



University of Wisconsin Madison

2009 SAE Clean Snowmobile Challenge

Electric Snow Machine Design Presentation

Presented by:

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Design Emphasis

"Outfitter"

"Operator"

Parameter	NSF Emphasis	CSC Emphasis	UW Emphasis
Range	Primary	Secondary (100 points)	Primary
Towing Capacity	Primary	Secondary (100 points)	Primary
Weight	Secondary	Secondary (100 points)	Secondary
Handling	Minor (safety only)	Secondary (125 points)	Secondary
Acceleration	None	Minor (50 points)	Secondary
Noise	None	Primary (300 points)	Secondary
Cost	Primary	Minor (50 points)	Secondary
Durability and Maintainability	Primary	Secondary (100 points)	Primary

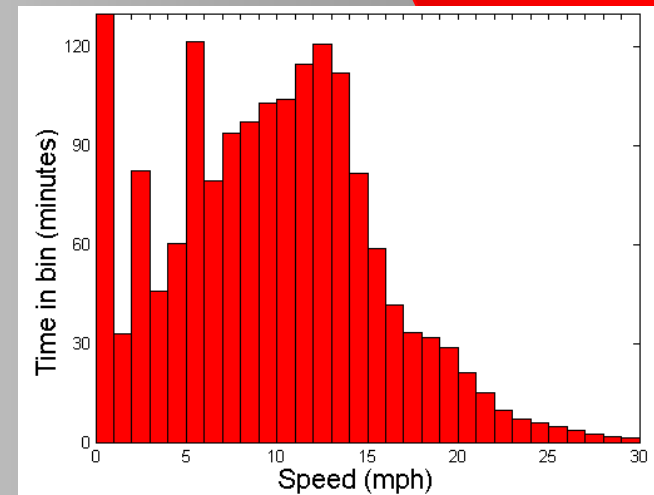


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Greenland 2008 Summary

- Most trips are short
 - Typical trip: Big House or Balloon Barn to Sat Camp
 - 2.2 km (1.4 mi) round-trip
 - Trip length: (of 72 trips >0.1 mi in a ten day period)
 - 47 \geq 0.5 mi, 14 \geq 1.0 mi, 6 \geq 2 mi, 3 \geq 3 mi.
 - Longest trips – 6 mi round-trip
- Total usage
 - 341 km (212 mi) in 57 days (4 mi daily average)
 - 26 hr of operation (non-zero speed)
 - Mean speed 13 km/hr (8 mph)
- Practical range
 - 5-10 mi with a 1500 lb towed payload
 - 2x-3x reduction from maximum unloaded range





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Specific Design Goals

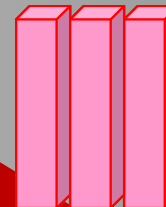
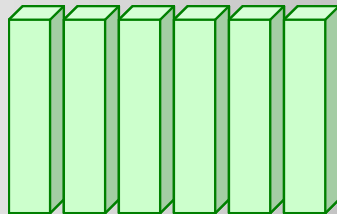
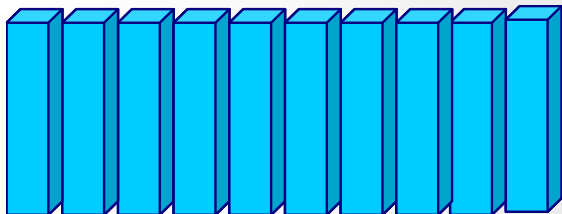
Parameter	Competition Goal	UW Goal	UW Achieved
Range	≥ 16 km (10 mi)	≥ 32 km (20 mi)	20 km (12.4 mi)
Top Speed (ZE goal)	≥ 70 km/hr (20 mph)	≥ 140 km/hr (90 mph)	≥ 120 km/hr (76 mph)
Acceleration (150 m)	≤ 12 s	≤ 10 s	6.9 s
Emissions	Zero	Zero	Zero
Weight		≤ 340 kg (750 lb)	320 kg (709 lb)
Drawbar Pull		≥ 250 kgf (550 lbf)	250 kgf (550 lbf)
Noise (IC)	≤ 78 dB	≤ 60 dB	55 dB



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Battery Selection



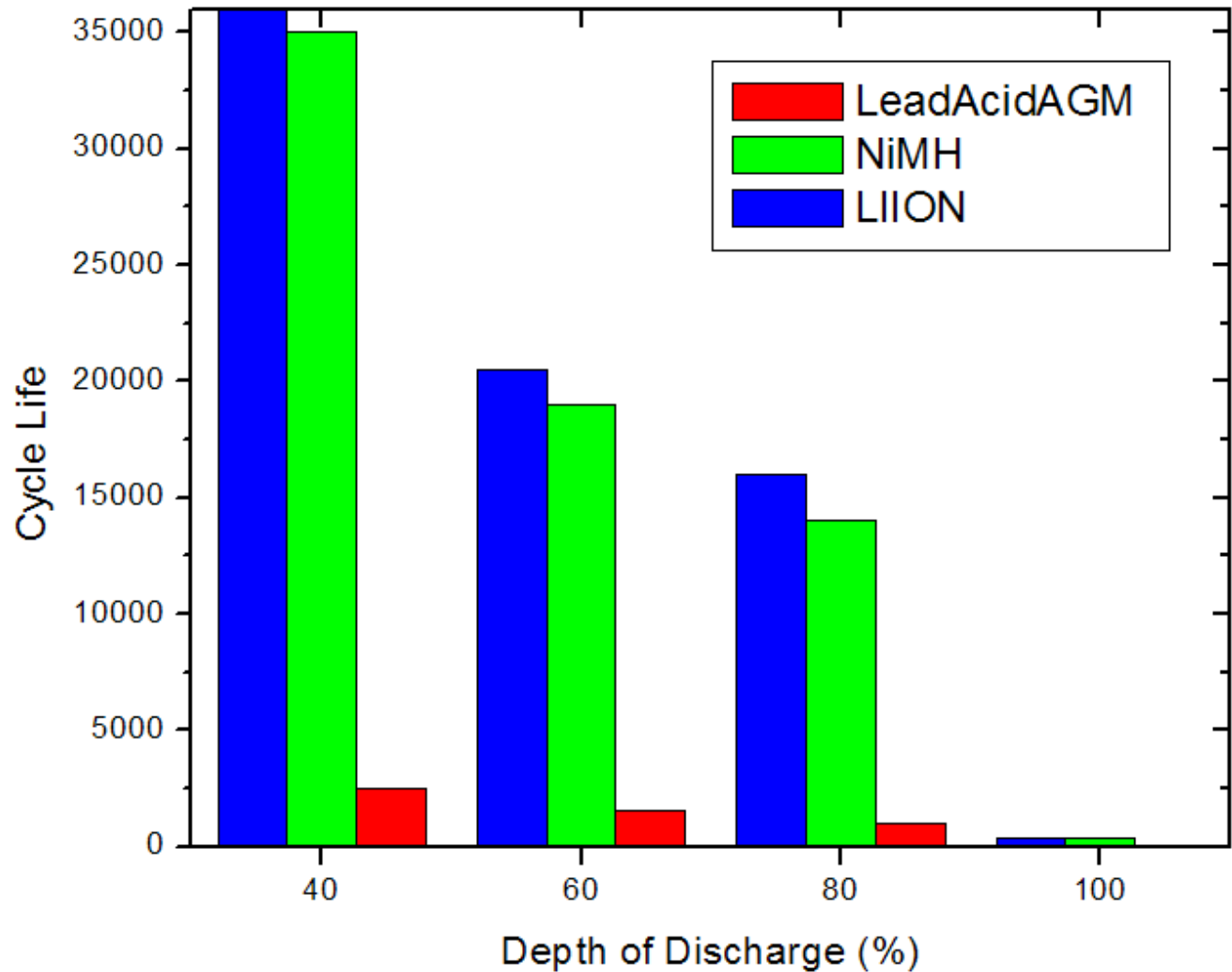
Nickel Metal Hydride	Lead Acid	Lithium-Ion
1.25 Volts/Cell	2.12 Volts/Cell	4.00 Volts/Cell
364 V → 291 Cells	364 V → 172 Cells	364 V → 91 Cells



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Battery Packaging Enhancements

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Milwaukee Tool V28 Li-Ion Battery Modules

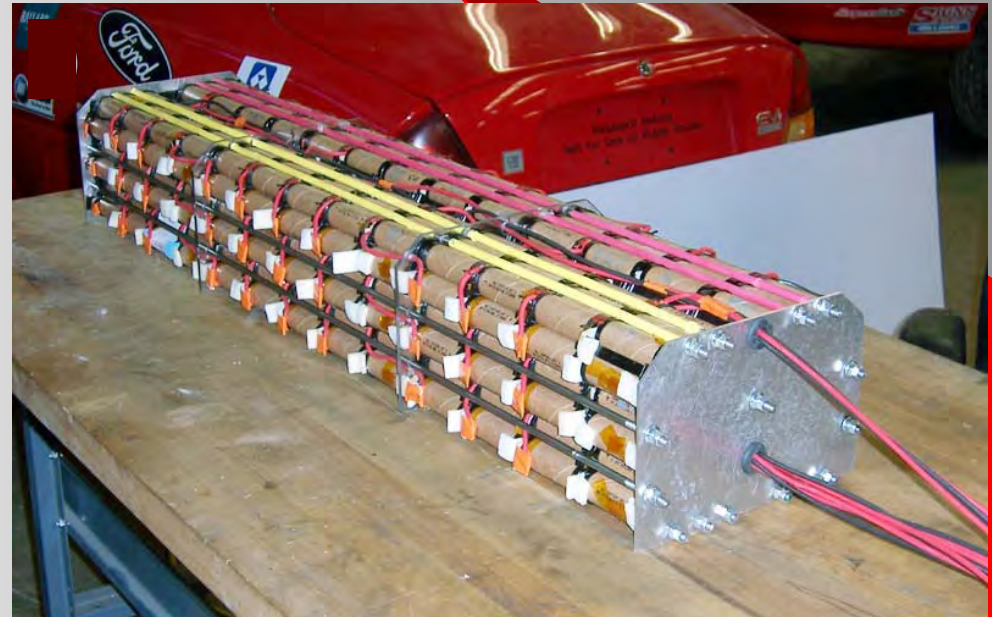


Old Design (Side Pod)

7 strings x 12 Modules

6.5 kW-hr @ 336 V_{nominal}

90 kg (198 lb)



New Design (Under-seat Pod)

8 strings x 13 Modules

8.2 kW-hr @ 364 V_{nominal}

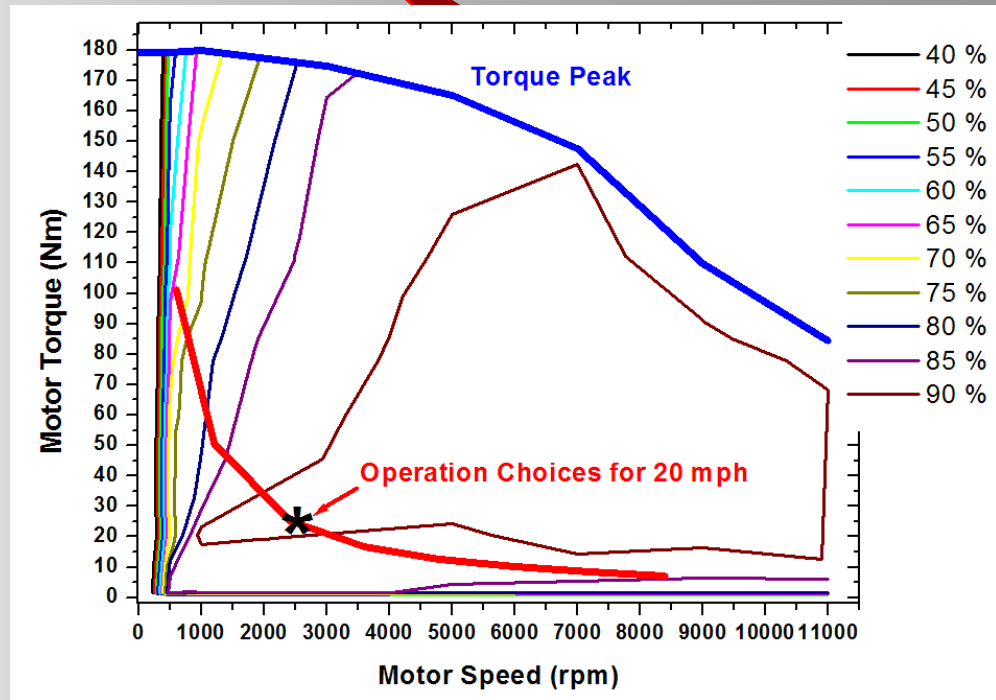
84 kg (185 lb)



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Delphi EV1 Motor

AC Induction



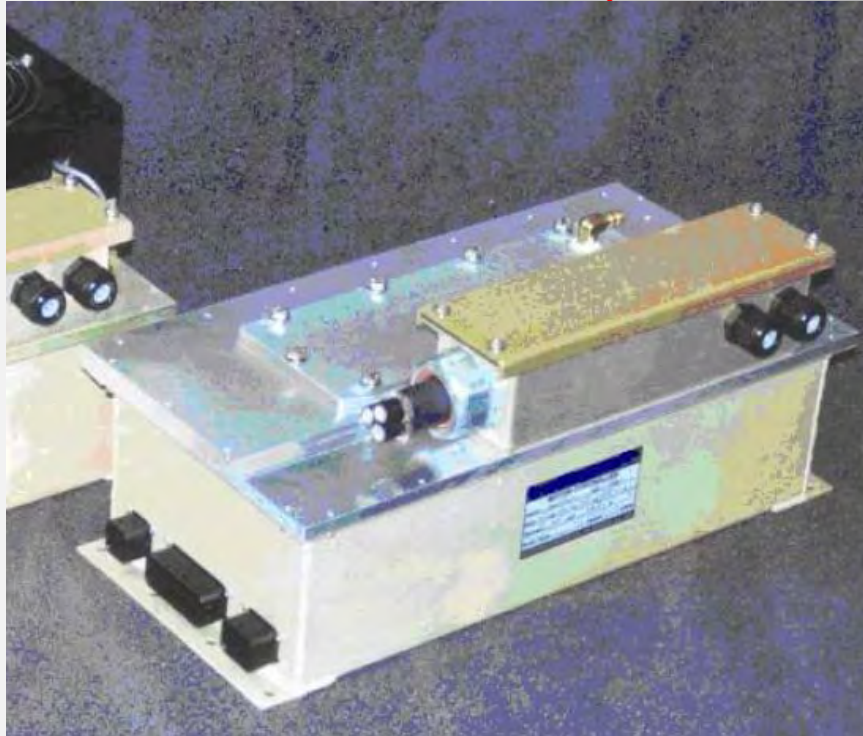
100 kW continuous

$\geq 90\%$ efficient



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Motor Controller



Azure DMOC445LC Motor Controller



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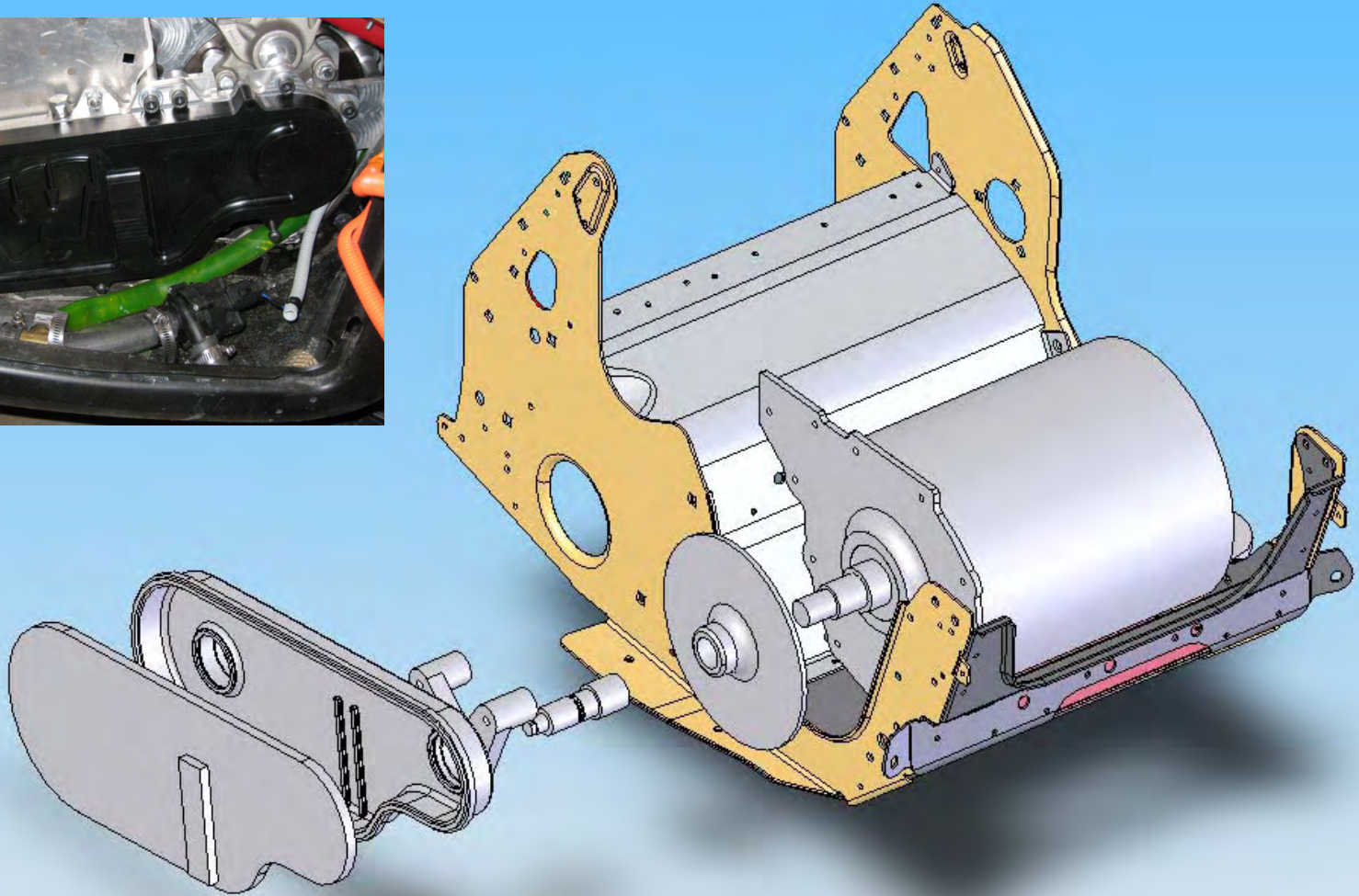
Powertrain Implementation

	Cost (x1)	Strength (x1)	Simplicity (x1.5)	Reliability (x1)	Factor Sum	
Belt	7	8	8	9	8.0	
Chain	7	9	6	8	7.5	
Gear	4	10	4	9	6.5	



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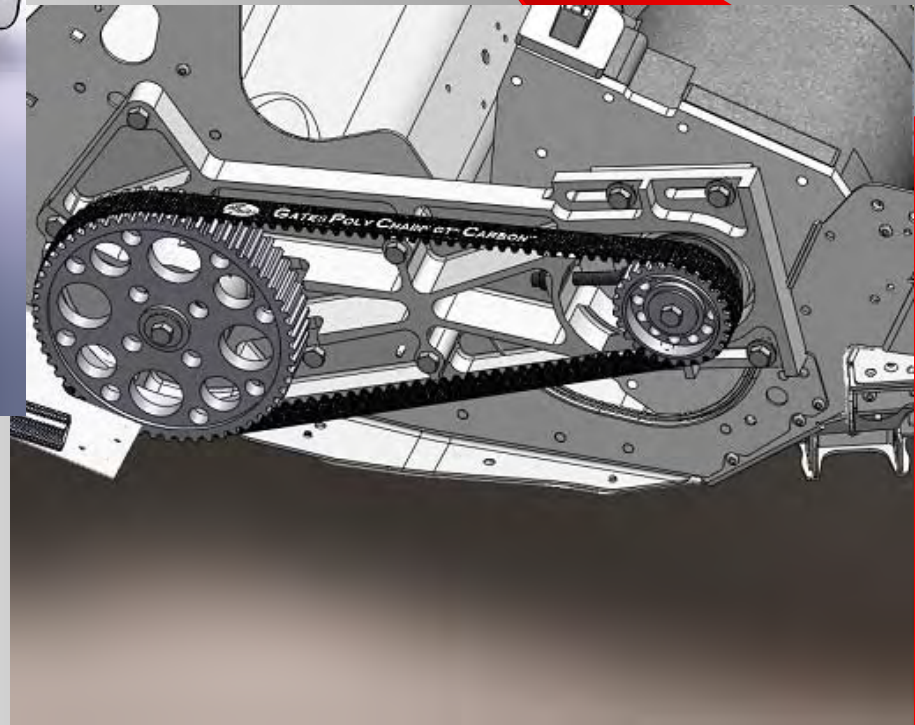
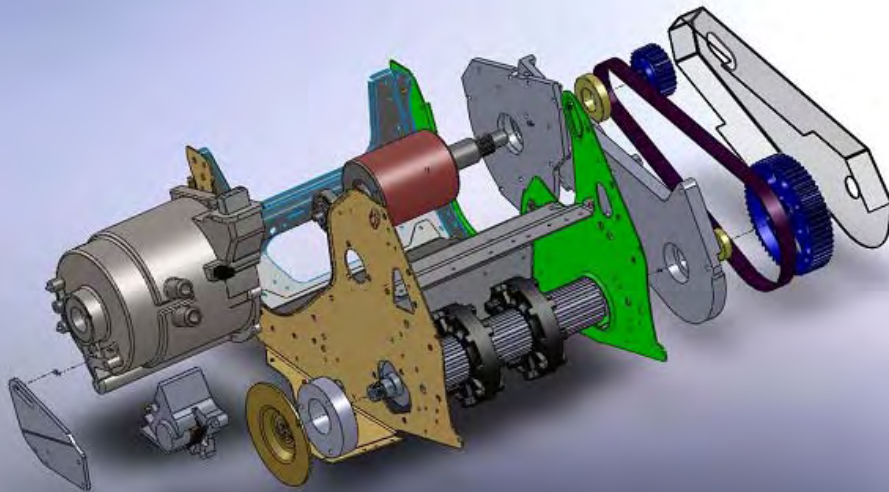
2008 Drivetrain





2009 Gen2 Drivetrain Concept

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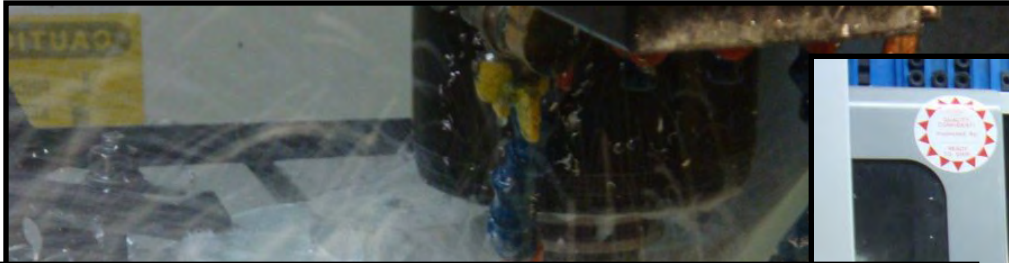




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2009 Gen2 Drivetrain Implementation

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Chassis Change Next Year



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Vehicle Management

- Monitors:
 - Battery: V , I_{string} , T_{string} , HV isolation
 - Motor/Inverter: τ_{actual} , $T_{mot/inv}$, faults
 - Vehicle Speed
 - Rider torque and brake cmd



- Controls
 - Motor torque
 - Coolant circulation pump
 - Cruise control
 - Main battery contactors
 - Indicators/gauges

MotoTron Powertrain Control Module Ratings

Automotive/Marine

-40° to 130 ° C

18 g Shock Load

Immersion to 3 m underwater

MATLAB Simulink Control Models
MotoHawk Automatic Code Gen

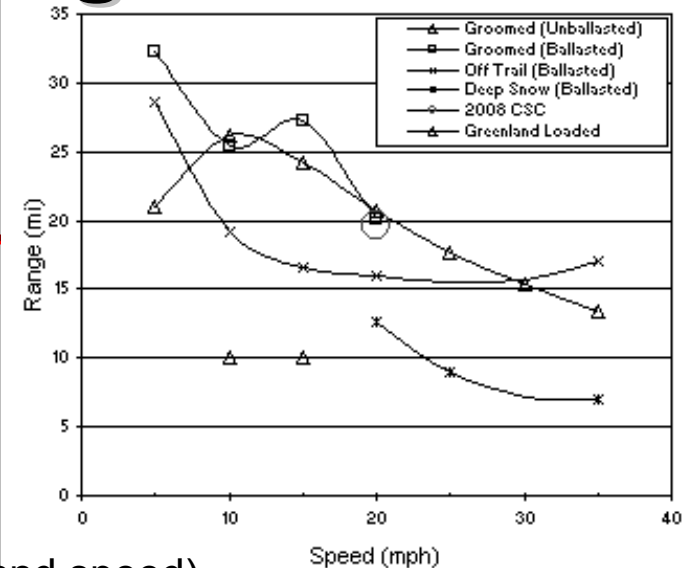


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2008 Range

- Pack Capacity
 - 19.6 A-hr → 6.5 kW-hr
- Road load
 - Initial model [Auth] – 4.6 kW at 20 mph
 - Testing (reduced pack and ballast)
 - **Extremely** variable based on snow conditions (and speed)
 - 6 kW at 20 mph (packed trail)
 - 7 kW at 20 mph (another packed trail)
 - 8 kW at 20 mph (deep snow)
 - 10 kW at 20 mph (6-8" soft packed snow)
- Predicted range
 - 20 mi absolute maximum (optimal conditions, full discharge)
 - 15 mi practical range (typical conditions, limited discharge)
- Achieved range
 - 18.4 mi (20 mph on hard-packed trail)
 - 360 W-hr/mi

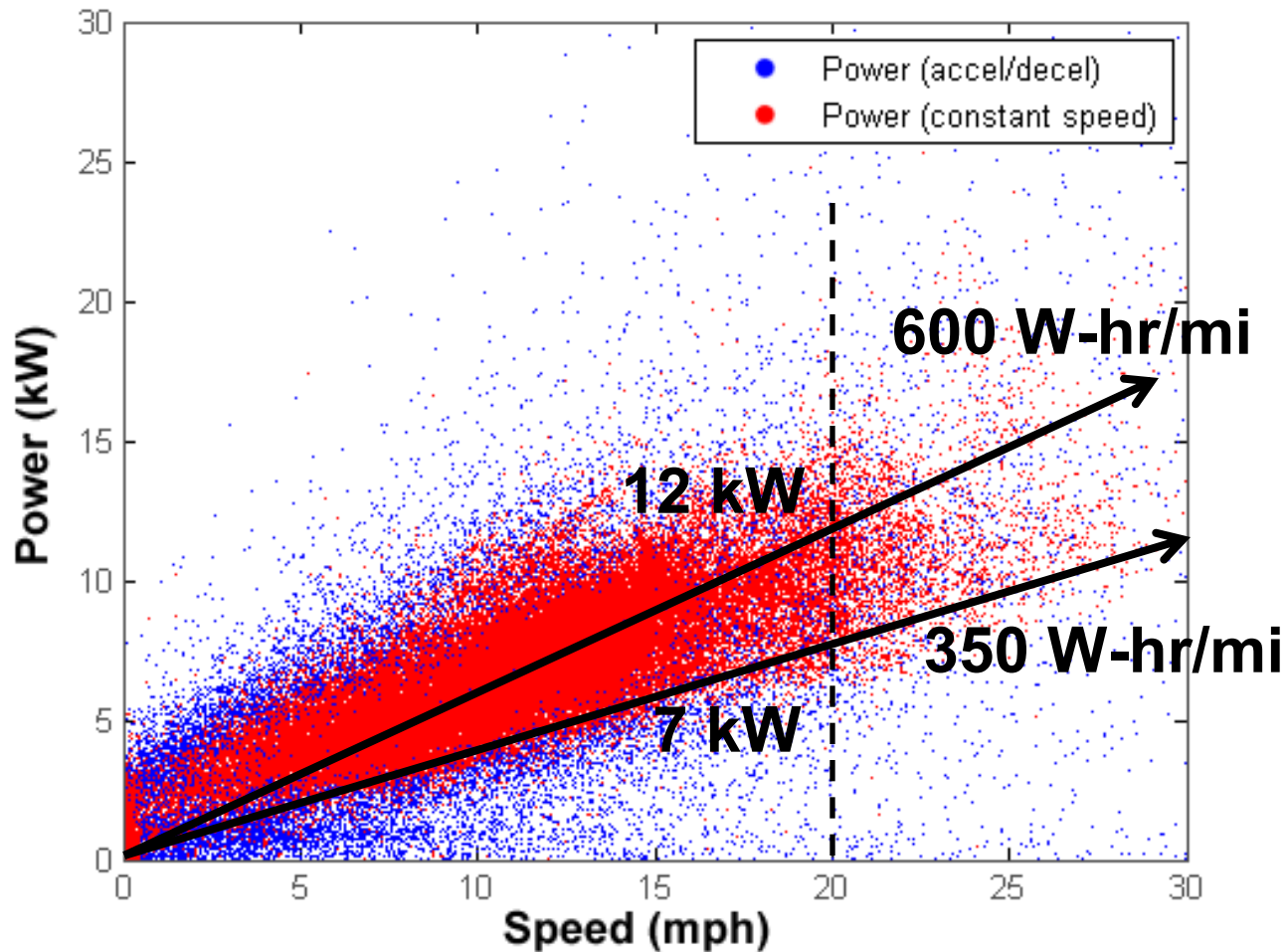




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Greenland Road Load Measurement





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2009 Range

- Pack Capacity
 - 24% increase in energy (6.5 → 8.1 kW-hr)
- Road load
 - Sled unchanged from '08
 - Snow conditions much poorer than '08
 - Soft wet snow leads to 2x-3x road load
 - (comparable to pulling trailer)
- Predicted range
 - Optimal conditions: 40 km (24 mi)
 - Expected competition conditions: 26 km (16 mi)
- Achieved range
 - 12.4 mi
 - Extremely poor course conditions (8" standing water) – 550 W-hr/mi
 - Batteries did not yield expected capacity (18.7 instead of 22.4 A-hr)



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Sound Testing

	Left @ 50 ft	Right @ 50 ft	Rider's Head
15 mph	55 dB	57 dB	76 dB
30 mph	58 dB	59 dB	82 dB

Competition Test

SAE Standard

Based on mean peak sound level (dBA fast response) of 4-6 constant speed passes, background level ≤ 40 dB

Snow conditions: 2" soft powder on crust above 4" of packed powder



Acceleration



Beats competition IC minimum of 12 s to 500 ft
2008: 8.34 s to 500 ft (2nd place overall – best non-studded)
2009: 6.90 s to 500 ft (predicted)
Studded track with 96 Woody's Gold-Digger 1.075" studs



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Handling



2008 results

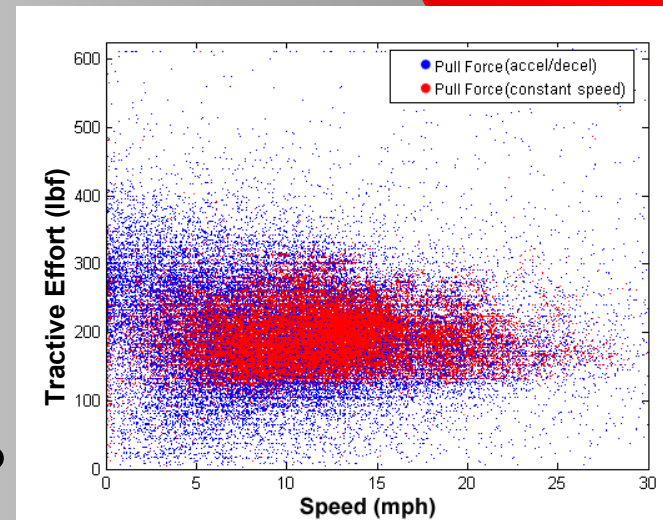
Within 0.09 s of best “Objective Handling” time (overall)
Won “Subjective Handling” (overall)

Towing Capacity



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- Traction dominated
 - 2008 scores ordered by weight
 - Weight hurts every other aspect
 - ↓ range, ↓ acceleration, ↓ handling, ↓ load capacity
- Maximum tractive effort of electric drive
 - 275 kgf (650 lbf)
 - Maintained up to 35 mph (unlike DC motor solutions)
 - 206 kgf (455 lbf) officially achieved
- Solutions
 - Adjust weight balance aft
 - Moved more batteries under seat
 - Improve coefficient of traction
 - Studded track
- How necessary are pull forces $\gg 300$?





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Estimate state-of-charge (SOC)

• Battery terminal voltage model

- Voltage source
- Series resistance
 - R based on temperature
- Series RC element
 - τ, R based on temperature

• Estimate SOC based on

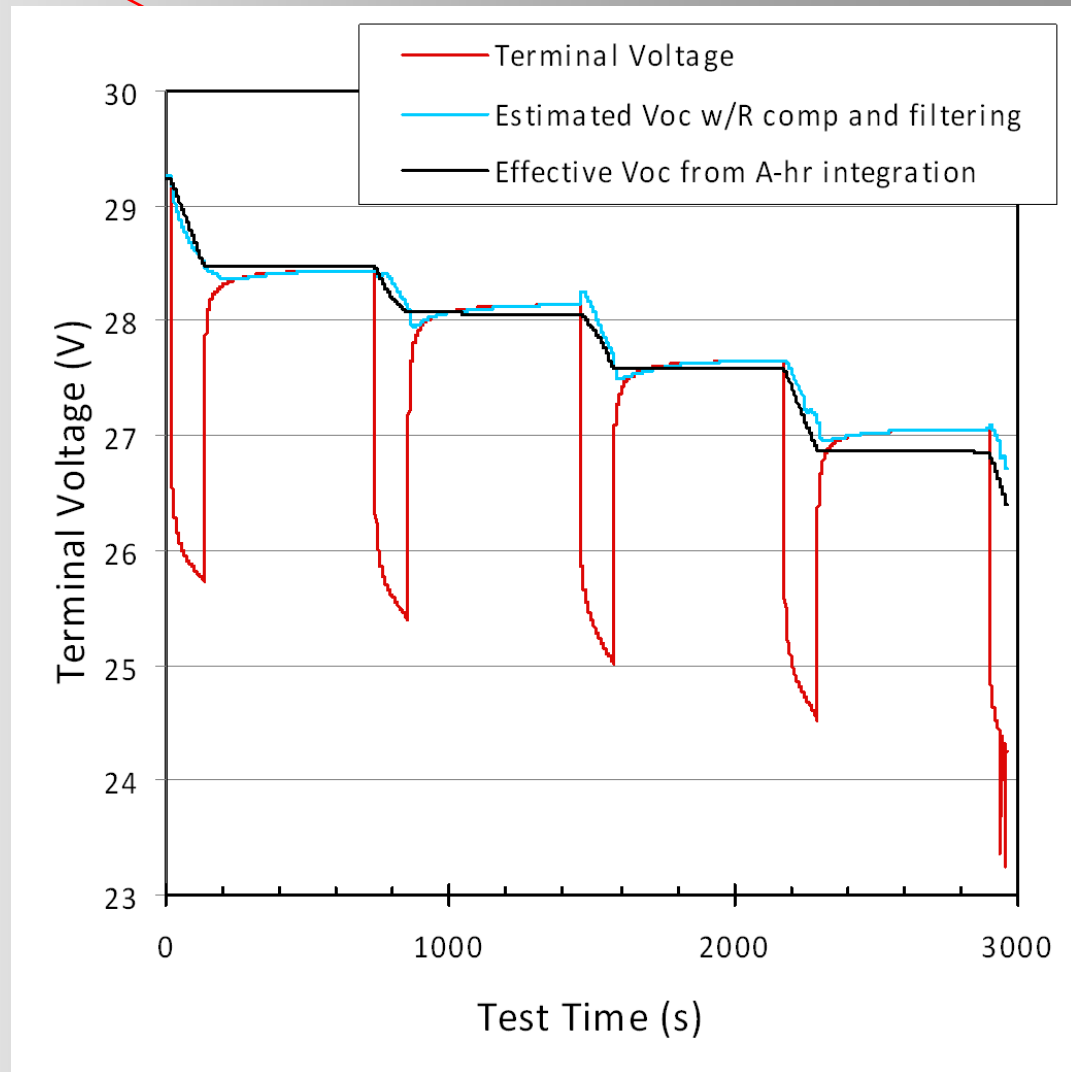
- V_{terminal}
- $I_{\text{instantaneous}}, I_{\text{LPF}}$
- Battery temperature

• Outputs

- SOC, DTE indications
- Warn rider at 10%
- Terminate operation at 3%

• Working with industry partners to obtain automotive/turn-key system for 2010

Battery Management



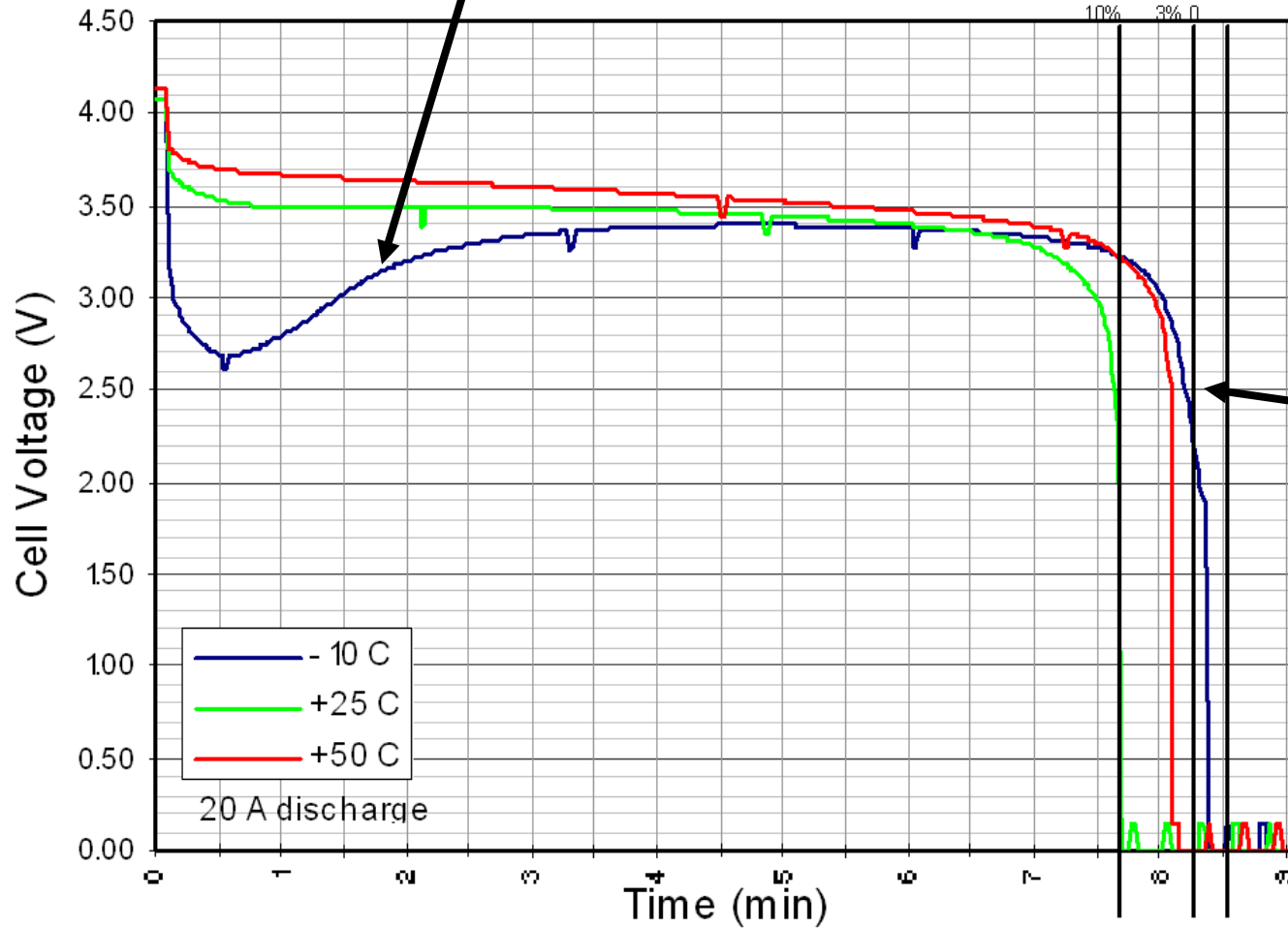


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Cold Performance

90% power available within 105 s



Nearly full capacity available

Rated by manufacturer at -10°C



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Goal Recap

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2008 Greenland Summer Season





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Questions?

