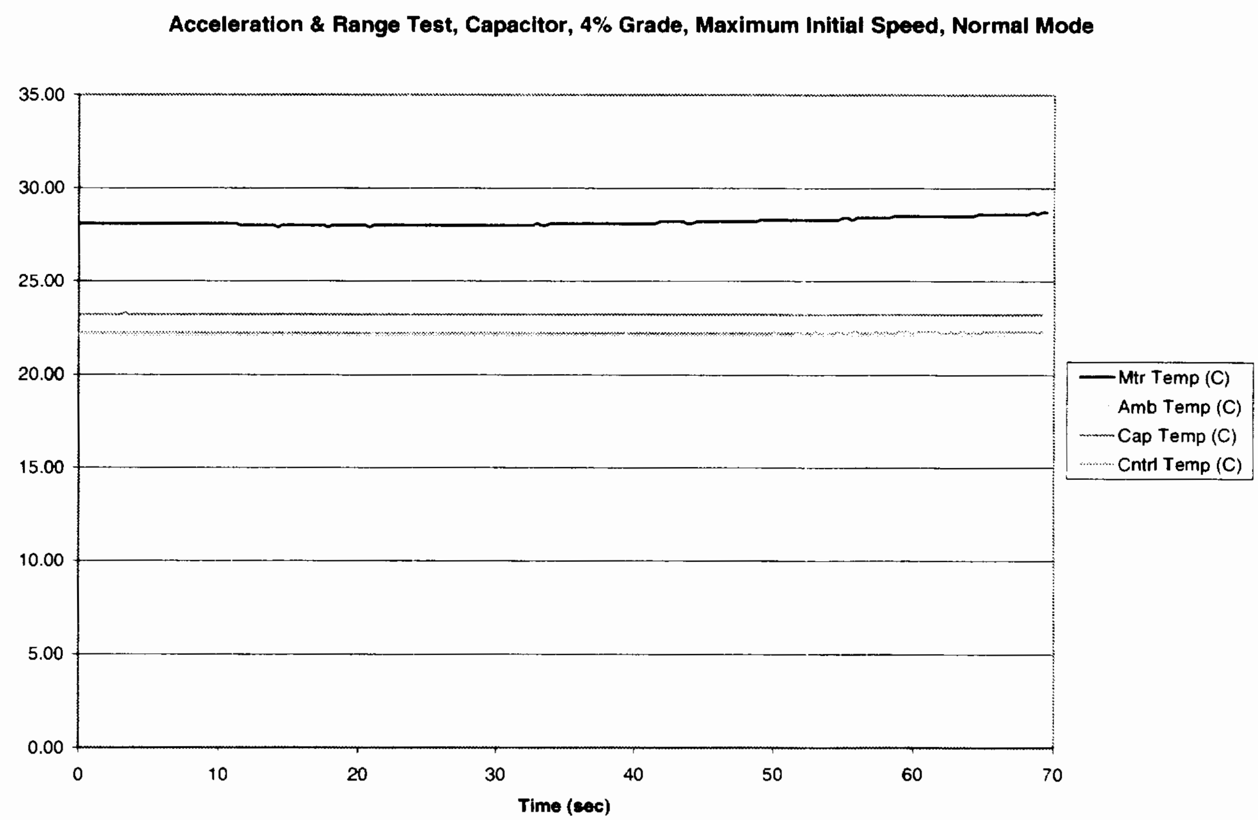



Acceleration & Range Test, Capacitor, 4% Grade, Maximum Initial Speed, Normal Mode
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
Time (sec)
Cap Volt (V)
Cap Cur (A)


Acceleration & Range Test, Capacitor, 4% Grade, Maximum Initial Speed, Normal Mode
35.00
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Time (sec)
Mtr Temp (C)
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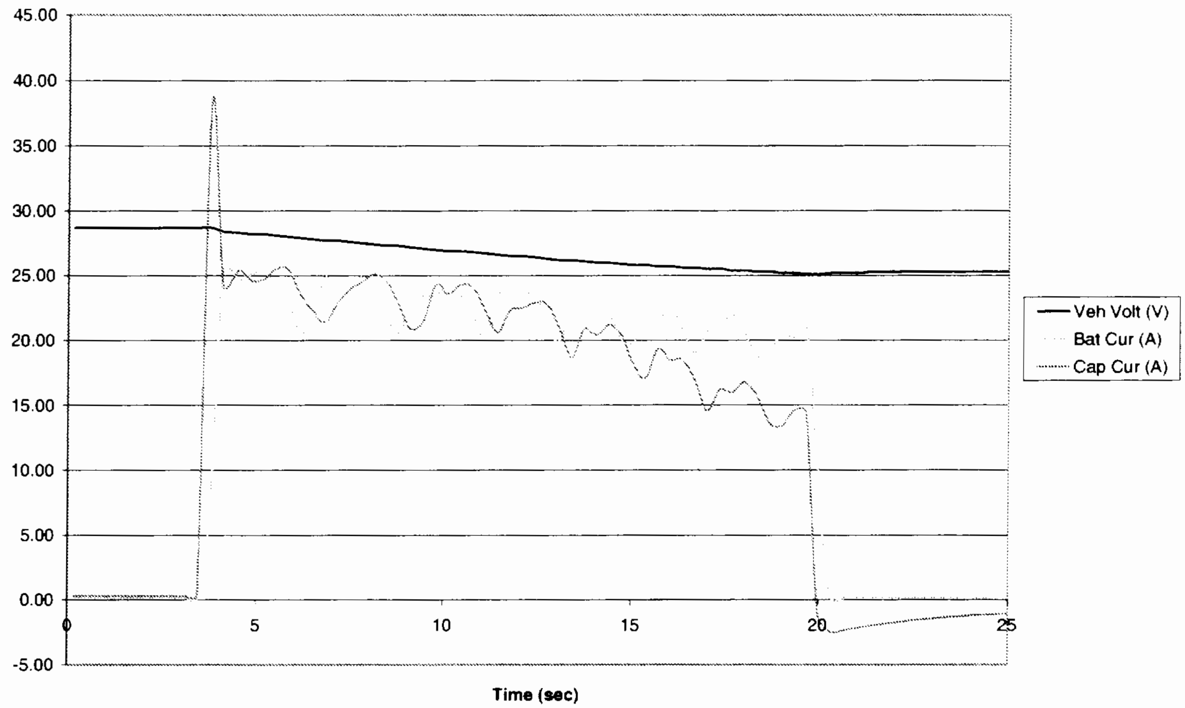
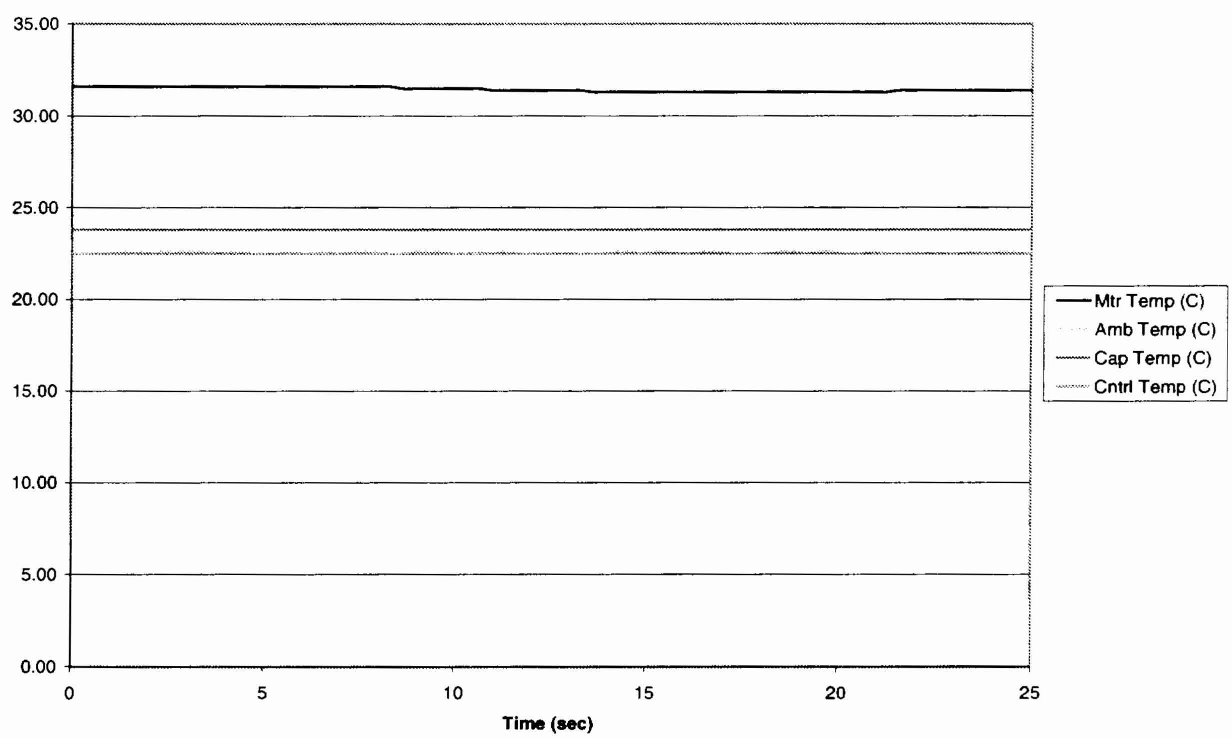
Cap Temp (C)
Cntrl Temp (C)

Acceleration Test, Battery & Capacitor, 4% Grade, Maximum Initial Speed, Normal Mode



Acceleration Test, Battery & Capacitor, 4% Grade, Maximum Initial Speed, Normal Mode



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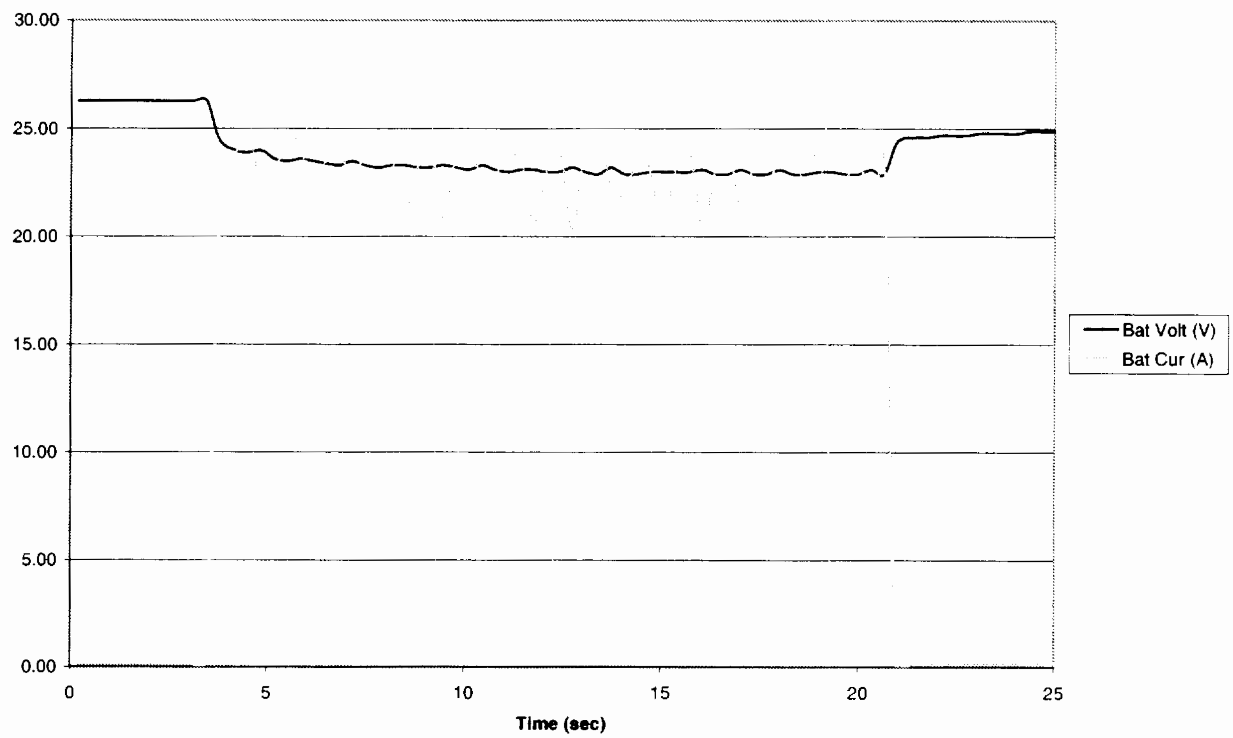

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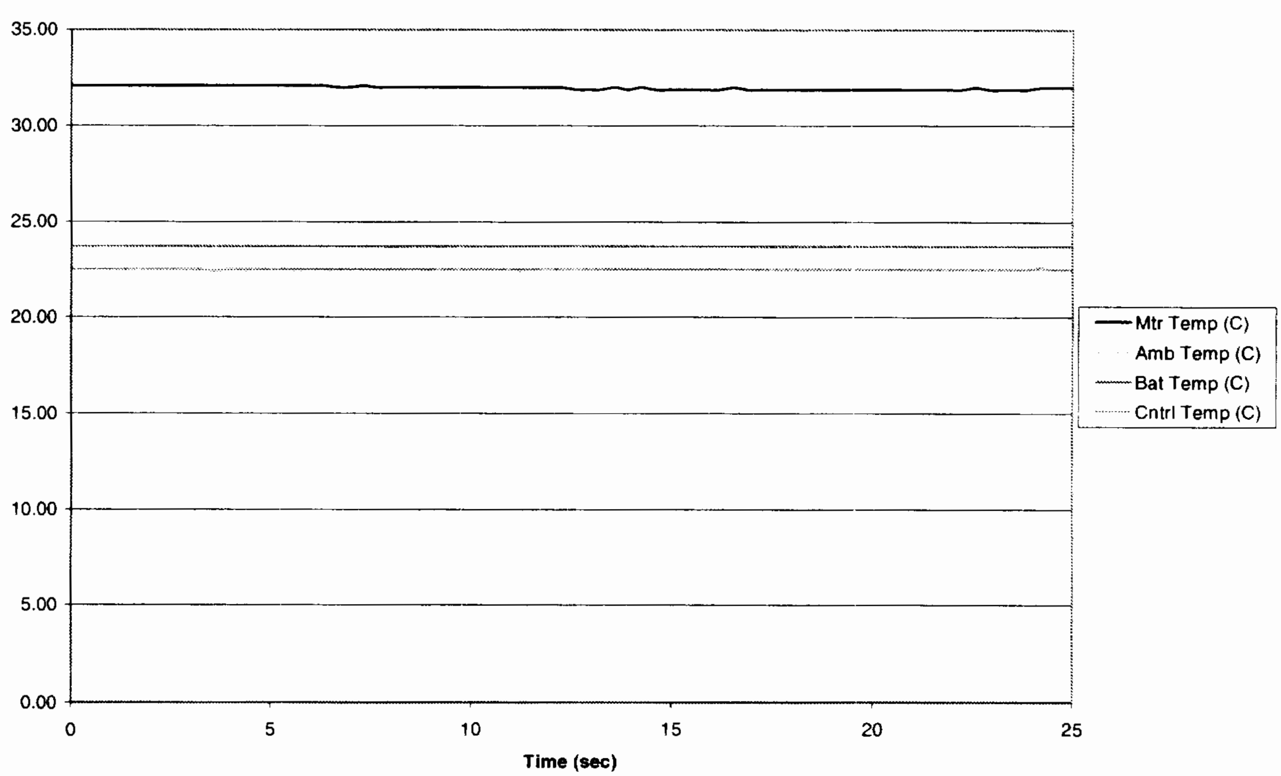
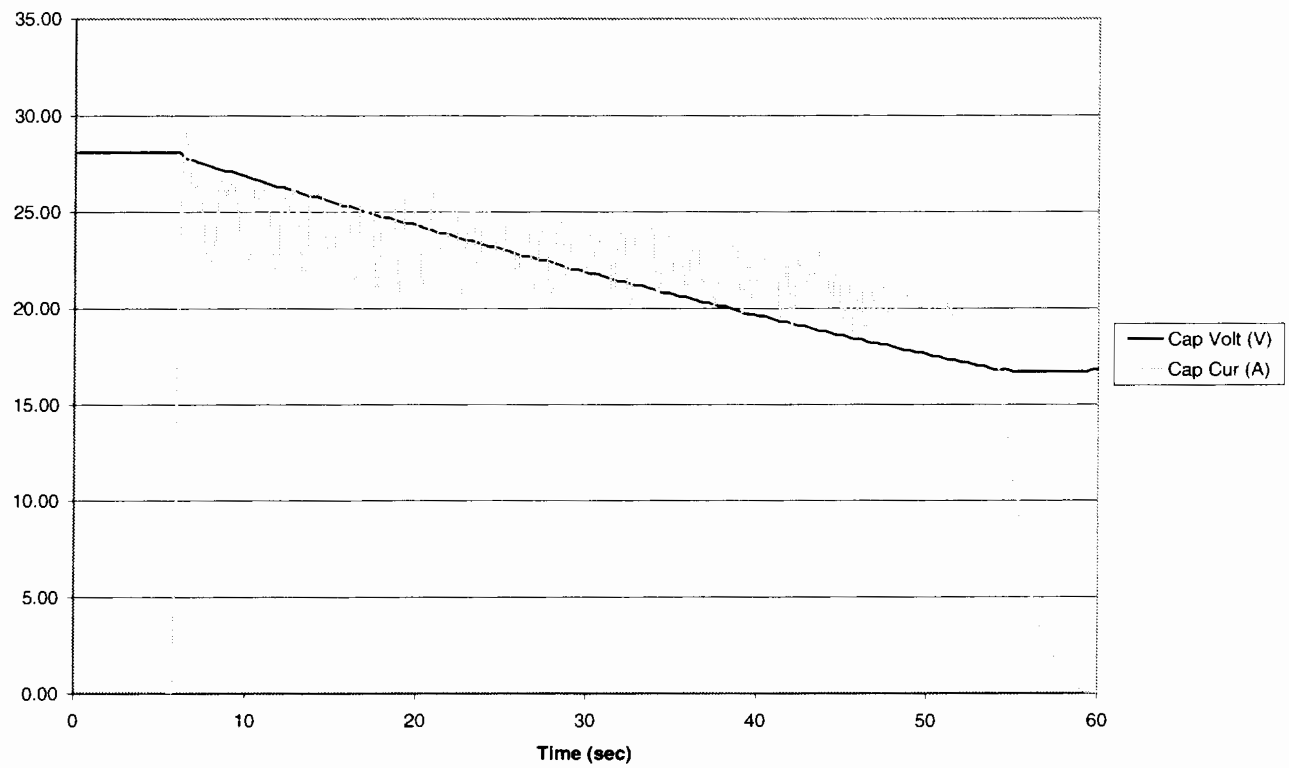
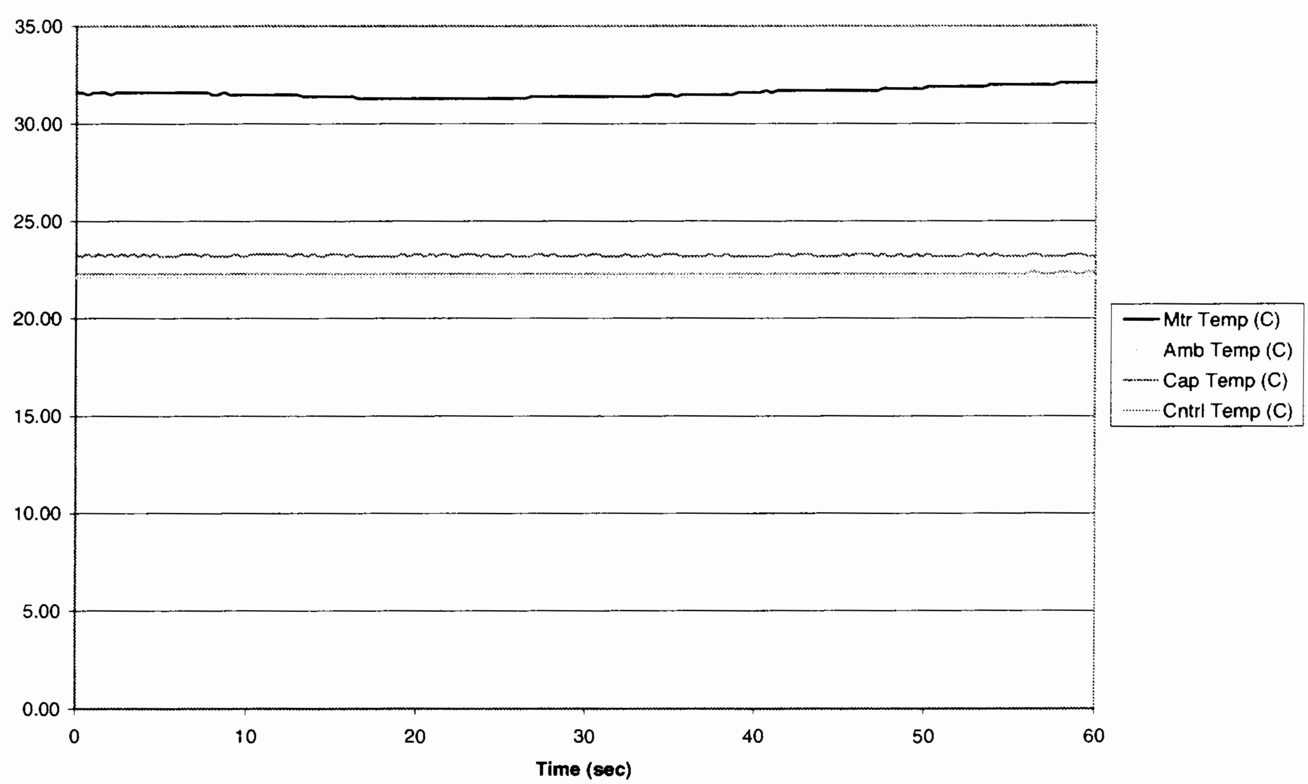
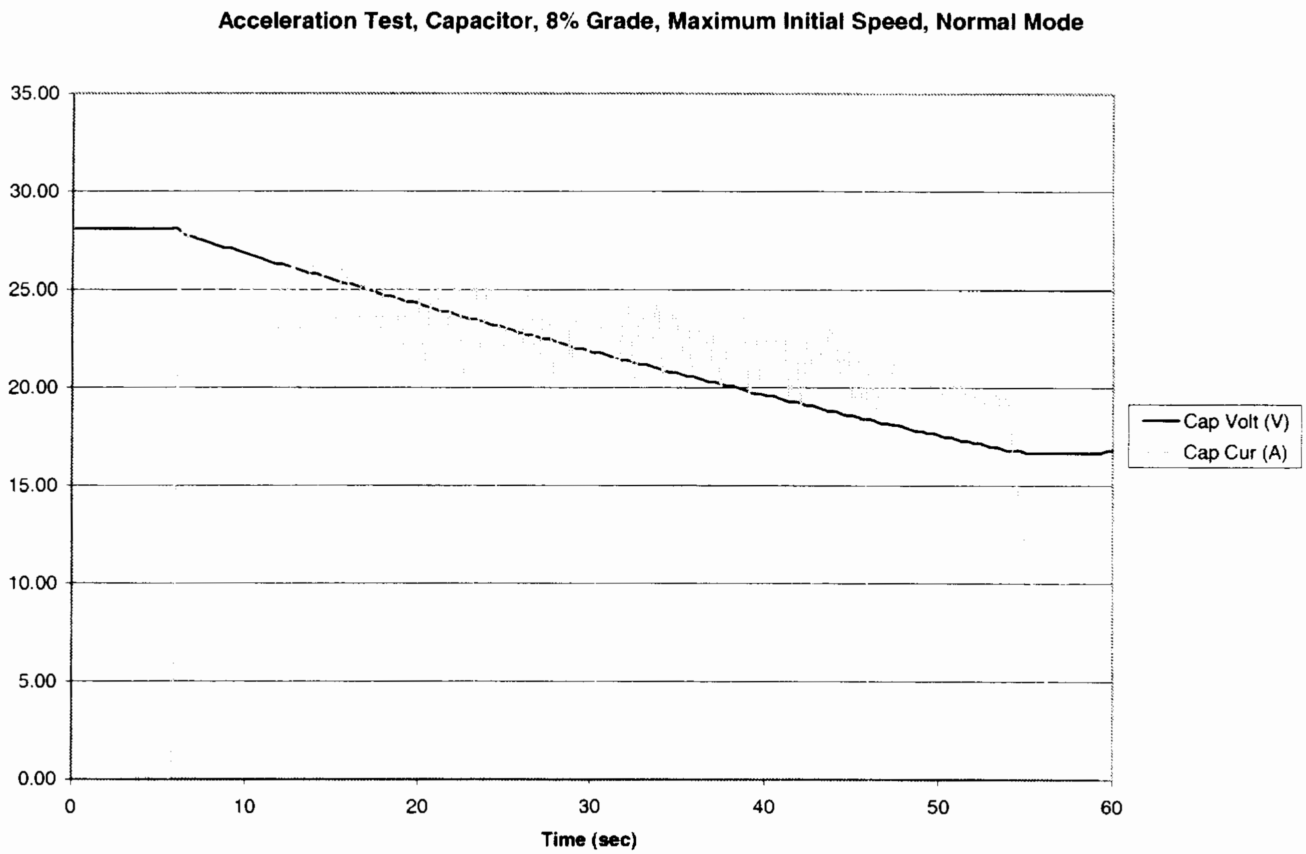


Acceleration Test, Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode



Acceleration Test, Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode




Acceleration Test, Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode
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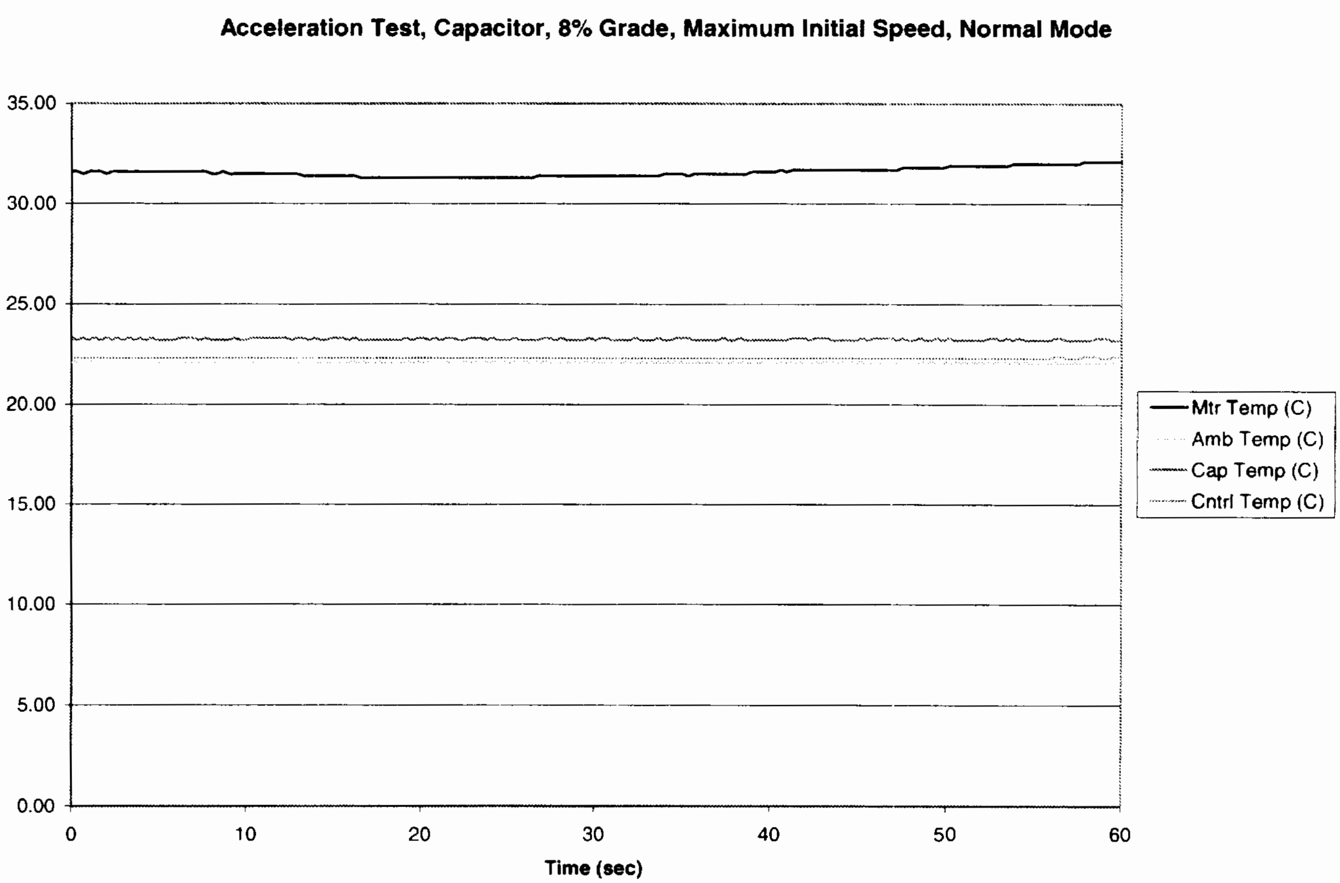
Cap Volt (V)
Cap Cur (A)


Acceleration Test, Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode
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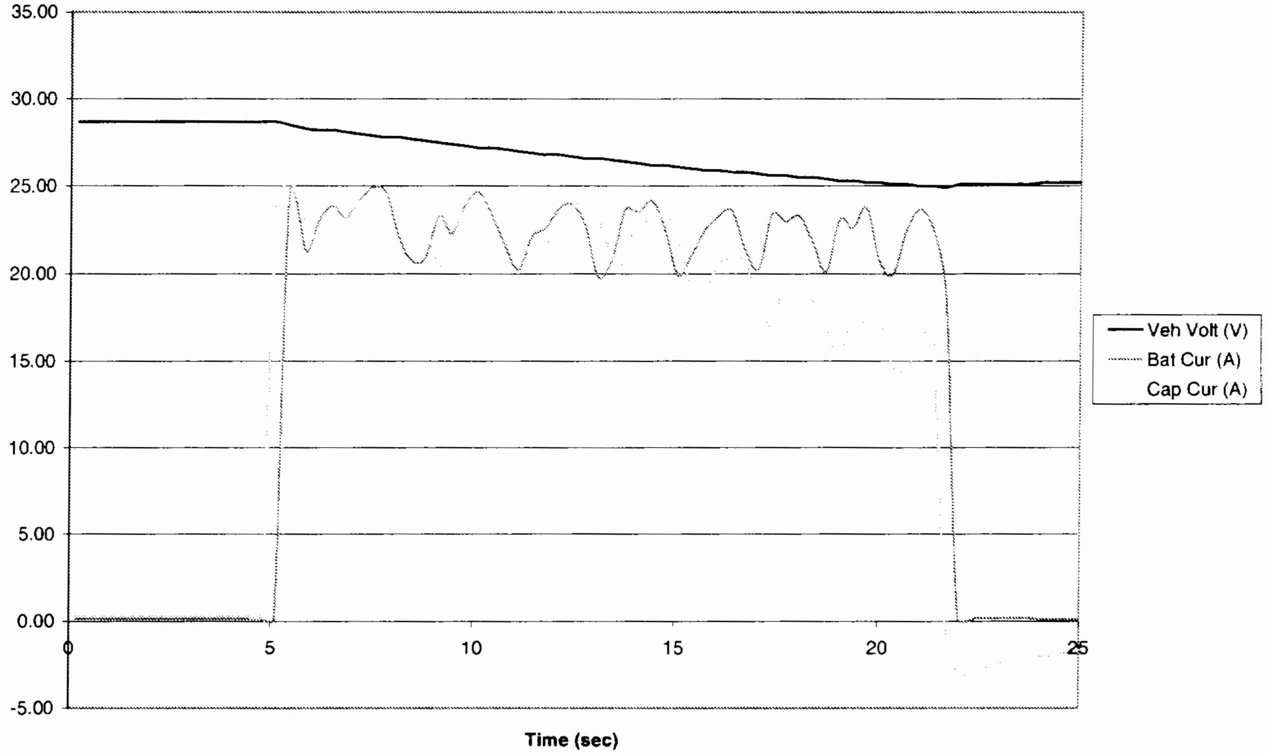
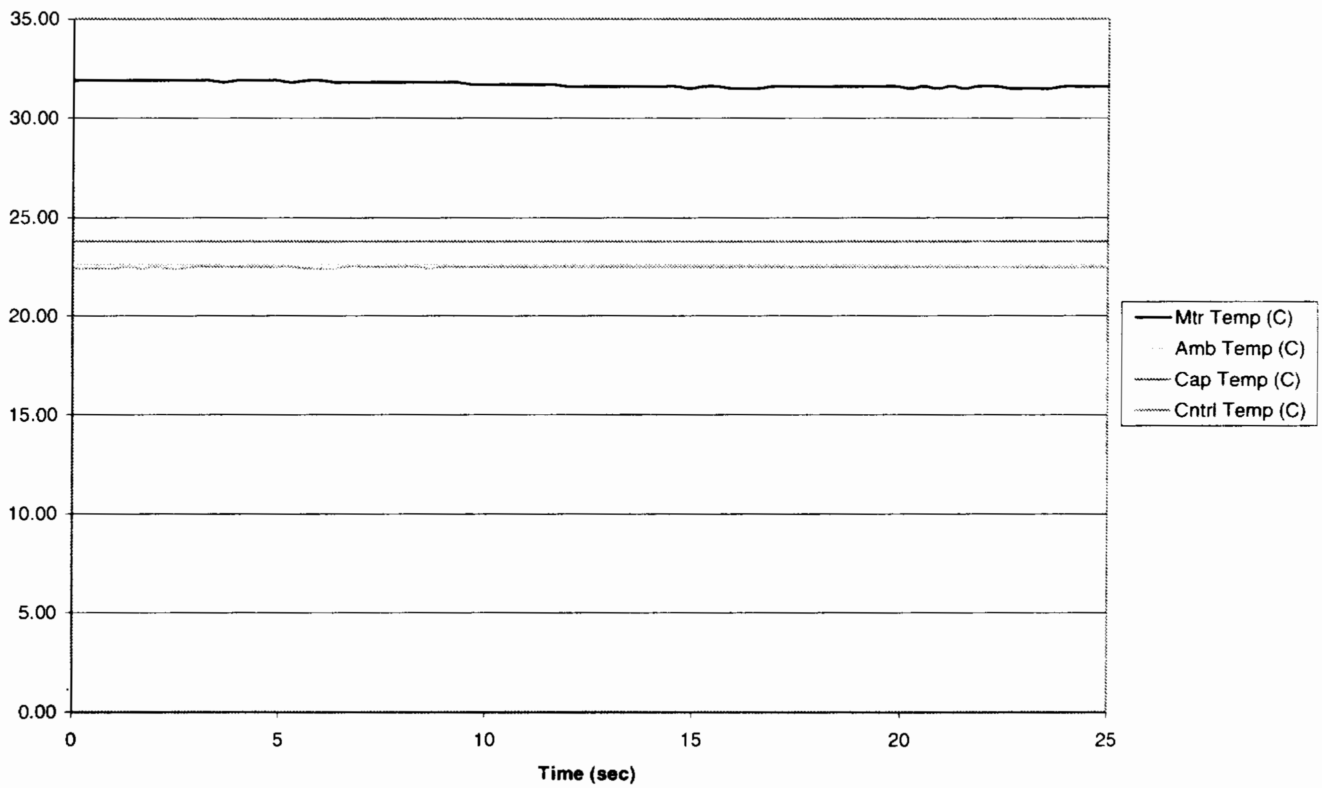
Time (sec)
Mtr Temp (C)
Amb Temp (C)
Cap Temp (C)
Cntrl Temp (C)

Acceleration Test, Battery & Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode



Acceleration Test, Battery & Capacitor, 8% Grade, Maximum Initial Speed, Normal Mode



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13. ABSTRACT ***(Maximum 200 words)***

The NASA John H. Glenn Research Center initiated baseline testing of the EV Global E-Bike with ultracapacitors as a way to reduce pollution in urban areas, reduce fossil fuel consumption, and reduce operating costs for transportation systems. The E-Bike provides an inexpensive approach to advance the state of the art in hybrid technology in a practical application. The project transfers space technology to terrestrial use via nontraditional partners, and provides power system data valuable for future space applications. The work was done under the Hybrid Power Management (HPM) Program, which includes the Hybrid Electric Transit Bus (HETB). The E-Bike is a state of the art, ground up, hybrid electric bicycle. Unique features of the vehicle's power system include the use of an efficient, 400 W, electric hub motor, and a 7-speed derailleur system that permits operation as fully electric, fully pedal, or a combination of the two. Other innovative features, such as regenerative braking through ultracapacitor energy storage, are planned. Regenerative braking recovers much of the kinetic energy of the vehicle during deceleration. The E-bike has been tested with the standard battery energy storage system, an ultracapacitor energy storage system, and a combination battery, and ultracapacitor energy storage system. A description of the E-bike, the results of performance testing and future vehicle development plans is the subject of this report. The report concludes that the E-Bike provides excellent performance, and that the implementation of ultracapacitors in the power system can provide significant performance improvements.

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