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Baseline Testing of the EV Global E-Bike SX

Dennis J. Eichenberg, John S. Kolacz, and Paul F. Tavernelli
Glenn Research Center, Cleveland, Ohio

June 2001

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SUMMARY

The NASA John H. Glenn Research Center initiated baseline testing of the EV Global E-Bike SX as an update of the state of the art in hybrid electric bicycles. The E-bike is seen as a way to reduce pollution in urban areas, reduce fossil fuel consumption and reduce operating costs for transportation systems. The work was done under the Hybrid Power Management (HPM) Program, which includes the Hybrid Electric Transit Bus (HETB). The SX is a high performance, state of the art, ground up, hybrid electric bicycle. Unique features of the SX's 36 volt 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 is 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. A description of the SX, the results of performance testing, and future vehicle development plans are given in this report. The report, concludes that the SX 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 SX 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 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, and acceleration time. 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 SX is a high performance, state of the art, ground up, hybrid electric bicycle. The vehicle is shown in Figs. 1 and described in detail in Appendix A. The E-Bike SX 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 energy storage system consists of a single block, 36-volt, 8-amp hour sealed lead acid, deep discharge battery to store electrical energy. The battery charger is built into the battery pack. The charger is rated at 36 volts, 2 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 electric traction motor shown in Fig. 4 is a 500-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 SX on Dynamometer

Fig. 2 – E-Bike Schematic Diagram

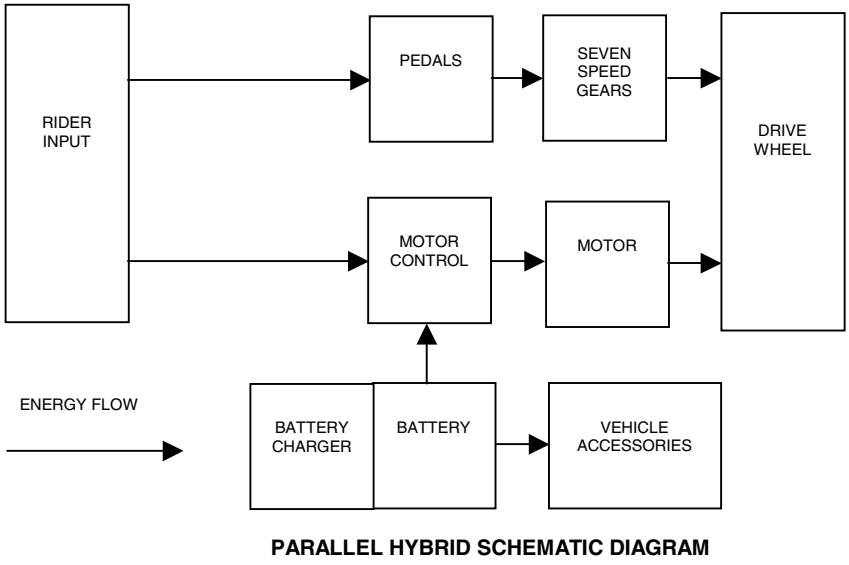


Fig. 3 – Battery Pack

Fig. 4 – Hub Motor

INSTRUMENTATION

The E-Bike SX 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, battery, 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.

Battery charging power requirements were determined from measuring the battery charger voltage and current. The battery temperature was also monitored. These data were sent to an off-board digital data acquisition system, sampled once a minute and stored on a laptop PC.

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

Eight tests were conducted to determine vehicle performance, and one test was conducted to characterize battery charging, per Table 1:

Table 1 – Performance Tests Conducted on the E-Bike

Test Number	*Grade (%)*	*Vehicle Mode*	*Top Vehicle Speed*	*Driving Cycle*
1	0	Normal	5 mph	Range test.
2	0	Normal	10 mph	Range test.
3	0	Normal	Maximum	Range test.
4	+8	Normal	Maximum	Range test.
5	0	Economy	Maximum	Acceleration test.
6	0	Normal	Maximum	Acceleration test.
7	+8	Economy	Maximum	Acceleration test.
8	+8	Normal	Maximum	Acceleration test.
9	N/A	N/A	N/A	Battery charging 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.

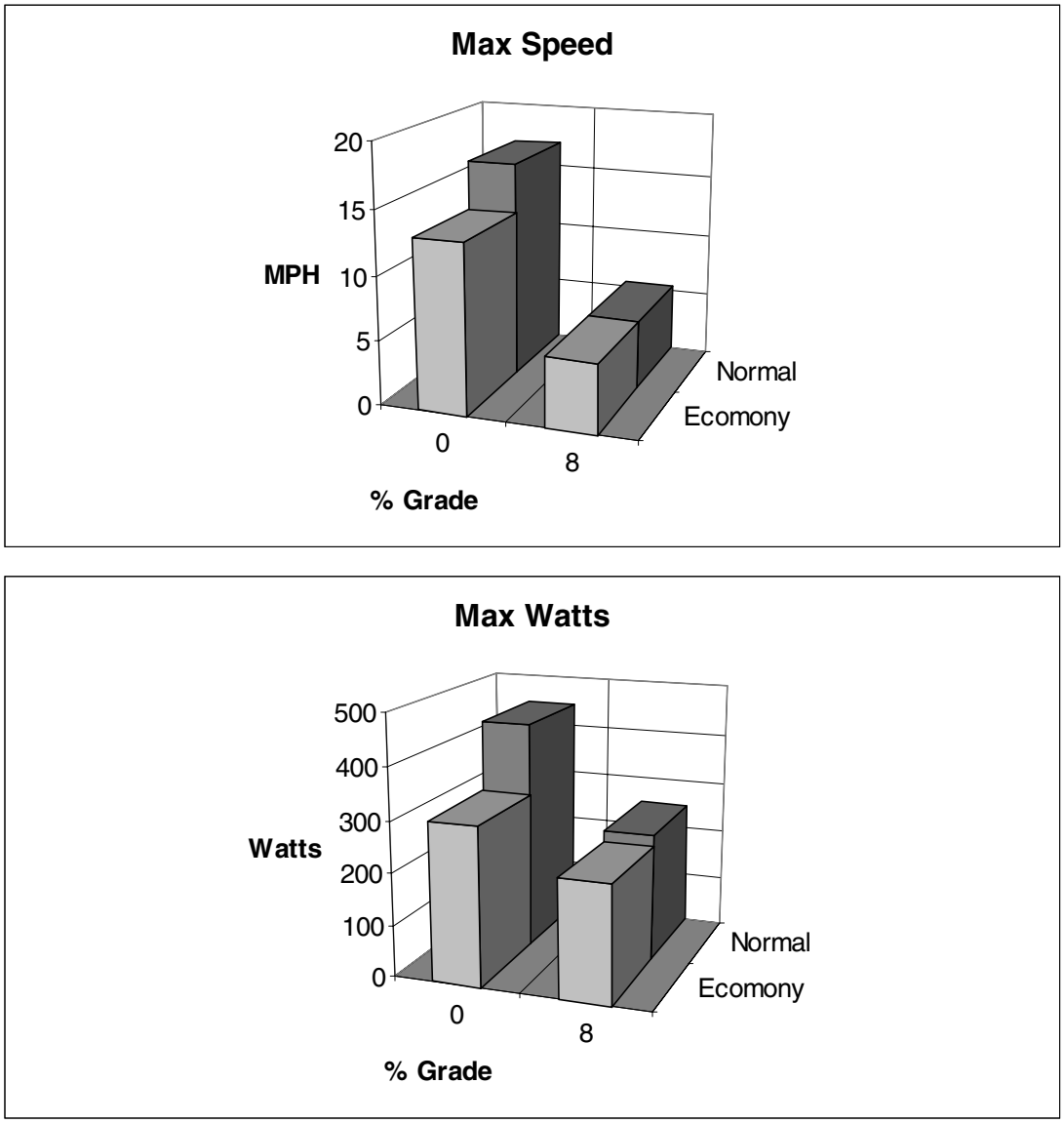
The battery-charging plot indicates the charging ac voltage, current and power, as well as the ambient and battery temperatures.

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 17.3 mph with no grade under full power. Figure 5 indicates the maximum speeds achieved at various grades, as well as the various powers that were obtained.

Figure 5 – 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.

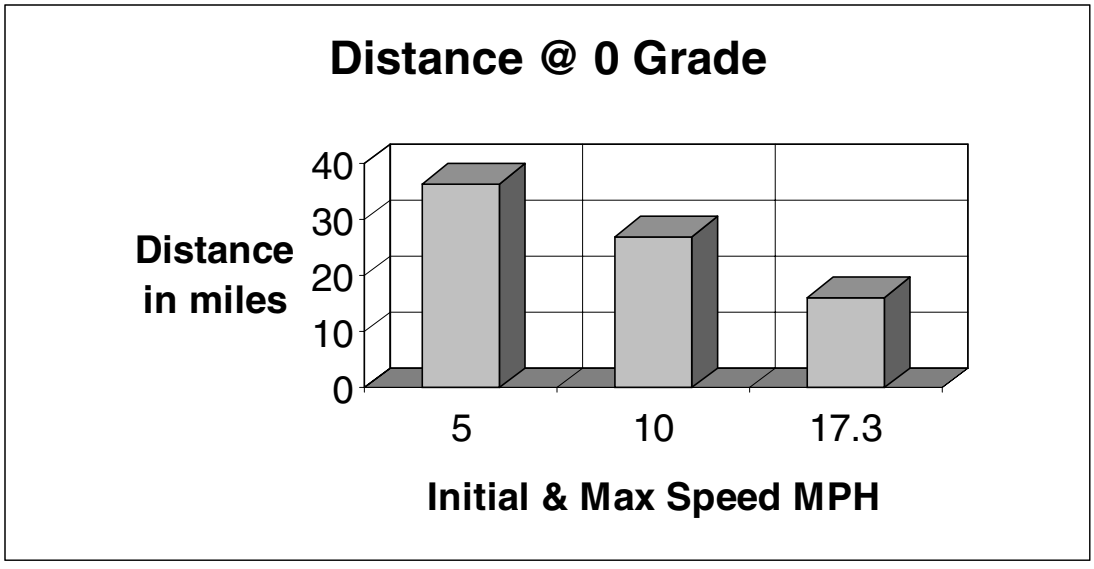
$$a_n = \frac{v_n - v_{n-1}}{t_n - t_{n-1}}$$

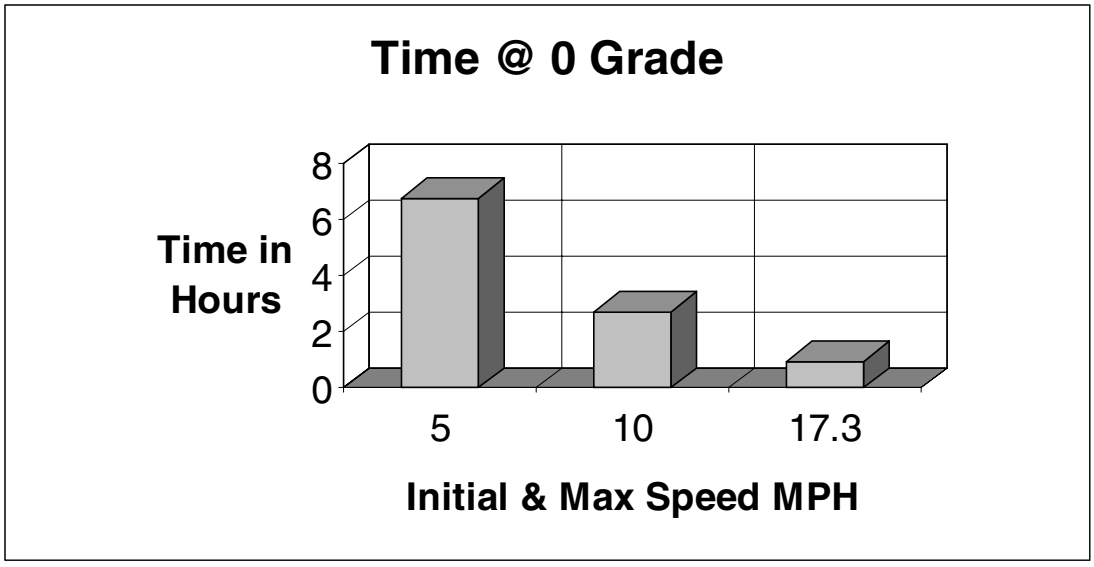
Acceleration times are given in Table 2.

Range

The range of the vehicle was determined from the dynamometer tests under full electric operation. This yields a range of 36.39 miles for no grade in the normal mode with an initial speed of 5 mph.

Fig. 6 – Range in Normal Mode with 0% Grade

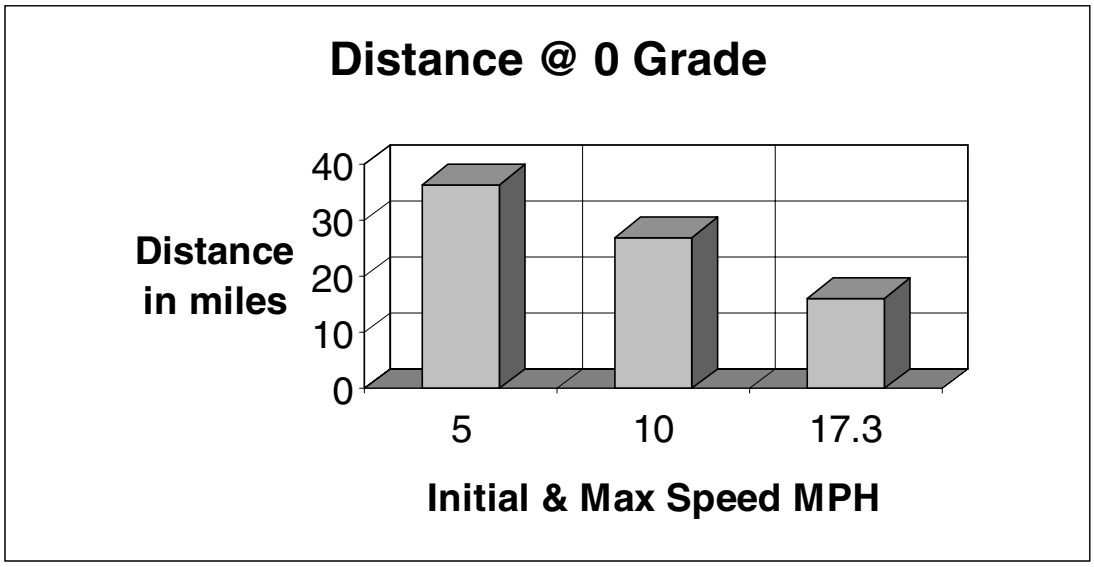




Range

The range of the vehicle was determined from the dynamometer tests under full electric operation. This yields a range of 36.39 miles for no grade in the normal mode with an initial speed of 5 mph.

Fig. 6 – Range in Normal Mode with 0% Grade



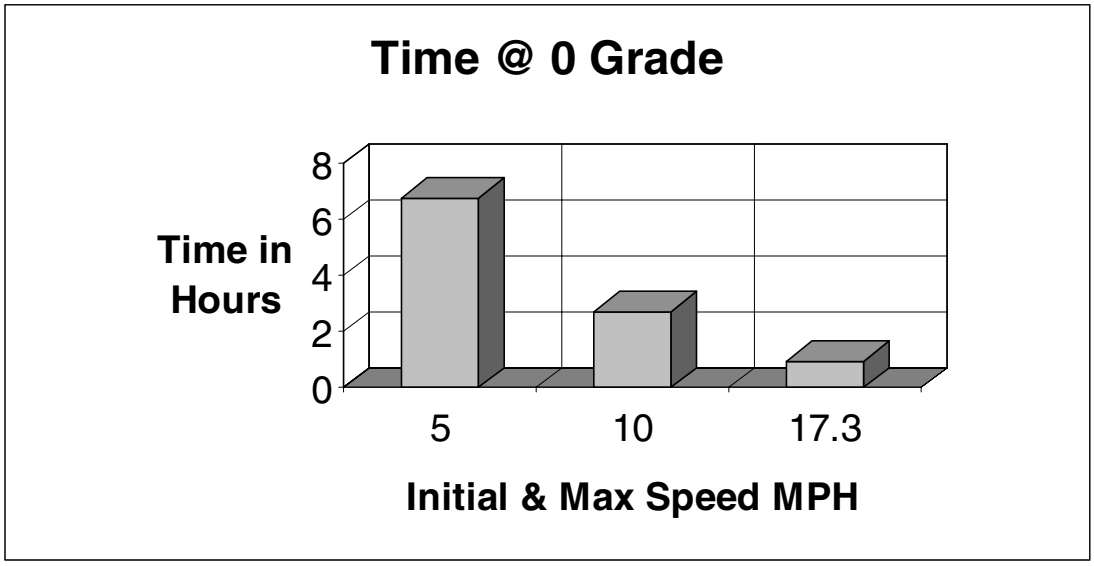
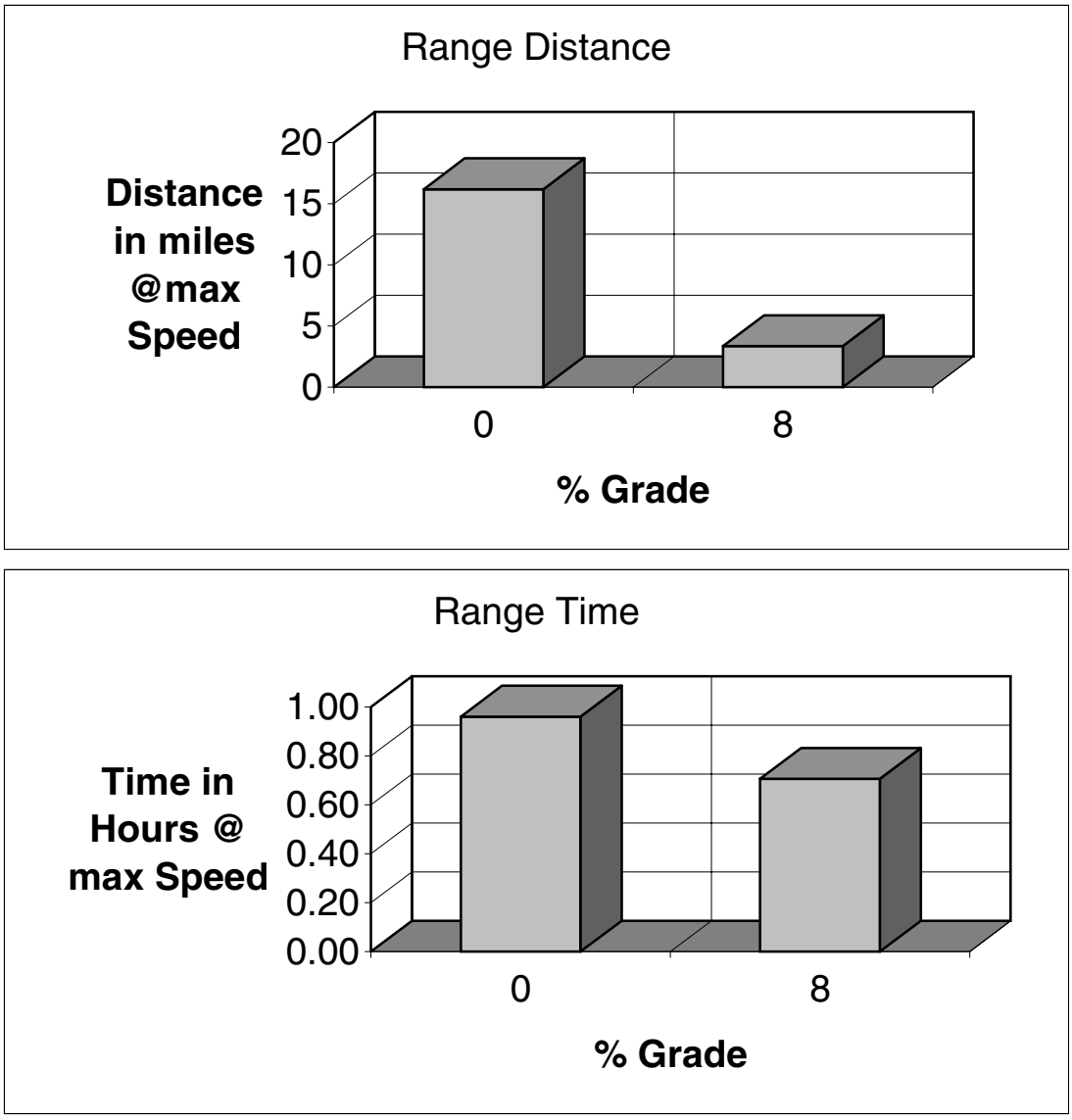


Fig. 7 – Range in Normal Mode with Various Grades



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 SX

Parameter	Test Conditions	Test Results	Remarks
Range			
5 mph Initial Speed	0% Grade, Normal Mode	36.39 miles 6.77 hrs	
10 mph Initial Speed	0% Grade, Normal Mode	26.94 miles 2.71 hrs	
17.3 mph Initial Speed	0% Grade, Normal Mode	16.19 miles 0.96 hrs	Maximum speed.
Top Speed	0% Grade, Normal Mode	17.3 mph	
Acceleration Times			
5 mph	0% Grade, Normal Mode	0.99 sec	
10 mph	0% Grade, Normal Mode	4.26 sec	
17.3 mph	0% Grade, Normal Mode	20.27 sec	Maximum speed.
Battery Charging			Battery discharged to cutoff (27 VDC) by SX.
Time	123.2 VAC Line	4.3 hrs	
Maximum AC Current	123.2 VAC Line	1.3 amps	
Maximum AC Power	123.2 VAC Line	160 watts	
Total Energy	123.2 VAC Line	0.452 kWh	

CONCLUDING REMARKS

The EV Global E-Bike SX as tested and described in this report is a commercially available, high performance vehicle that is fully prepared for the mass market. The vehicle exhibited no problems under the rigorous test conditions that it was exposed to. The performance of the vehicle proved to be excellent.

The range performance of the vehicle was extraordinary. The range of 36.4 miles that was achieved with an initial speed of 5 mph with no grade is more than twice the advertised range of 15 miles. The vehicle operated for 6.8 hours under these conditions. At an initial speed of 10 mph with no grade, a range of 26.9 miles was achieved. The vehicle operated for 2.7 hours under these conditions. At maximum throttle with no grade, a range of 16.2 miles was achieved. The vehicle operated for almost one hour under these conditions.

The top speed of the vehicle with no grade and full throttle was 17.3 mph, which is just slightly under the advertised 17.5-mph. 17.3 mph is greater than the normal average bicycle riding speed. The acceleration of the vehicle was phenomenal, with a 0 to 10-mph time of 4.2 seconds.

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.

APPENDIX A

VEHICLE SUMMARY DATA SHEET

1.0 Vehicle Manufacturer	EV Global Motors Company Los Angeles, CA
2.0 Vehicle	E-Bike SX Model
3.0 Vehicle Configuration	Parallel Hybrid
4.0 Traction Motor	
4.1 Traction Motor Configuration	DC brushed
4.2 Traction Motor Power	500 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	38 teeth
5.1.3 Rear Cluster	14, 16, 18, 20, 22, 24, 28 teeth
5.1.4 Gear Ratio	0.368, 0.421, 0.474, 0.526, 0.579, 0.632, 0.737
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	75 mm
6.8 Stem 1	15 degrees, 110 mm extension
6.9 Stem 2	28.6 mm x 25.4 mm x 150 mm with quill
6.10 Handlebar Width	660 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 Front Rim	26 x 1.5 in, 14G x 32H, double wall
6.17 Rear Rim	26 x 1.5 in, 14G x 36H, double wall
6.18 Front Spokes	266 mm, 14G stainless
6.19 Rear Spokes	216 mm, 14G stainless
6.19 Bottom Bracket	127 mm cartridge
6.20 Base Curb Weight	82 lb
6.21 Total Weight (as tested)	282 lb

7.0 Energy Storage

7.1 Battery Pack

7.1.1	Configuration	Single block with integral charger
7.1.2	Battery Type `	Deep discharge, sealed lead acid
7.1.3	Battery Energy Rating	8 amp hours
7.1.4	Battery Voltage Rating	36 volts
7.1.5	Charger Input	115 volts ac, 60 Hz, 2 amps
7.1.6	Charger Output	36 volts dc, 2 amps
7.1.7	Dimensions	15 in x 4 in x 4 in
7.1.8	Weight	24 lb

APPENDIX B

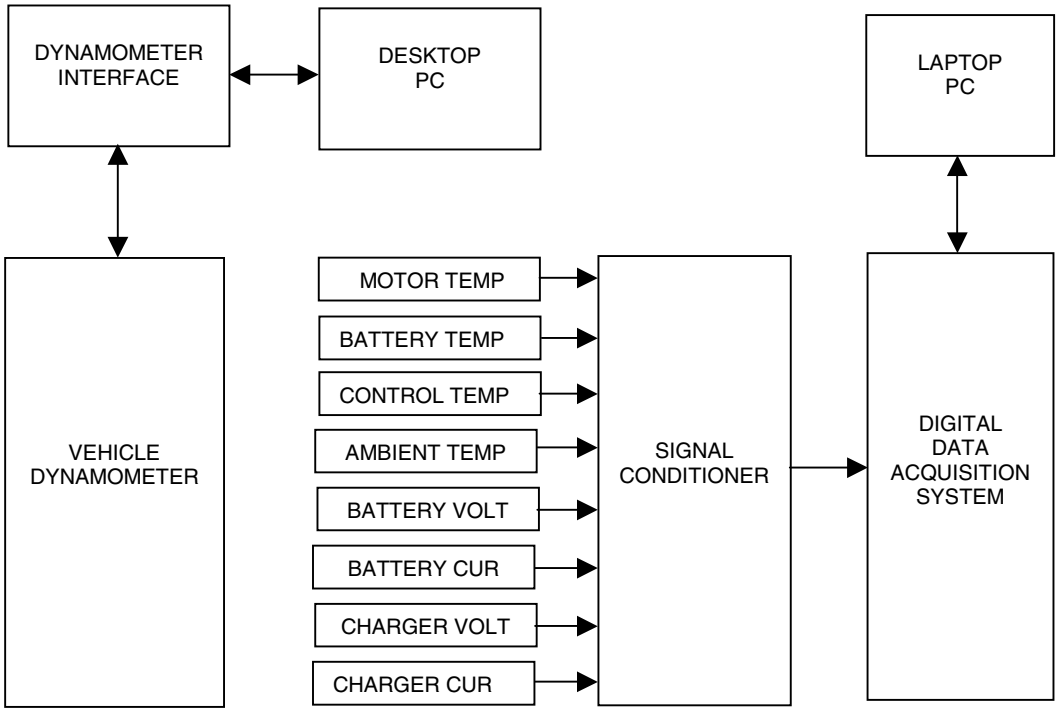
DESCRIPTION OF THE INSTRUMENTATION SYSTEM

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. 2.

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.

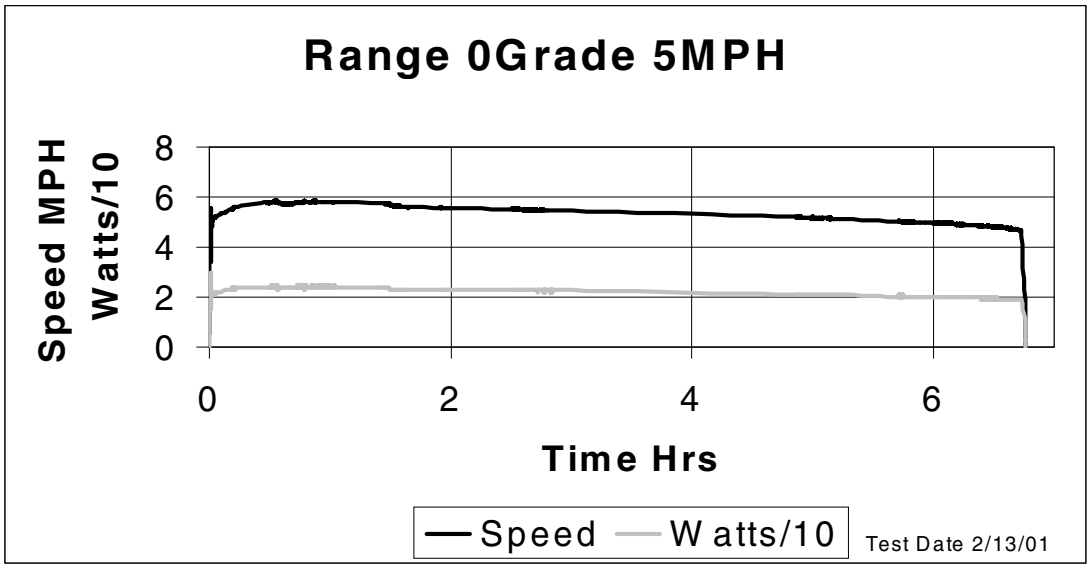
Table D-1 EV Global E-Bike SX Test Matrix

PARAMETER	CONDITIONS
Acceleration	To maximum speed at 0% and 8% grades in the normal and economy mode of operation.
Range	To maximum speed at 0% and 8% grades in the normal mode of operation. To 5 mph and 10 mph at 0% grade in the normal mode of operation.
Top Speed	To maximum speed at 0% grade in the normal mode of operation.
Battery Charging	From battery discharged to 27 volts, to full charge.

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.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Watts/10
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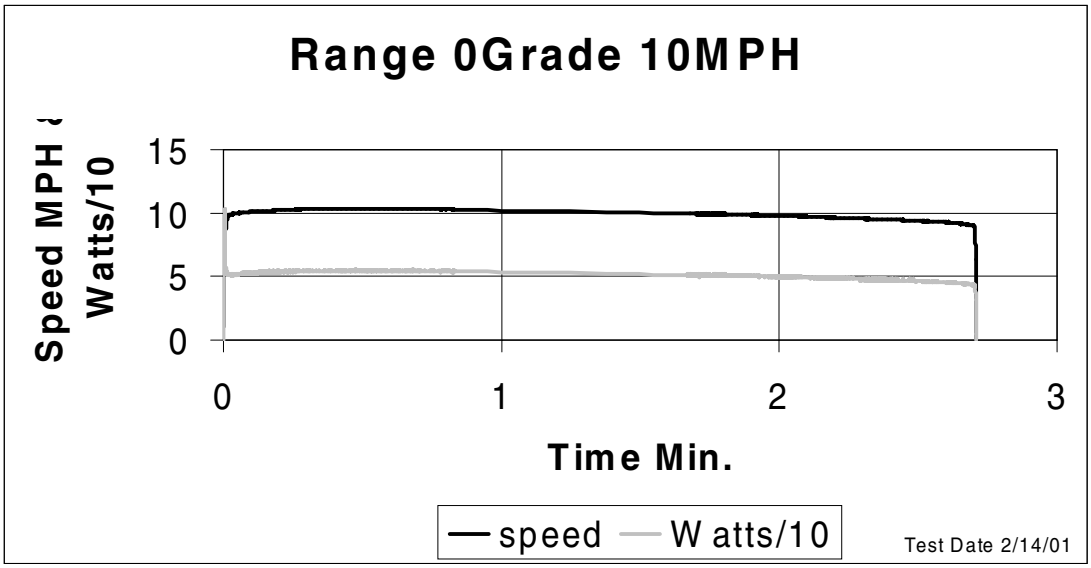
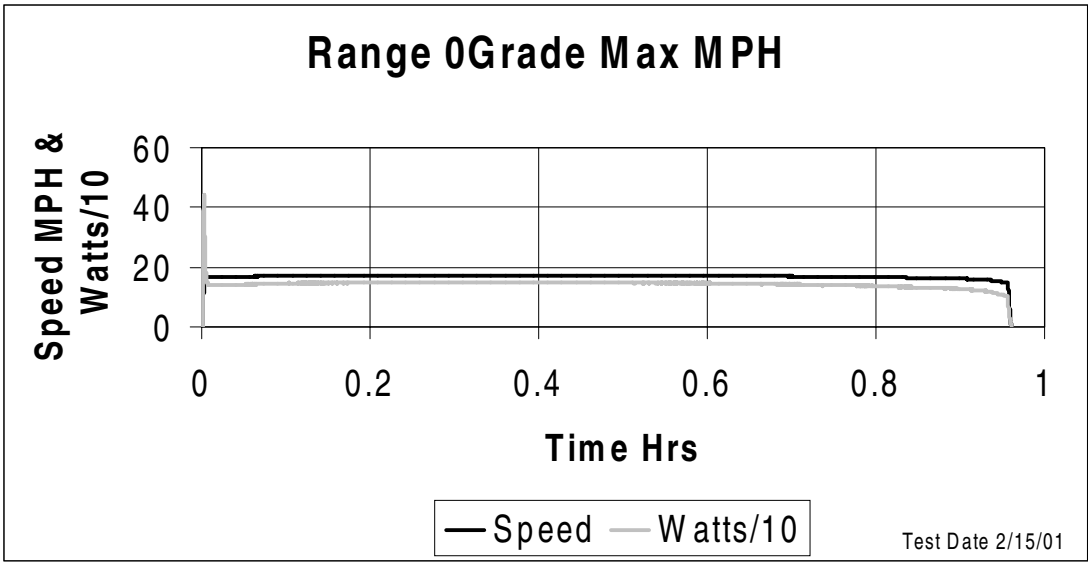
6
4
2
0
0
2
4
6
Time Hrs
Speed
Watts/10
Test Date 2/13/01


Range 0Grade 10MPH
Watts/10
15
10
5
0
0
1
2
3
Time Min.
speed
Watts/10
Test Date 2/14/01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Speed MPH &
Watts/10
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40
20
0
0
0.2
0.4
0.6
0.8
1
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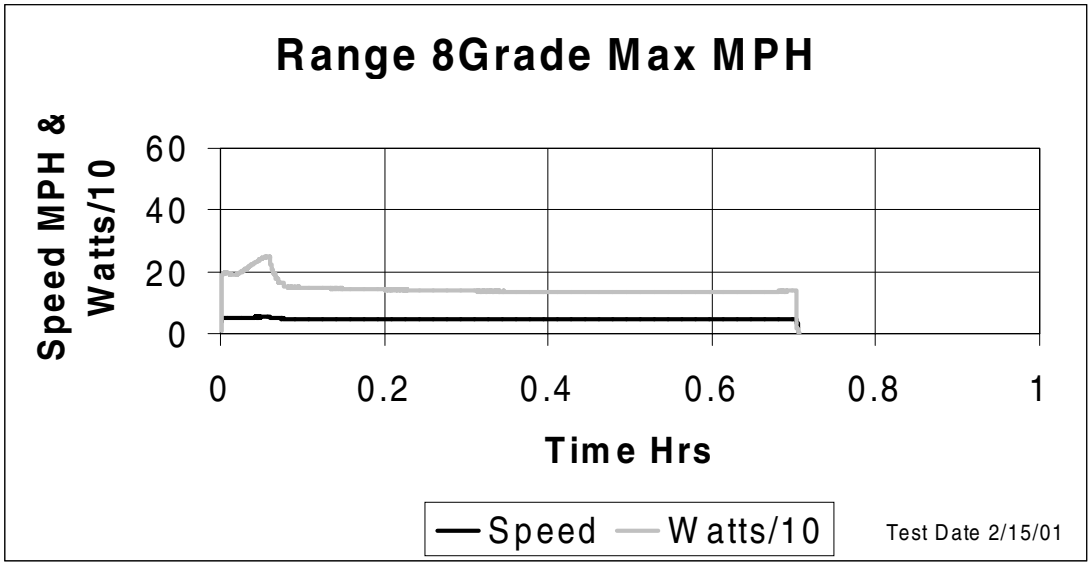
Speed
Watts/10
Test Date 2/15/01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Speed MPH & Watts/10
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40
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0.2
0.4
0.6
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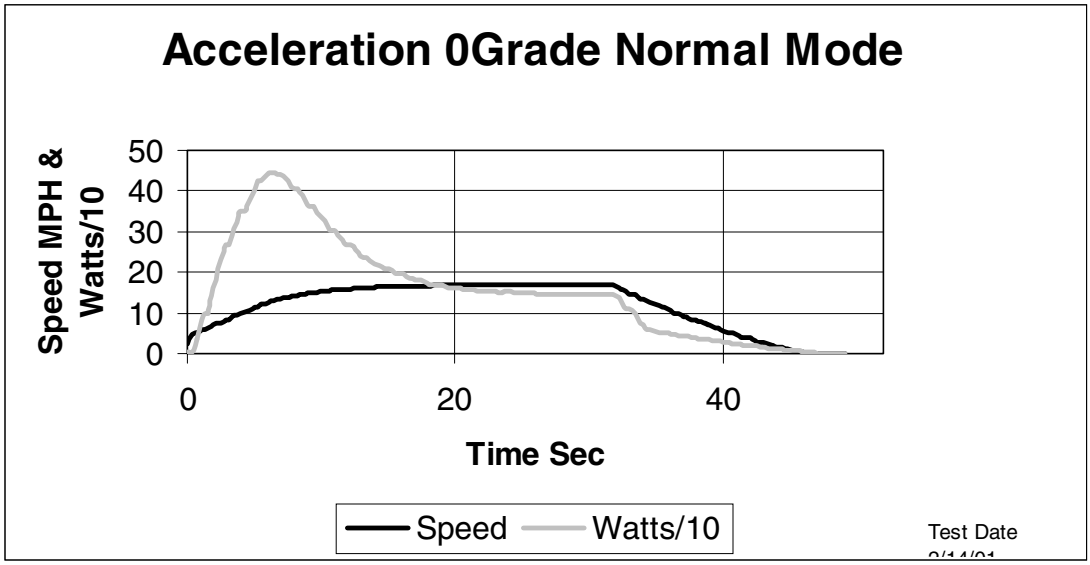
Time Hrs
Speed
Watts/10
Test Date 2/15/01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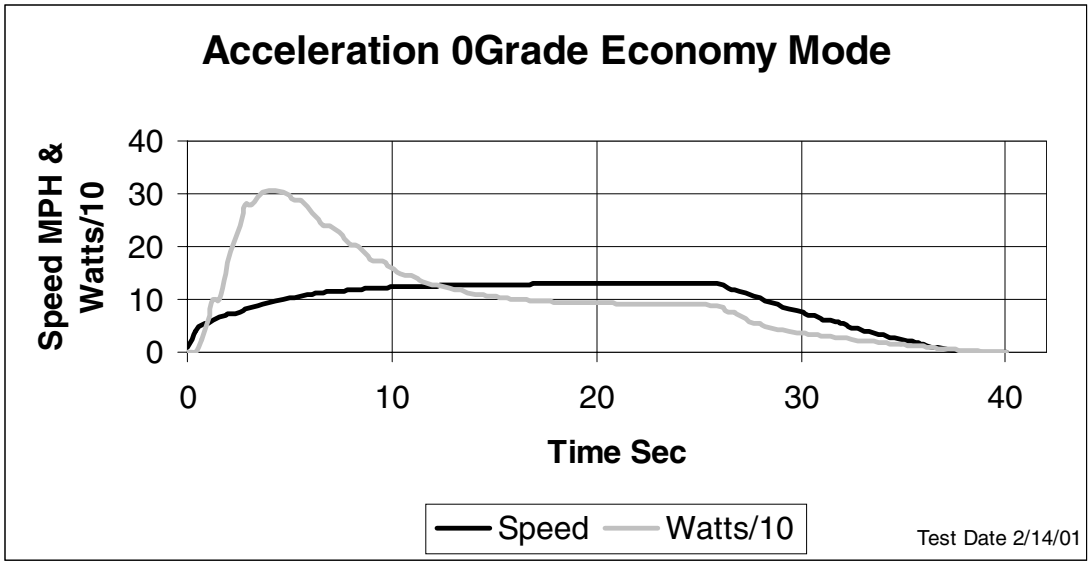
40
30
20
10
0
0
20
40
Time Sec
Speed
Watts/10
Test Date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Speed MPH & Watts/10
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10
20
30
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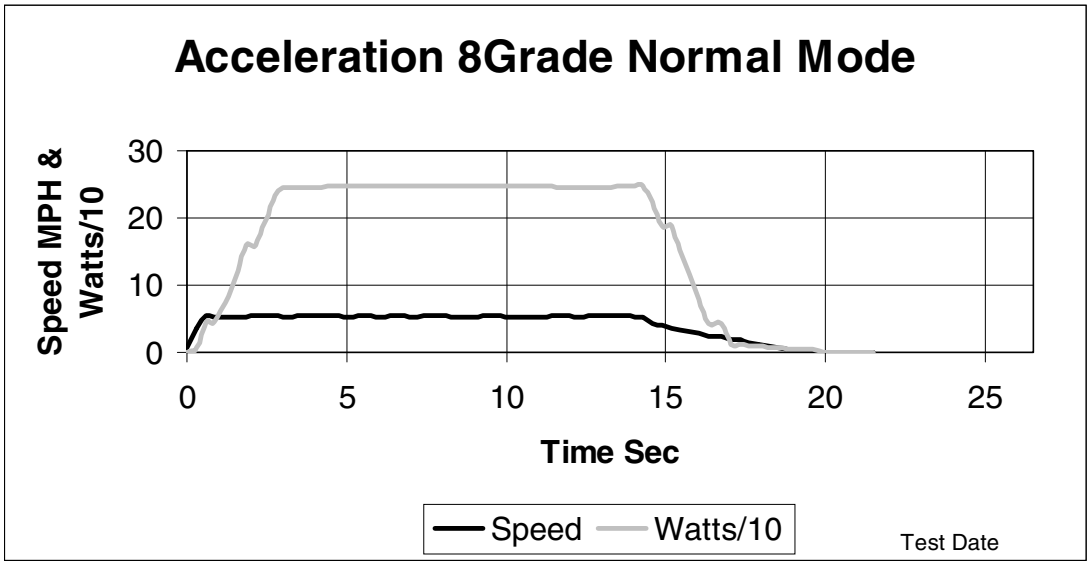
Time Sec
Speed
Watts/10
Test Date 2/14/01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0
5
10
15
20
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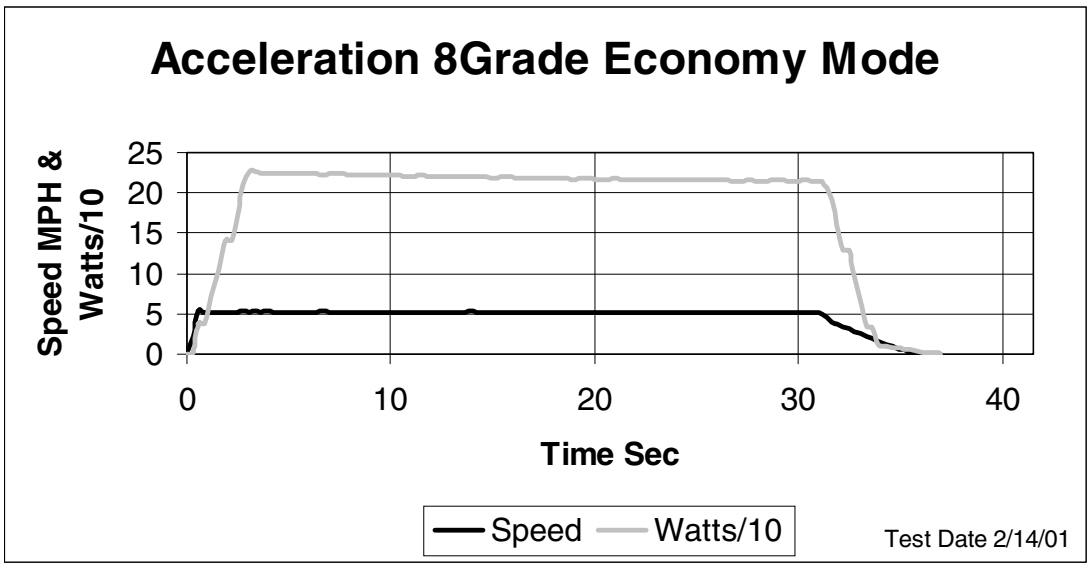
Time Sec
Speed
Watts/10
Test Date


Acceleration 8Grade Economy Mode
Speed MPH & Watts/10
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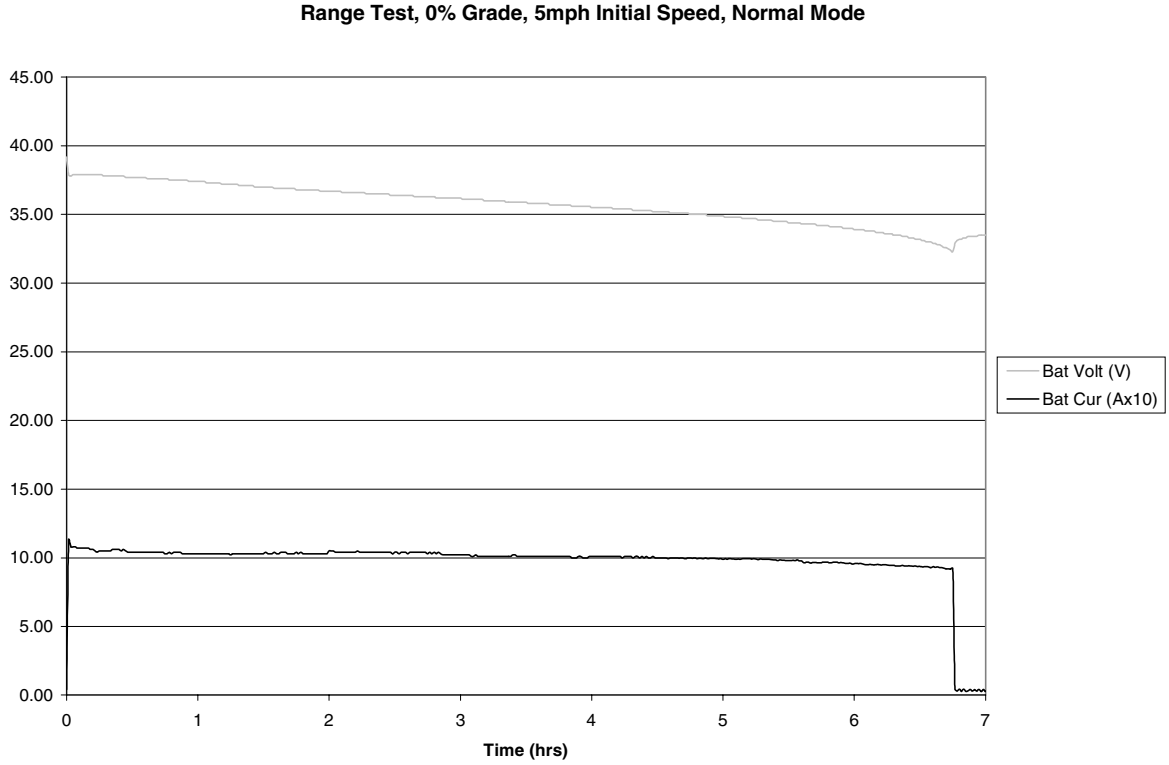
20
15
10
5
0
0
10
20
30
40
Time Sec
Speed
Watts/10
Test Date 2/14/01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40.00
35.00
30.00
25.00
20.00
15.00
10.00
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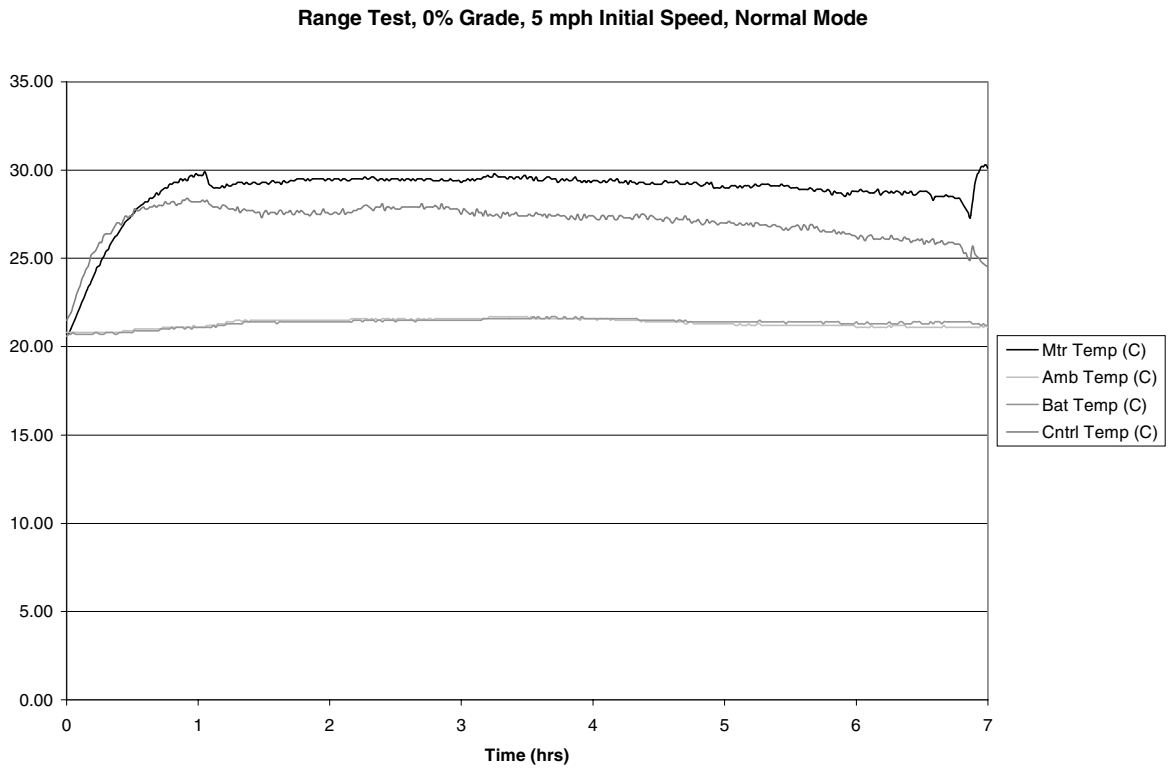
1
2
3
4
5
6
7
Time (hrs)
Bat Volt (V)
Bat Cur (Ax10)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15.00
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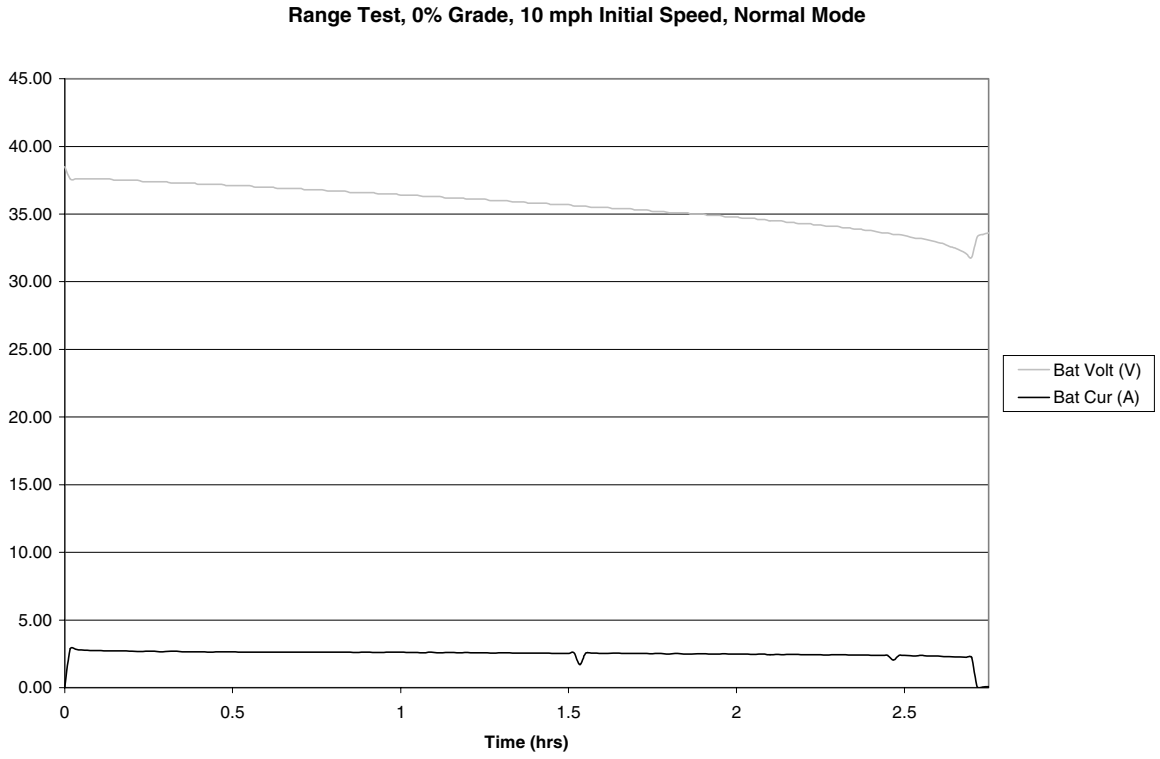
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)


Range Test, 0% Grade, 10 mph Initial Speed, Normal Mode
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35.00
30.00
25.00
20.00
15.00
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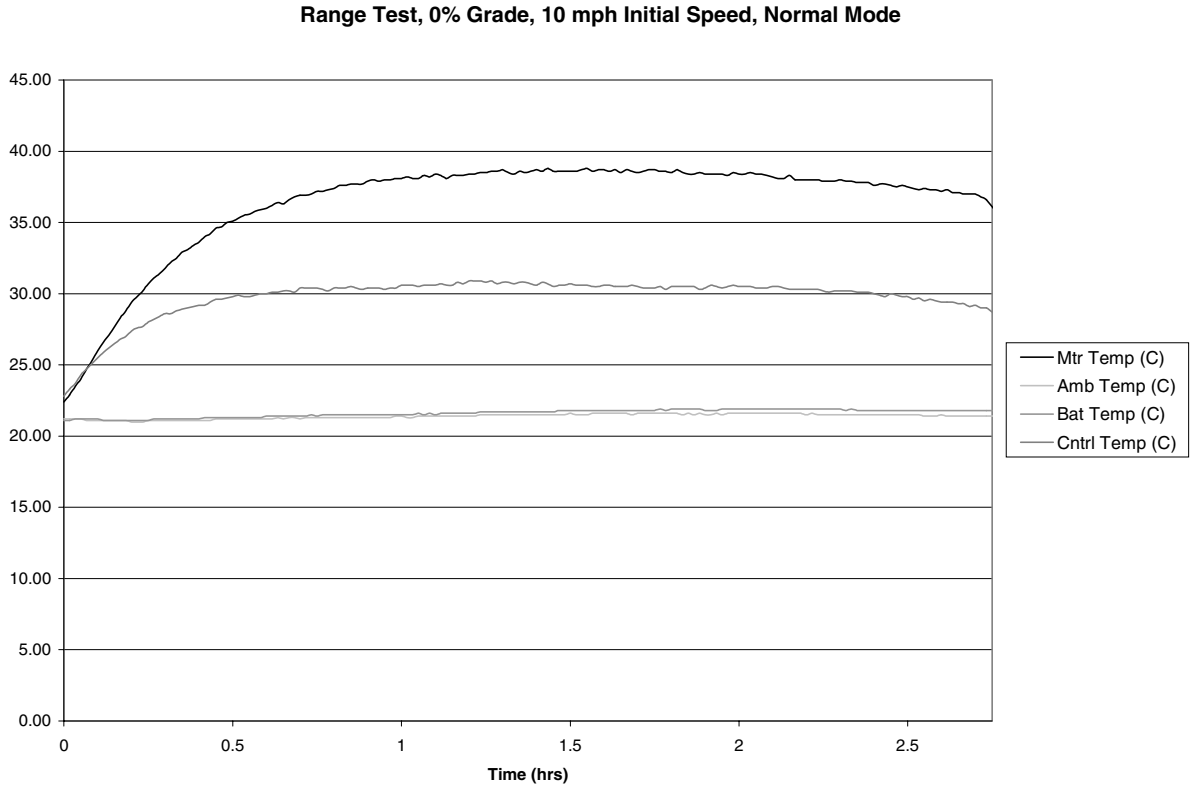
0
0.5
1
1.5
2
2.5
Time (hrs)
Bat Volt (V)
Bat Cur (A)


Range Test, 0% Grade, 10 mph Initial Speed, Normal Mode
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30.00
25.00
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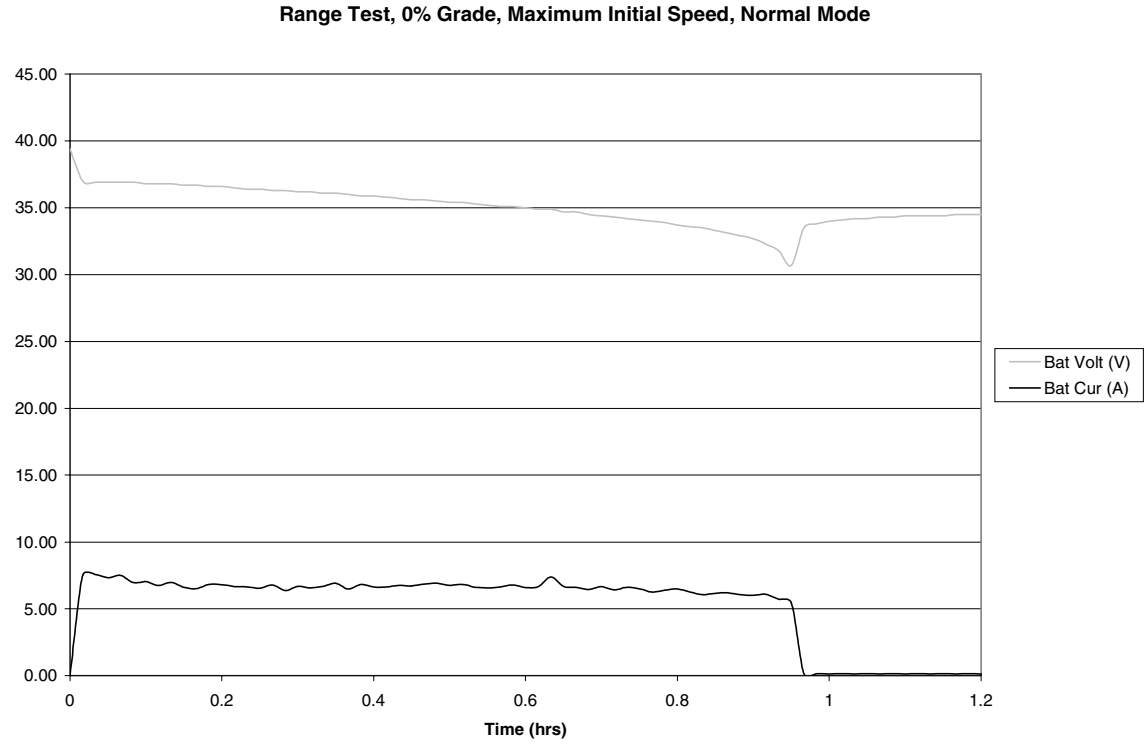
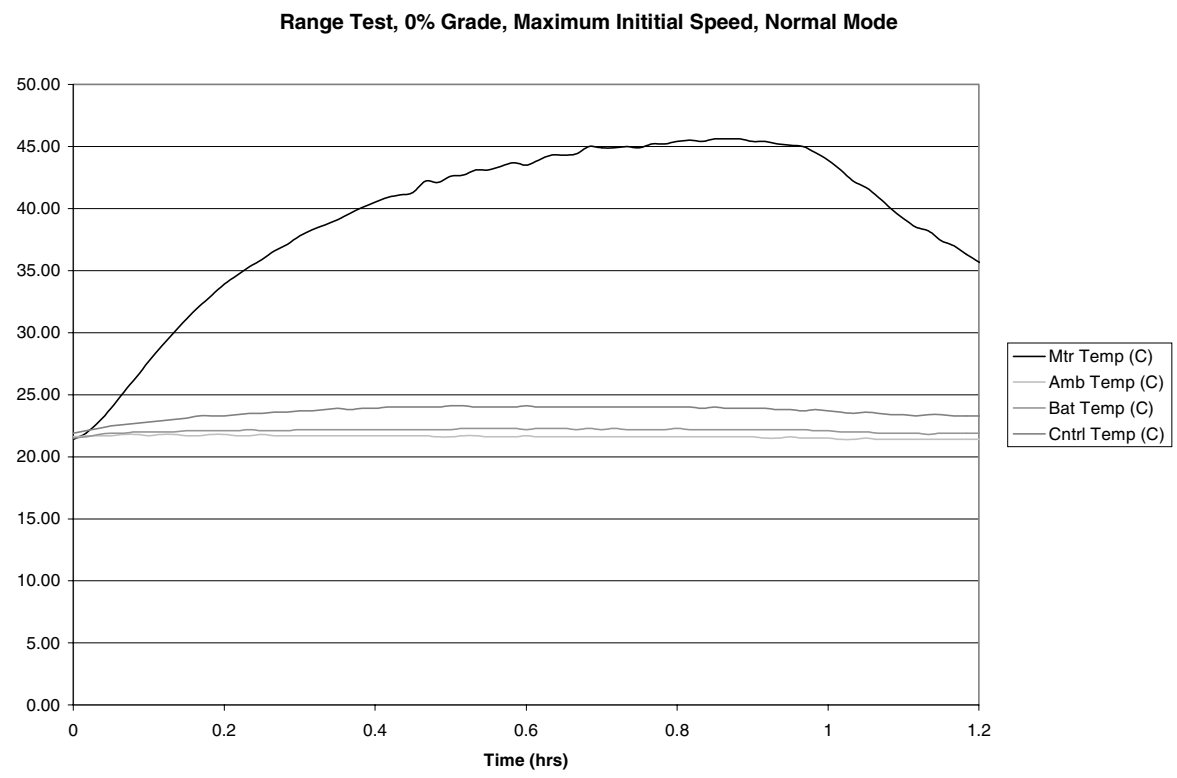
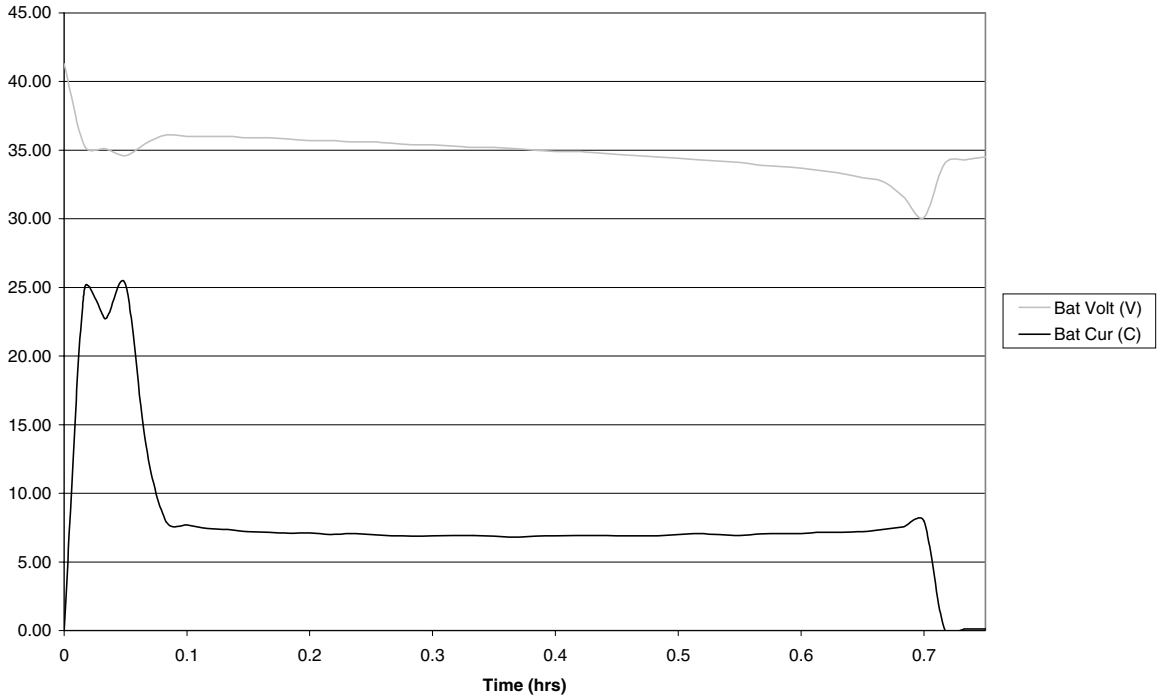
15.00
10.00
5.00
0.00
0
0.5
1
1.5
2
2.5
Time (hrs)
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)

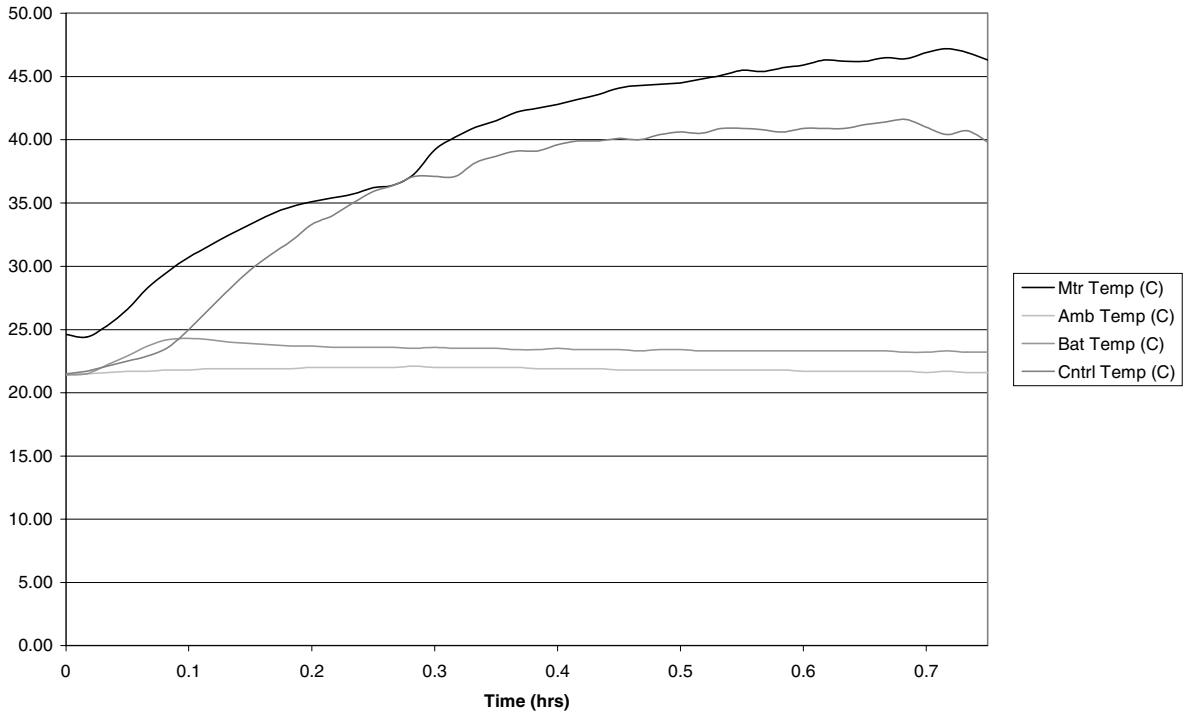

Range Test, 0% Grade, Maximum Initial Speed, Normal Mode
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
Time (hrs)
Bat Volt (V)
Bat Cur (A)

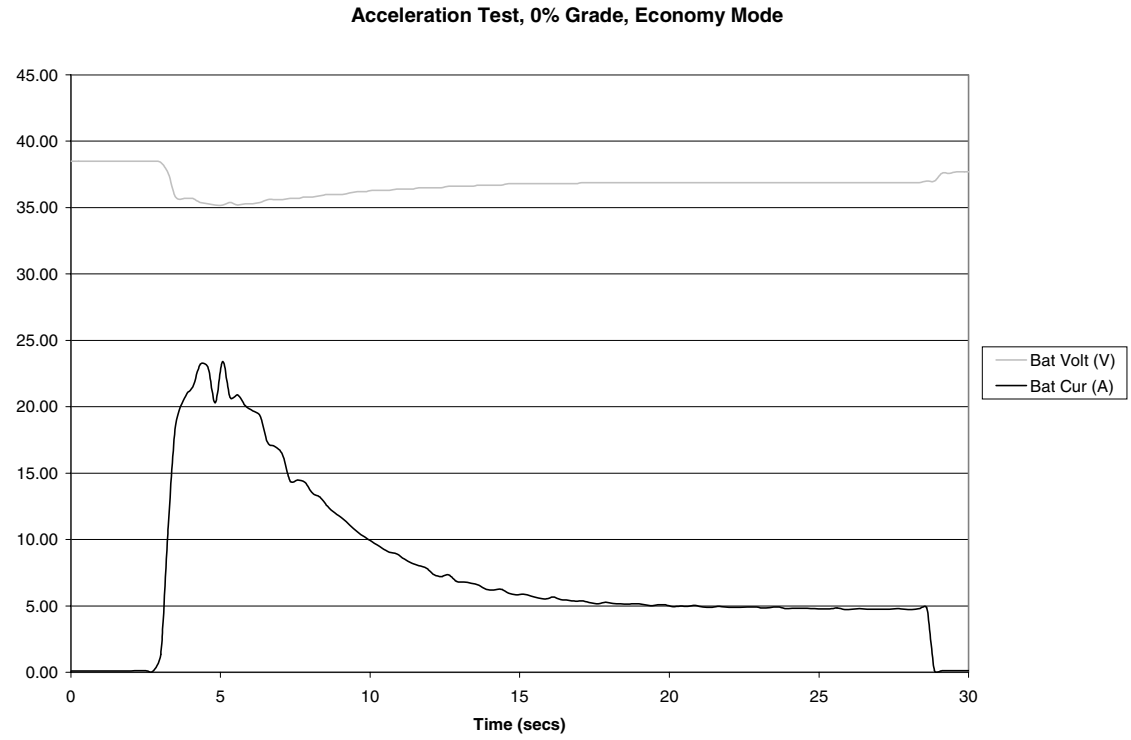

Range Test, 0% Grade, Maximum Inititial Speed, Normal Mode
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
Time (hrs)
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)

Range Test, 8% Grade, Maximum Initial Speed, Normal Mode



Range Test, 8% Grade, Maximum Initial Speed, Normal Mode

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20.00
15.00
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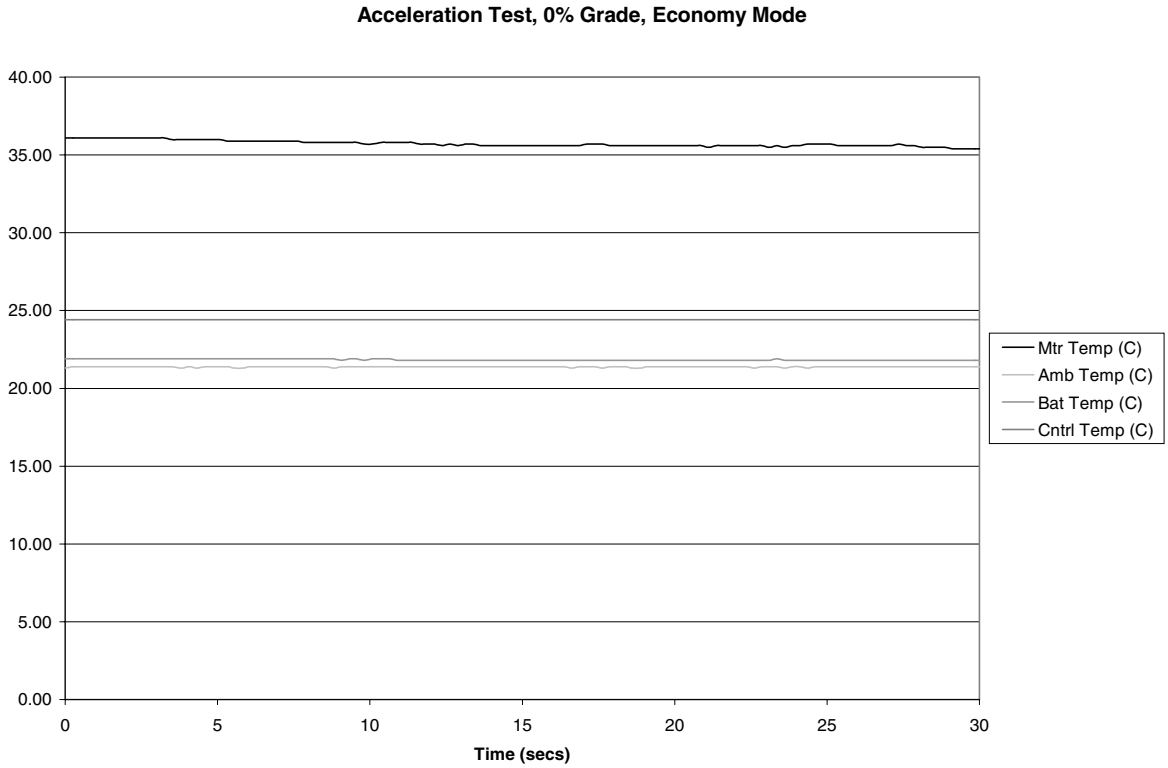
0.00
0
5
10
15
20
25
30
Time (secs)
Bat Volt (V)
Bat Cur (A)


Acceleration Test, 0% Grade, Economy Mode
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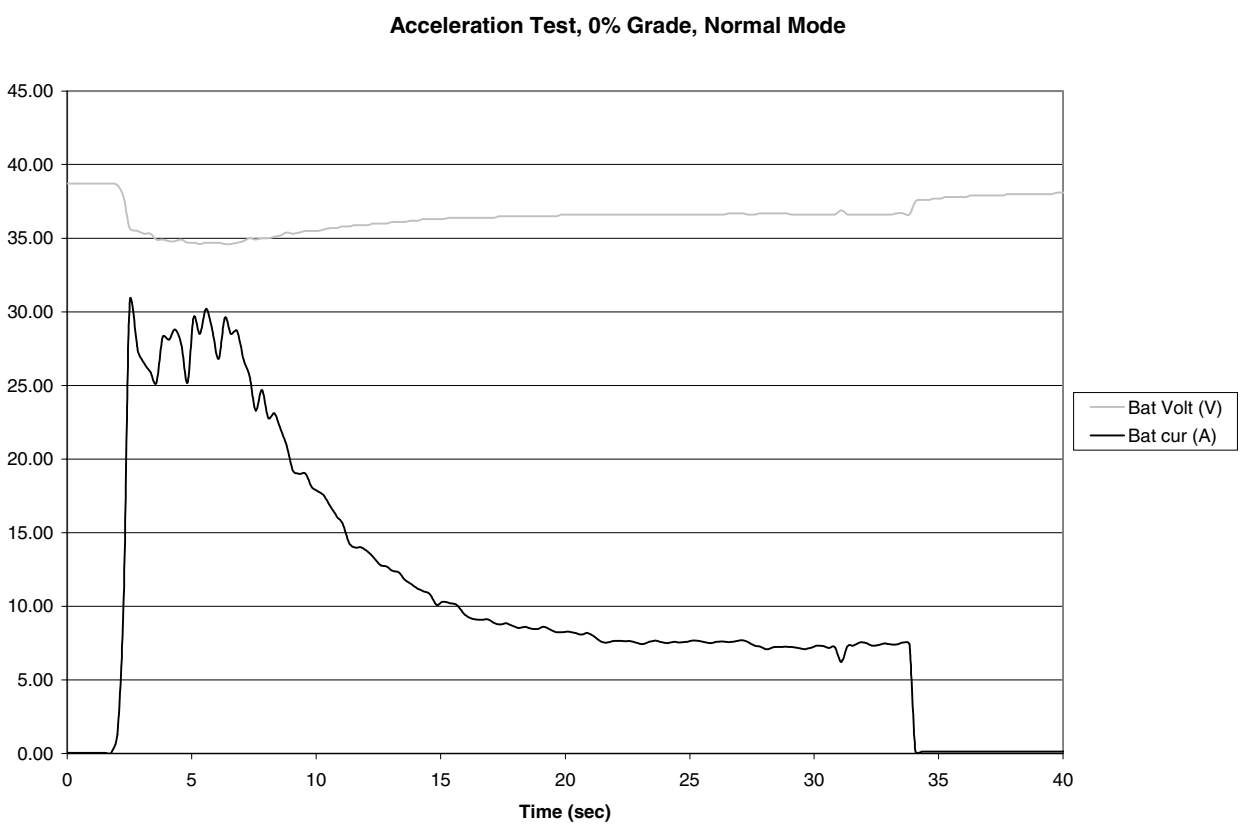
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
5
10
15
20
25
30
Time (secs)
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)


Acceleration Test, 0% Grade, Normal Mode
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30.00
25.00
20.00
15.00
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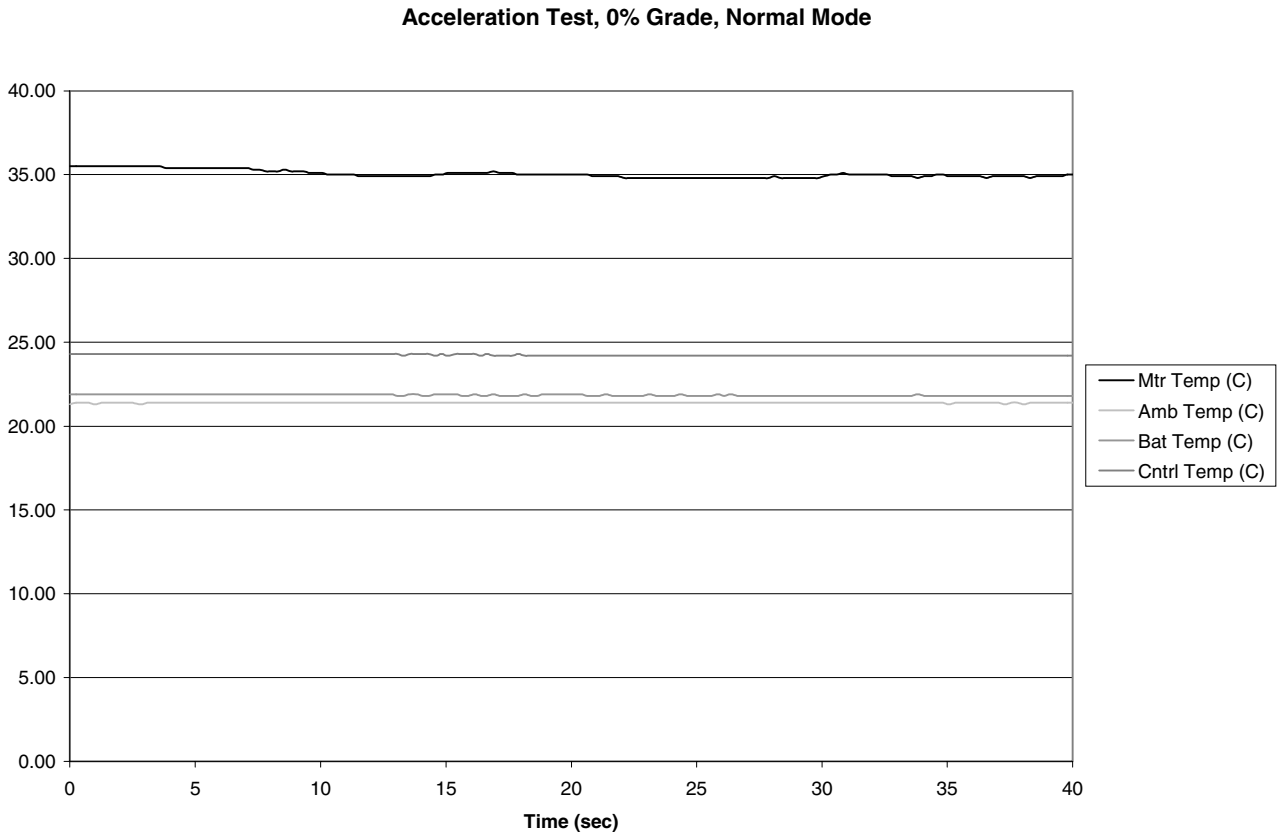
5.00
0.00
0
5
10
15
20
25
30
35
40
Time (sec)
Bat Volt (V)
Bat cur (A)


Acceleration Test, 0% Grade, Normal Mode
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35.00
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25.00
20.00
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10.00
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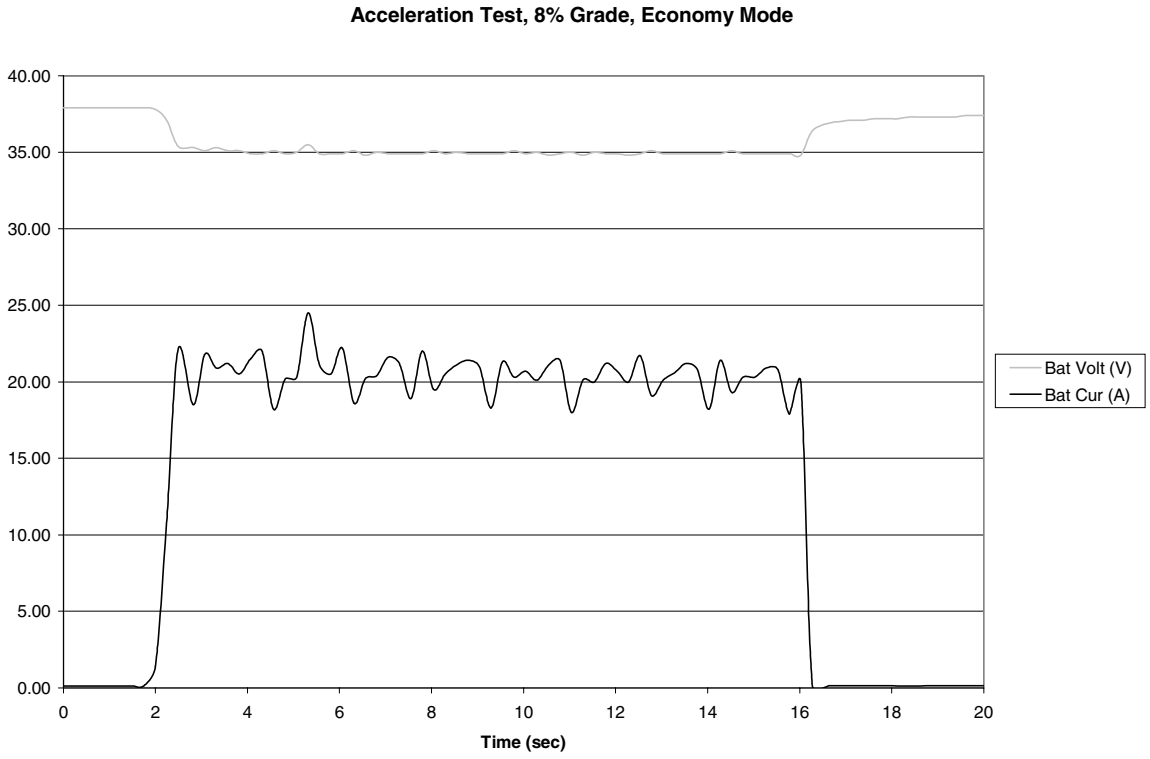
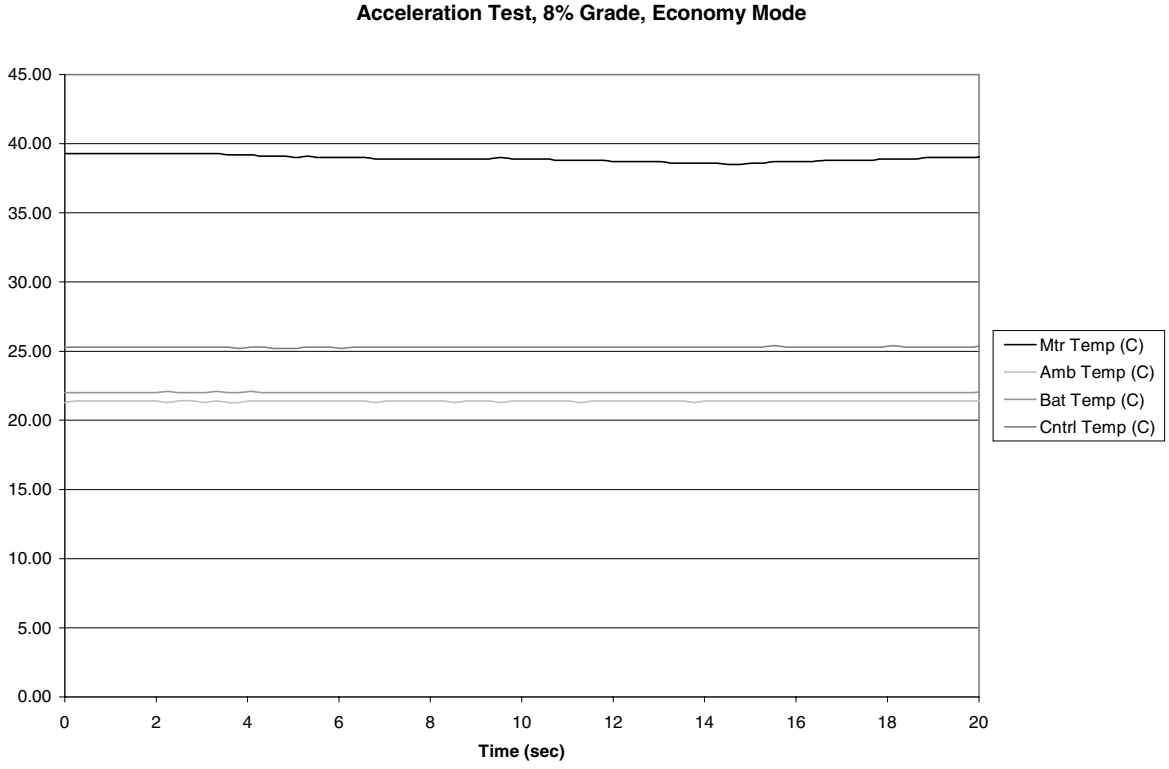
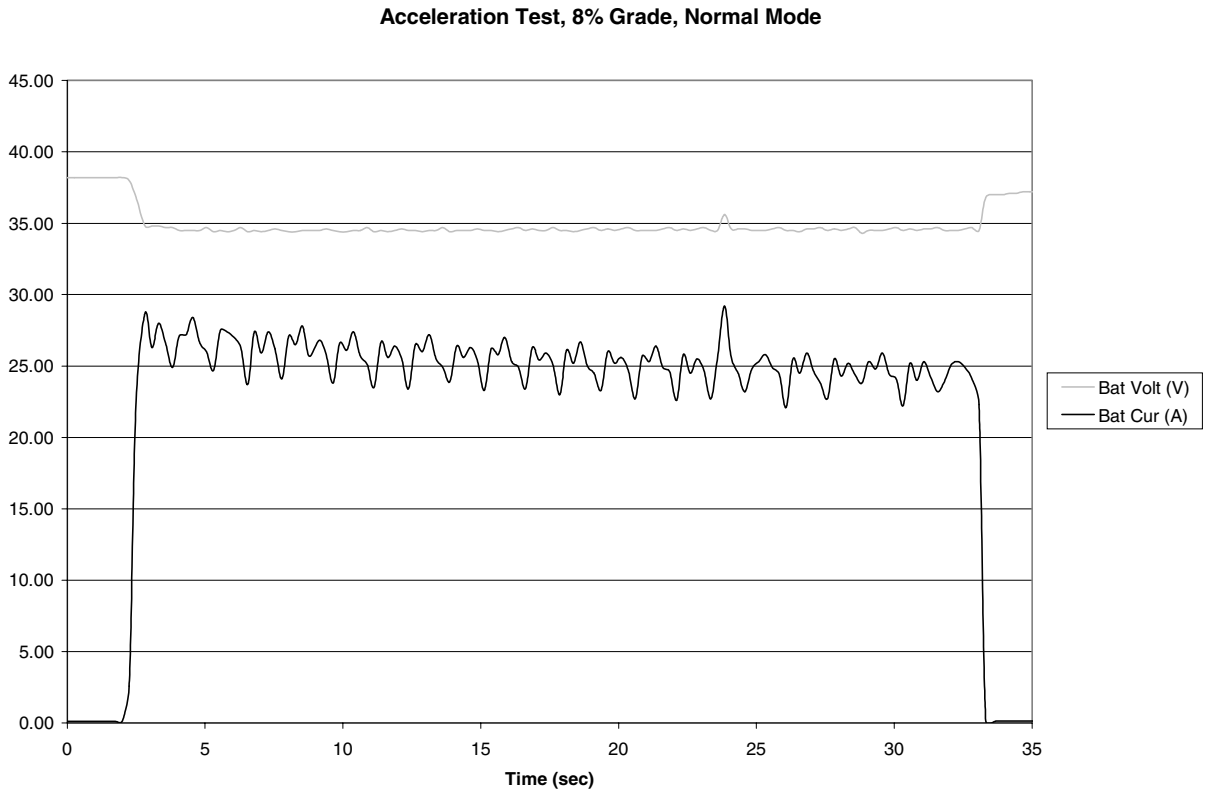
0
5
10
15
20
25
30
35
40
Time (sec)
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)


Acceleration Test, 8% Grade, Economy Mode
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
Bat Volt (V)
Bat Cur (A)


Acceleration Test, 8% Grade, Economy Mode
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
Mtr Temp (C)
Amb Temp (C)
Bat Temp (C)
Cntrl Temp (C)


Acceleration Test, 8% Grade, Normal Mode
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
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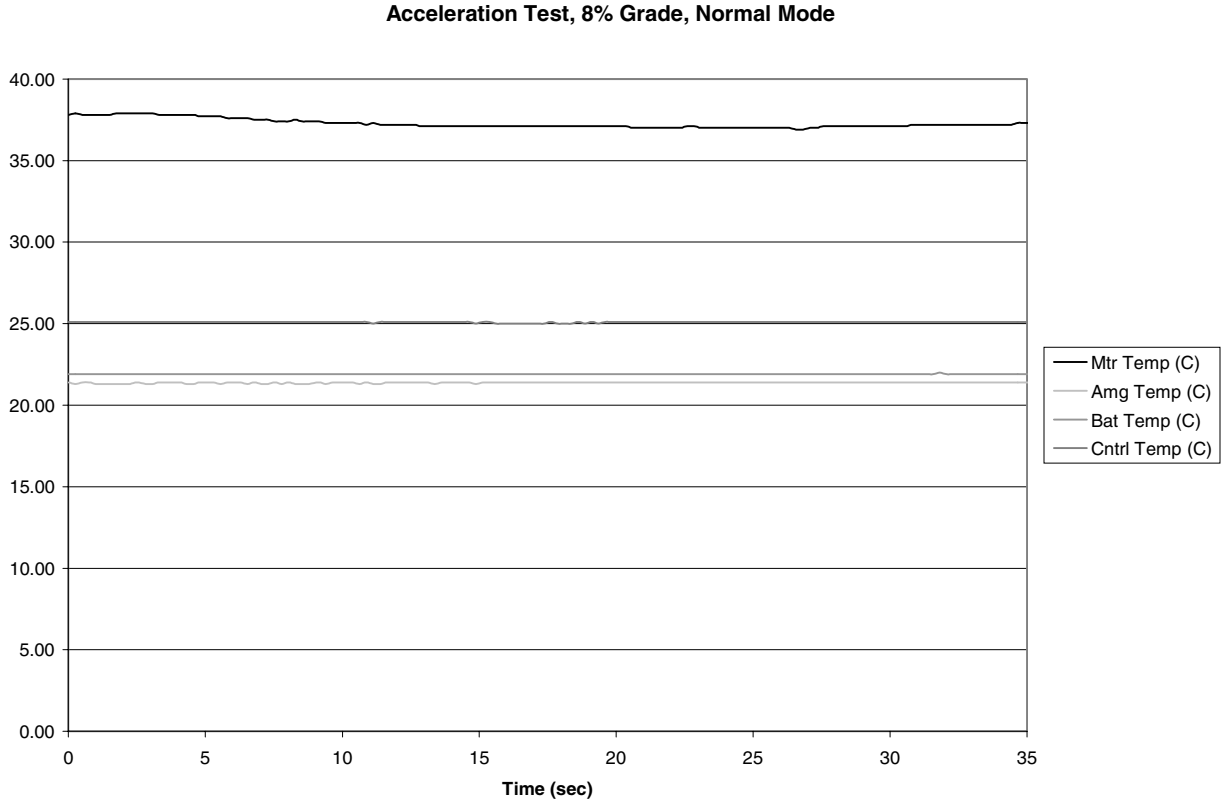
0
5
10
15
20
25
30
35
Time (sec)
Bat Volt (V)
Bat Cur (A)


Acceleration Test, 8% Grade, Normal Mode
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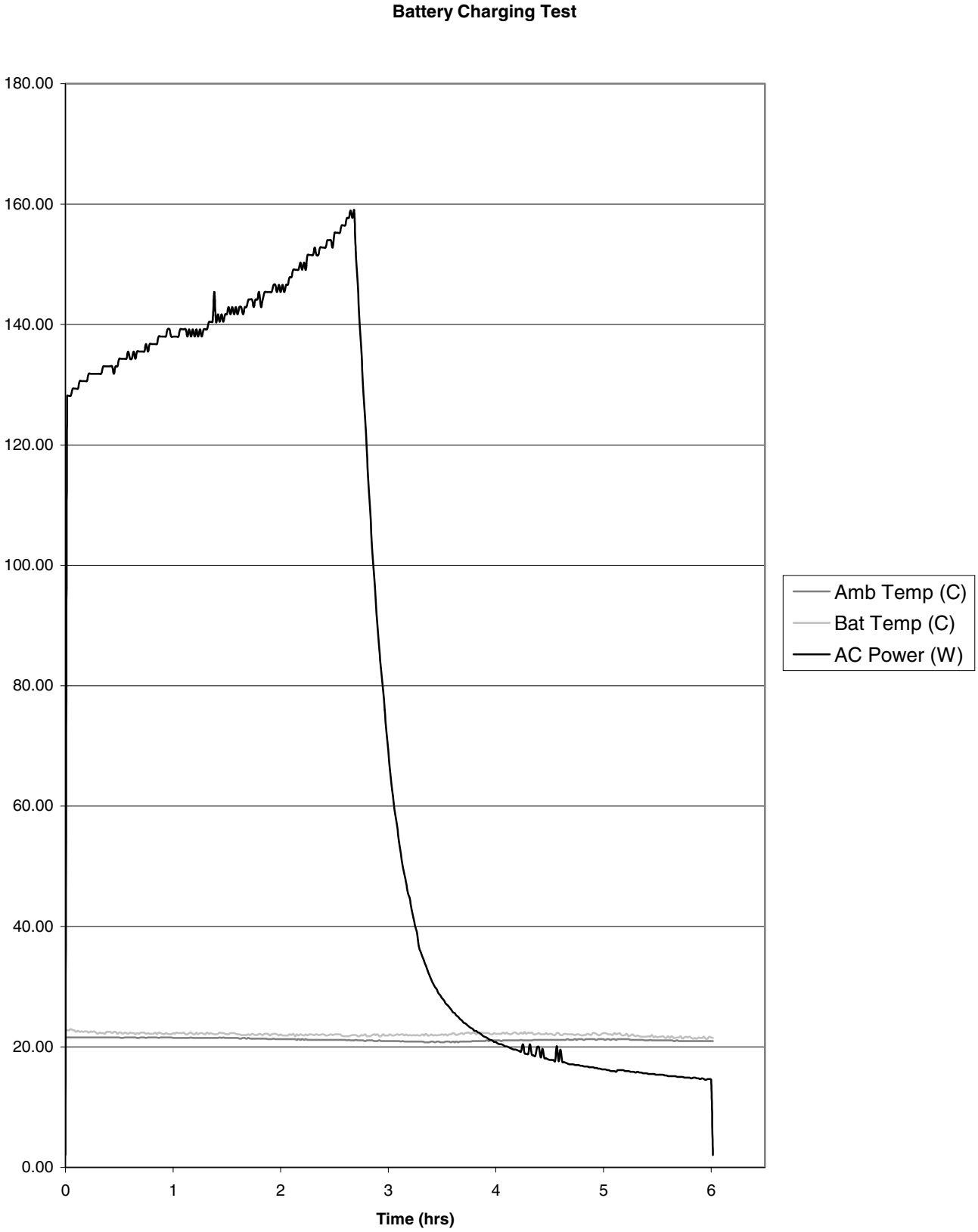
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
5
10
15
20
25
30
35
Time (sec)
Mtr Temp (C)
Amg Temp (C)
Bat Temp (C)
Cntrl Temp (C)


Battery Charging Test
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
1
2
3
4
5
6
Time (hrs)
Amb Temp (C)
Bat Temp (C)
AC Power (W)

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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 SX as an update of the state of the art in hybrid electric bicycles. The E-bike is seen as a way to reduce pollution in urban areas, reduce fossil fuel consumption, and reduce operating costs for transportation systems. The work was done under the Hybrid Power Management (HPM) Program, which includes the Hybrid Electric Transit Bus (HETB). The SX is a high performance, state of the art, ground up, hybrid electric bicycle. Unique features of the SX's 36 V 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 is 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. A description of the SX, the results of performance testing, and future vehicle development plans are given in this report. The report concludes that the SX provides excellent performance, and that the implementation of ultracapacitors in the power system can provide significant performance improvements.

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