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University of Wisconsin Madison

2010 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 (100 points)	Secondary
Acceleration	None	None	Secondary
Noise	None	Primary (150 points)	Secondary
Cost	Primary	Minor (50 points)	Secondary
Durability and Maintainability	Primary	Secondary (100 points)	**Primary**

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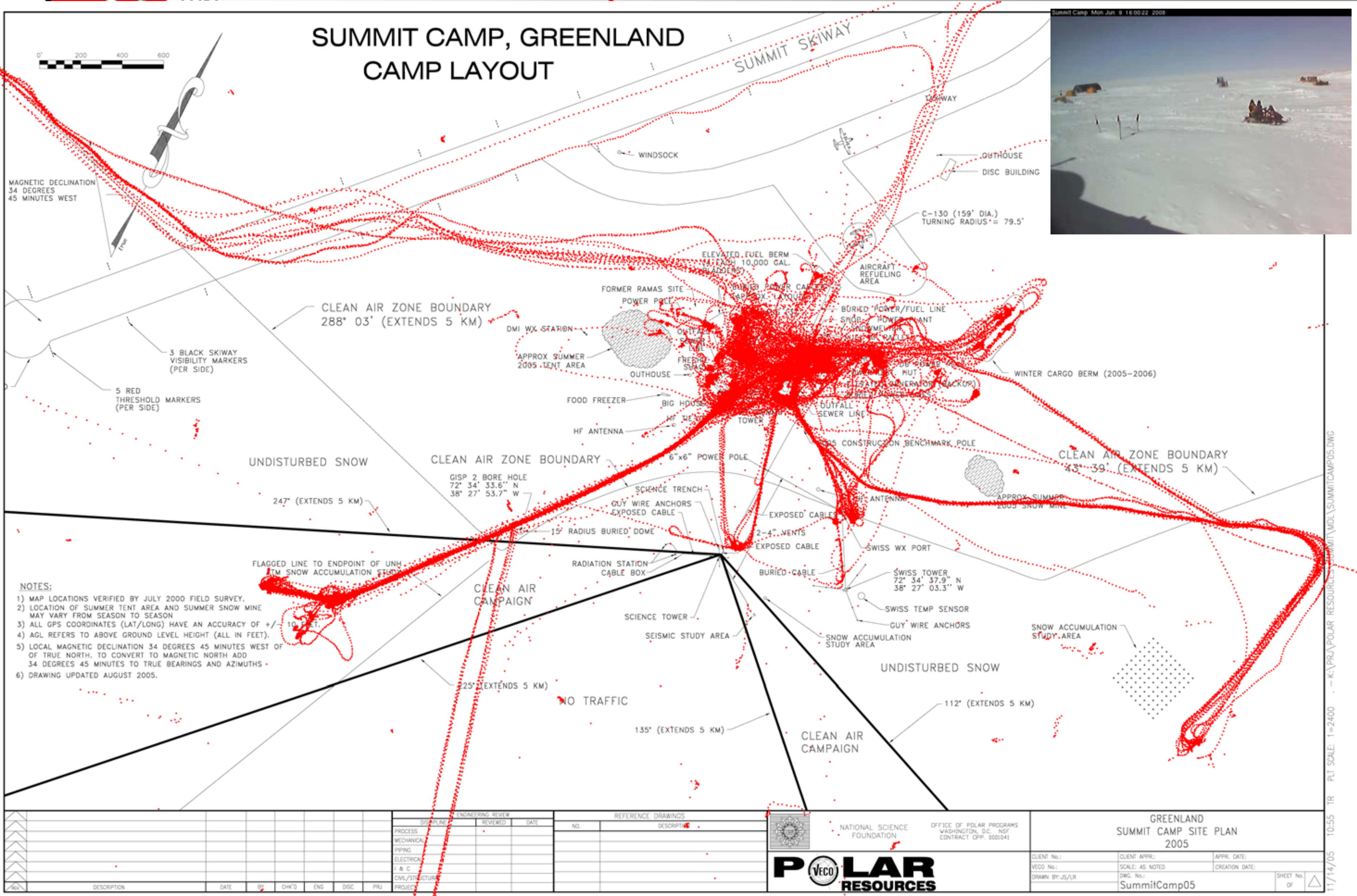
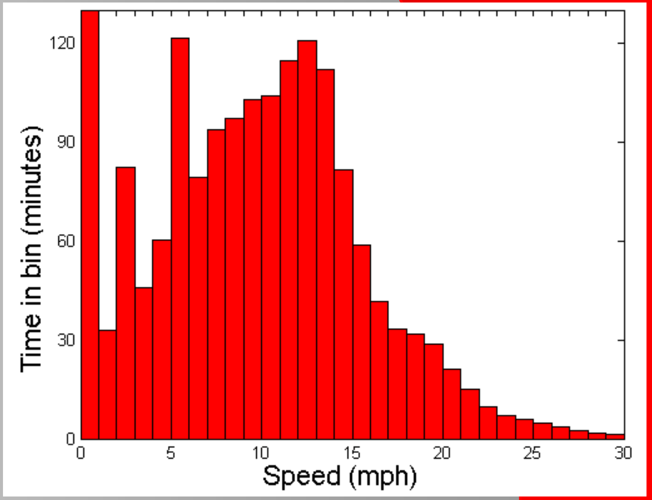
Greenland Summer '08 Trial



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 ≥0.5 mi, 14 ≥1.0 mi, 6 ≥2 mi, 3 ≥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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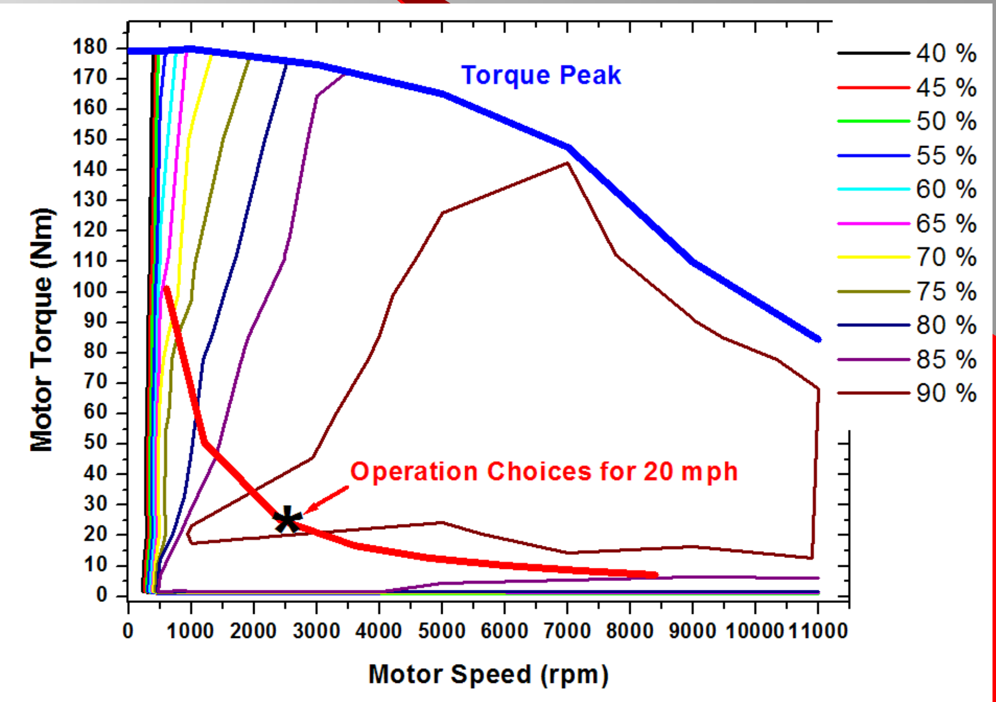
Specific Design Goals

Parameter	Competition Goal	UW 2010 Goal	UW 2010 Achieved
Range	≥ 16 km (10 mi)	≥ 40 km (24 mi)	13 km (8.2 mi)
Top Speed (ZE goal)	≥ 70 km/hr (20 mph)	≥ 120 km/hr (76 mph)	≥ 120 km/hr (76 mph)
Acceleration (150 m)	≤12 s	≤10 s	6.9 s
Emissions	Zero	Zero	Zero
Weight		≤ 320 kg (700 lb)	289 kg (637 lb)
Drawbar Pull		≥ 250 kgf (550 lbf)	250 kgf (550 lbf)
Noise (IC)	≤ 78 dB	≤ 60 dB	57 dB

Delphi EV1 Motor

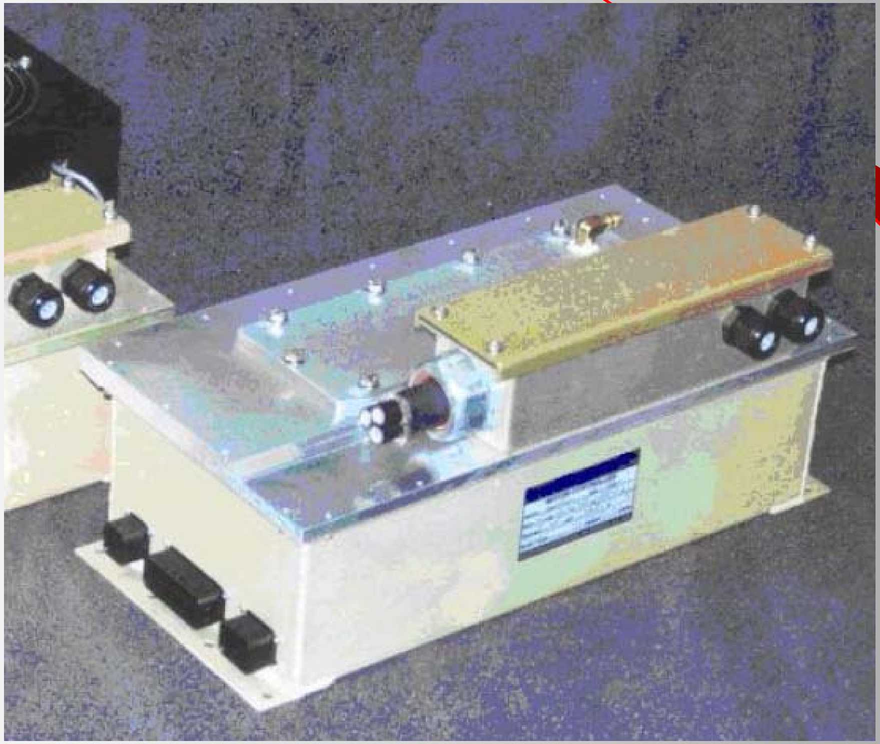
AC Induction



≥ 90% efficient

100 kW continuous

Motor Controller



Azure DMOC445LC Motor Controller

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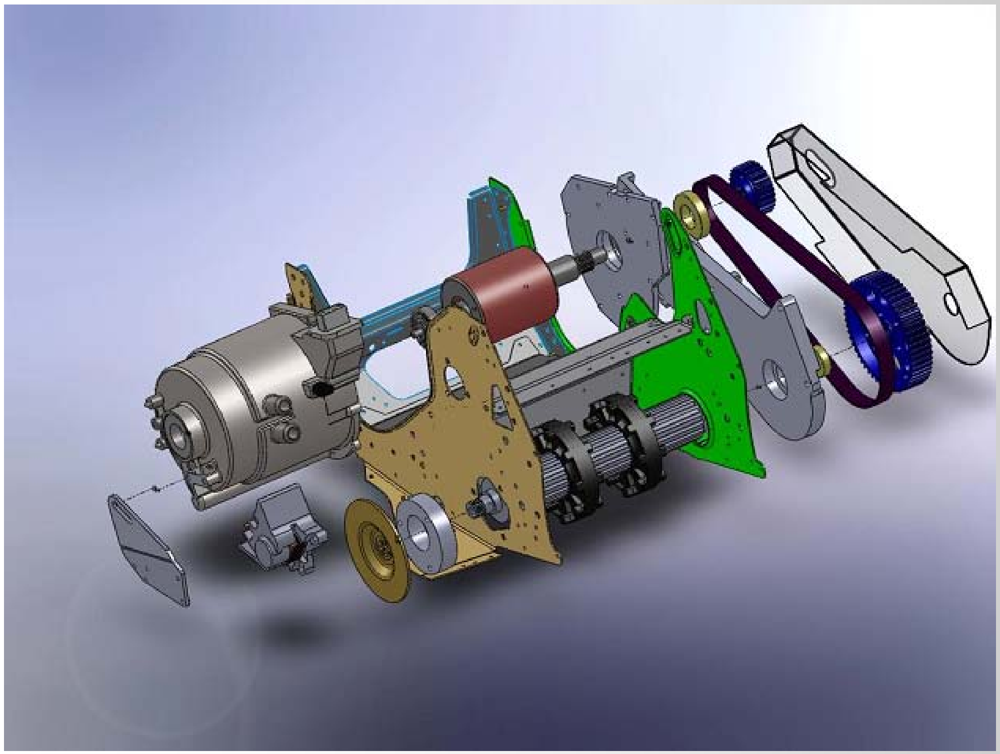
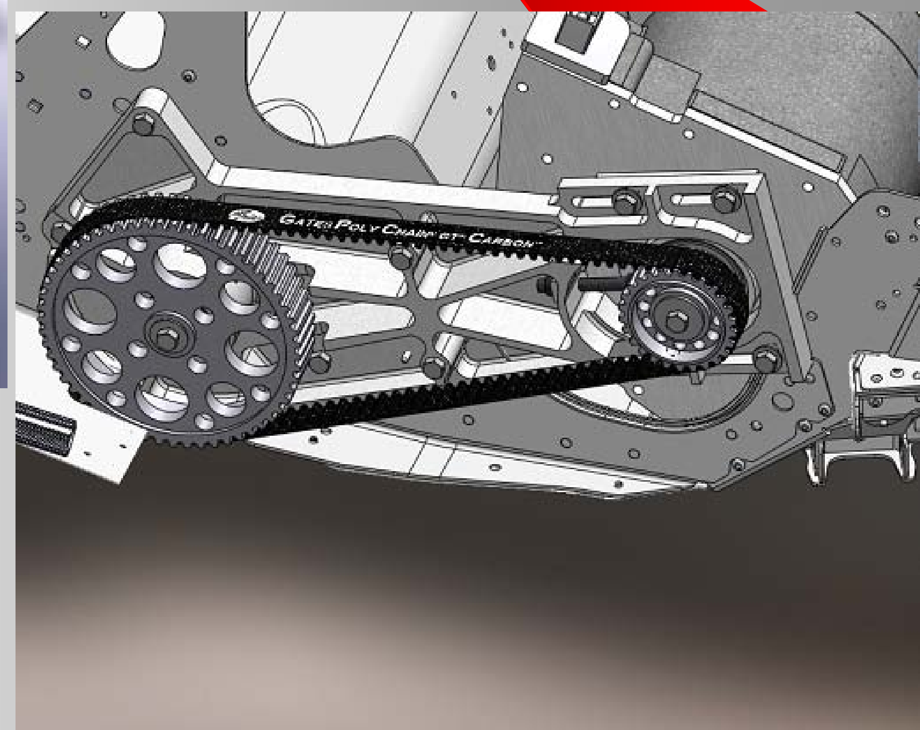
Powertrain Implementation

2009 Design

	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

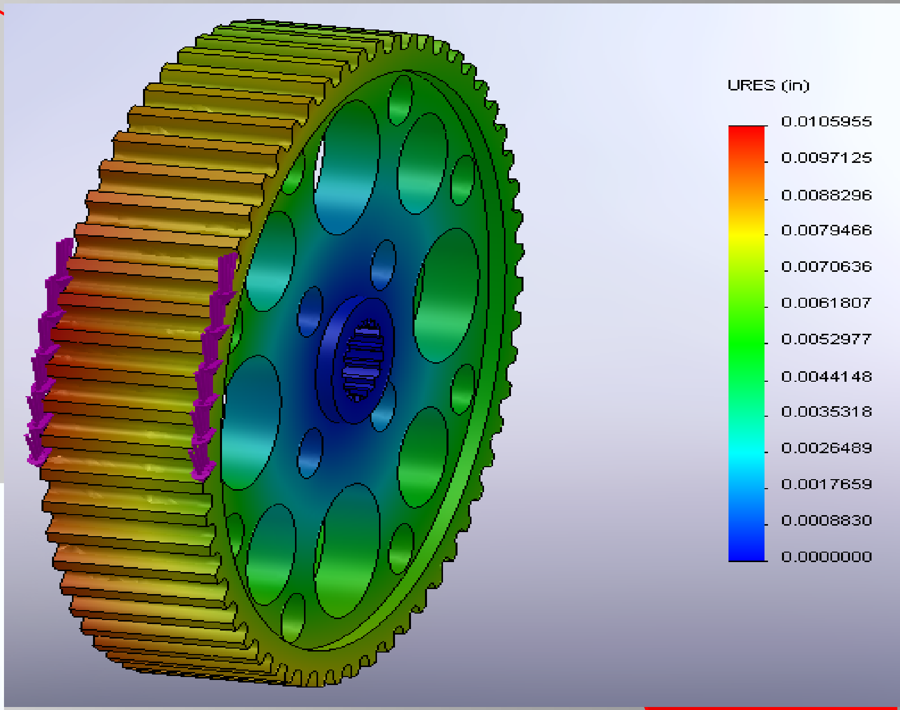
2010 Gen2 Drivetrain

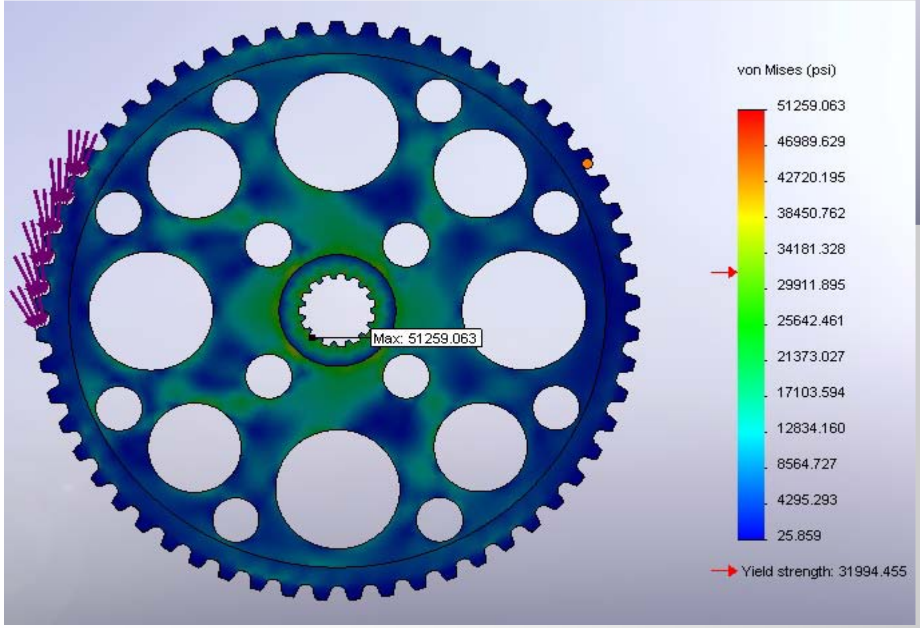




2010 Gen2 Drivetrain FEA

- Tested under static axial load of 2010 N (50% greater than EV1 max)
- Tested using dynamic load of 1423 N*m





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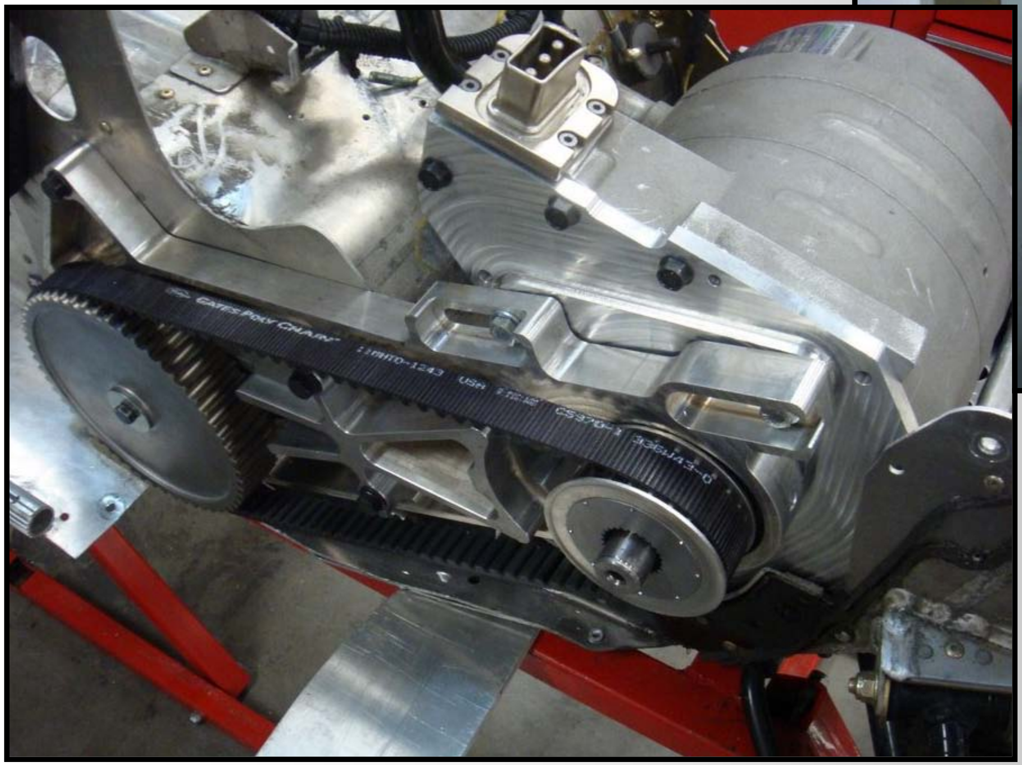
2010 Gen2 Drivetrain Implementation



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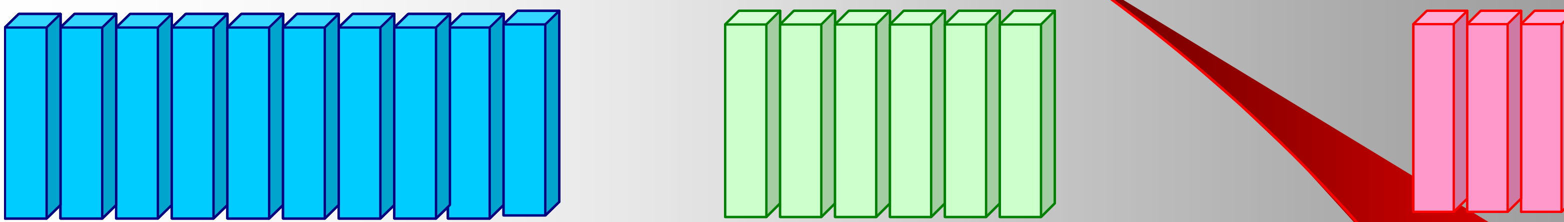
Battery Selection



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

Battery Selection

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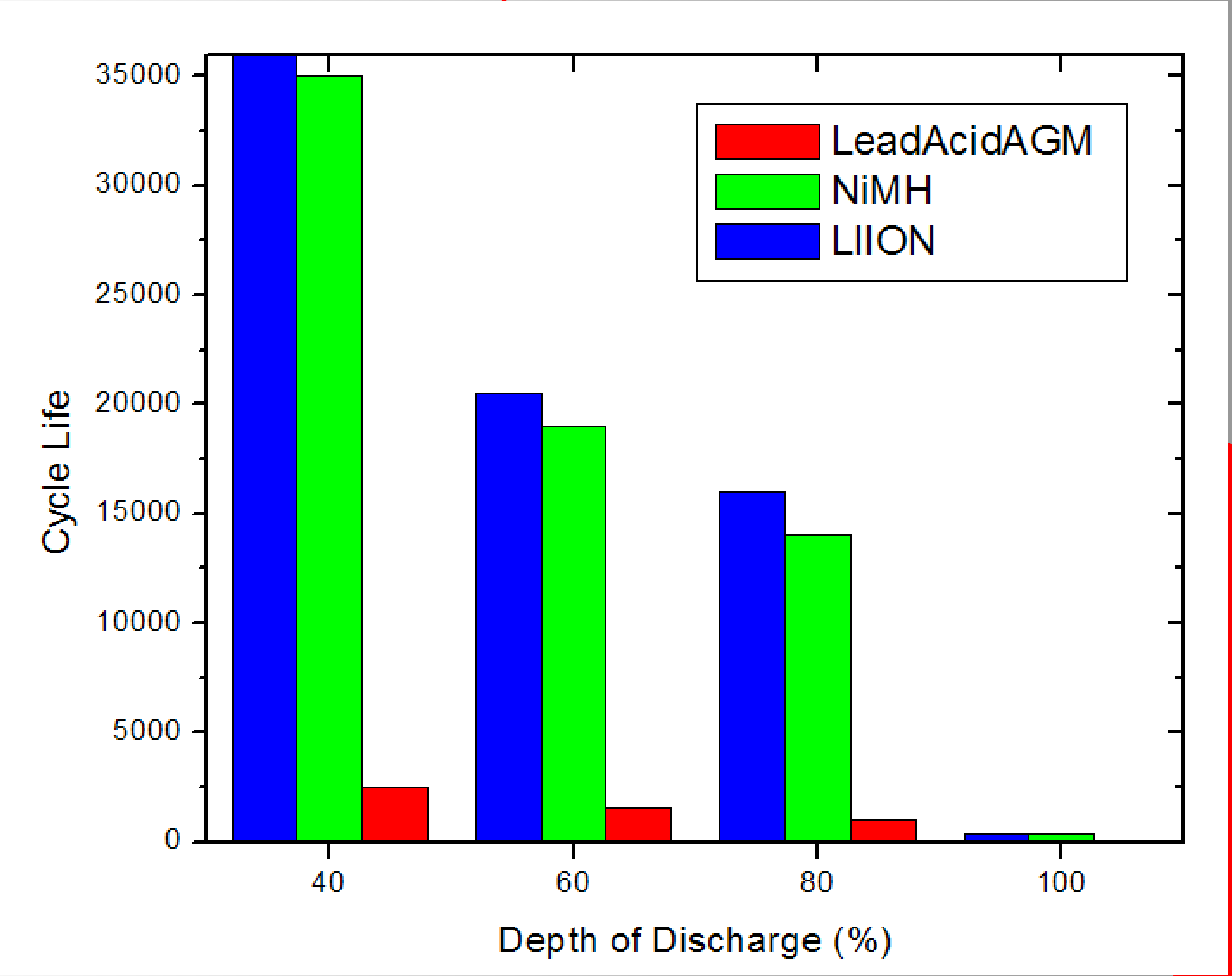

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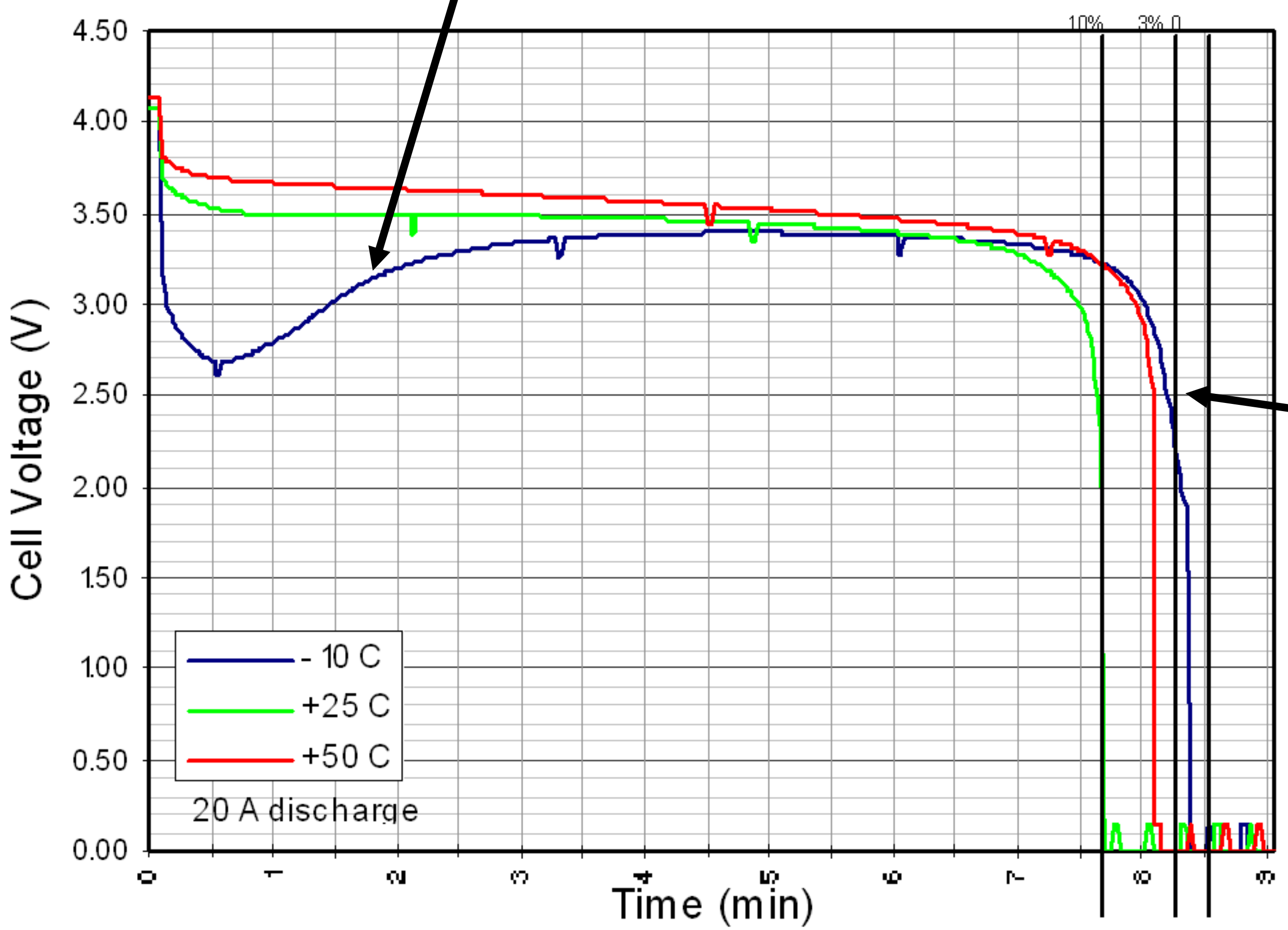
Cold Performance

90% power available within 105 s



Nearly full capacity available

Rated by manufacturer at -10°C

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Intended 2010 Battery Pack

- Pack built with A123 batteries
  - 356 $\text{Volts}_{\text{nominal}}$
  - Integrated BMS
    - Monitor and equalize cells
  - Aluminum casing
- Pack Capacity
  - 33% increase in energy (5.46 → 8.2 kW-hr)
  - 45% increase in charge (15→ 27.6 A-hr)
- Predicted range
  - Optimal conditions: 42 km (26 mi)
  - Expected competition conditions: 32 km (20 mi)

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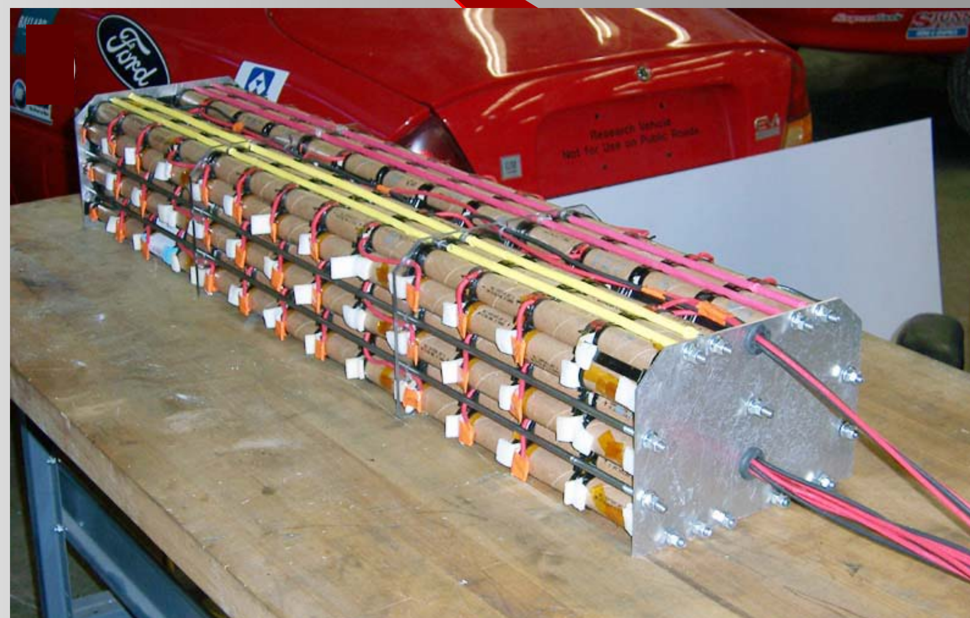
Battery Packaging Enhancements

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)

6 strings x 13 Modules
5.46 kW-hr @ 364 $V_{nominal}$
63.5 kg (140 lb)

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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

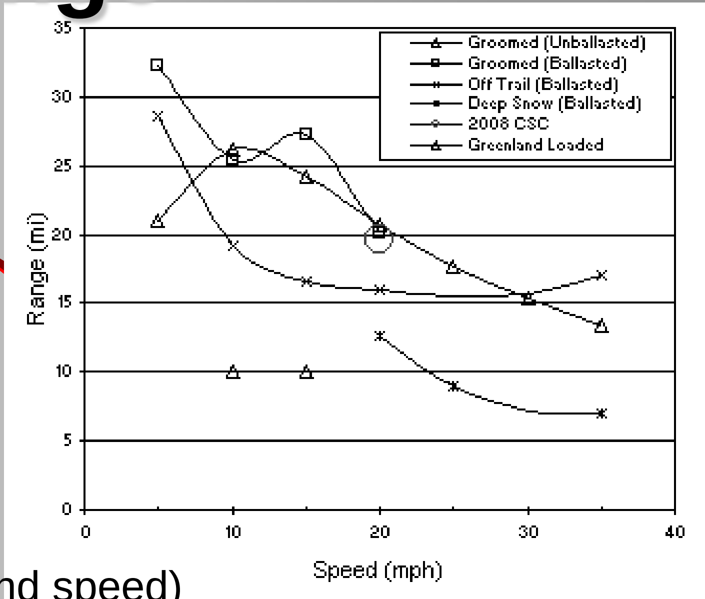
MotoTron
Powertrain Control Module

Ratings

Automotive/Marine
-40° to 130 ° C
18 g Shock Load
Immersion to 3 m underwater

MATLAB Simulink Control Models
MotoHawk Automatic Code Gen

2010 Range



- Pack Capacity
  - 15 A-hr → 5.46 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
  - 15 mi absolute maximum (optimal conditions, full discharge)
  - 10 mi practical range (typical conditions, limited discharge)
- Achieved range
  - 8.2 mi (20 mph on very sloppy trail)
  - 12 kW at 20 mph

Driveline Efficiency Testing

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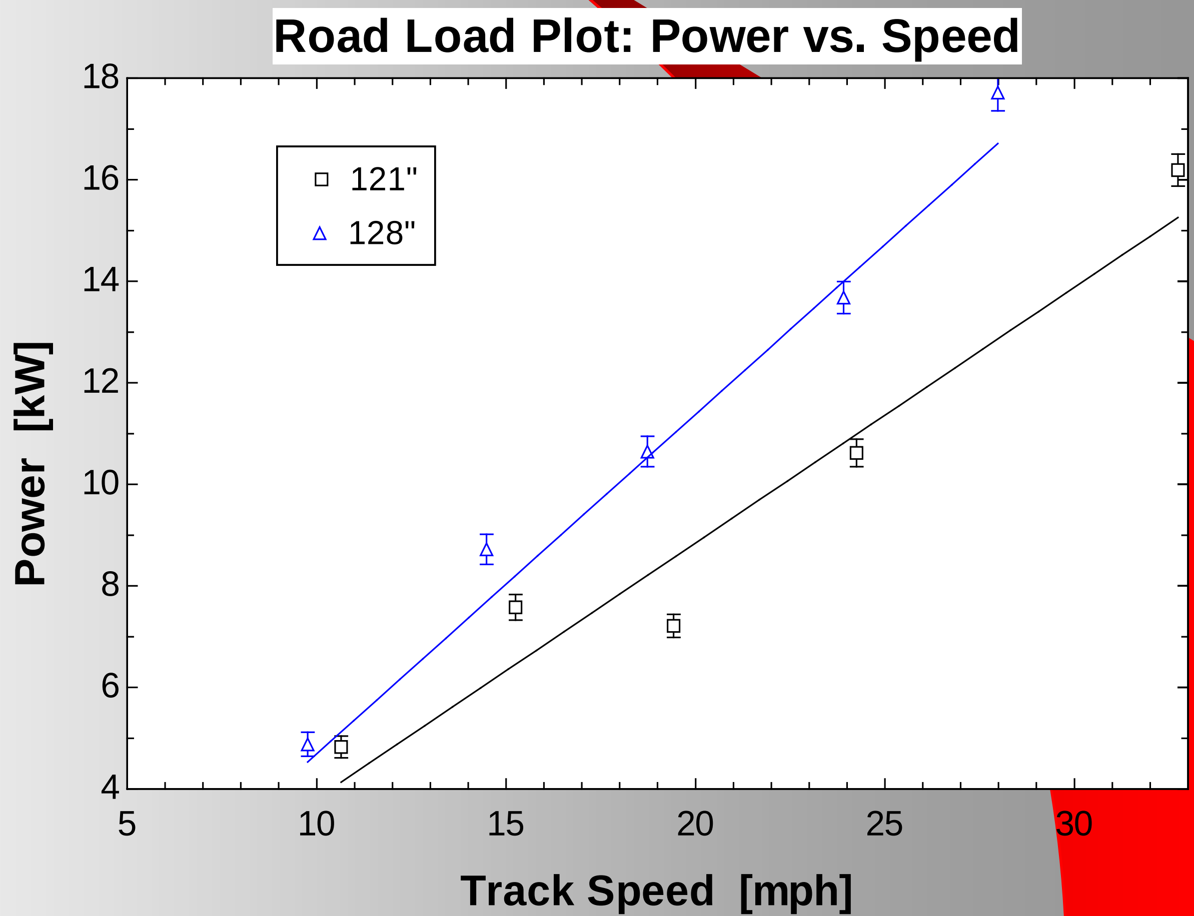
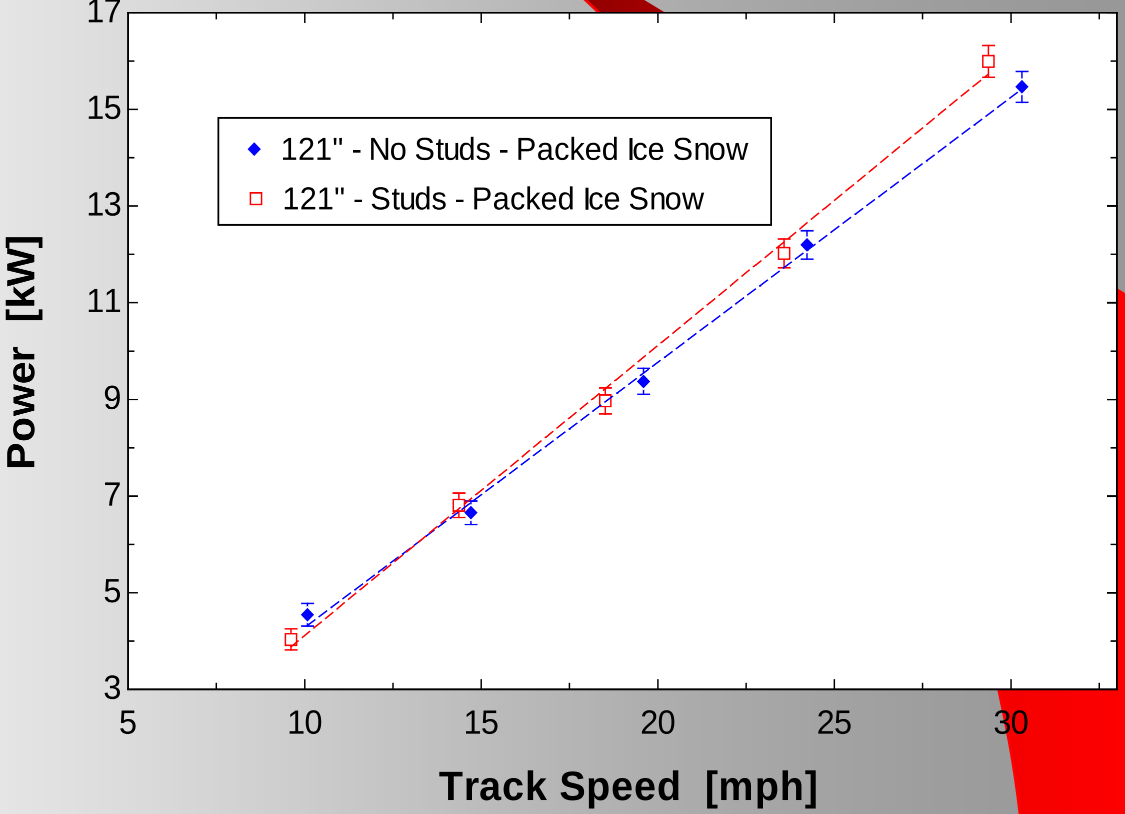
- Monitored Amps drawn and motor torque
- 128” track length standard on 2007 Polaris FST LX
- Found a 22% difference in power required to drive at 25 mph



Effect of Studs

- Tested same track studded vs. non-studded
- Found a 4% difference in power required to drive at 25 mph
- This impact was weighed against the positive aspects of studs

Road Load Plot: Power vs. Speed



Towing Capacity

- Traction dominated
  - 2008 scores ordered by weight
  - 2009 switched to studded track (won event)

- Maximum tractive effort of electric drive
  - 275 kgf (650 lbf)
  - Maintained up to 35 mph (unlike DC motor solutions)
  - 260 kgf (575 lbf) officially achieved

- Increased effort
  - Shifted all batteries aft to change weight balance
  - Again utilizing studded track

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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

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Handling

2009 results

- 5.25 s faster than any other E-sled last year (objective event)
- Won “Subjective Handling” (overall)

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Goal Recap

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Questions?

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Battery Management

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
    - $V_{terminal}$
    - $I_{instantaneous}$, I_{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 2011