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SAE Snowmobile Team

University of Wisconsin Madison

2011 SAE Clean Snowmobile Challenge

Electric Snow Machine Design Presentation

Presented by:

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Kim Ruiz

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Design Emphasis

Parameter	NSF Emphasis	CSC Emphasis	UW Emphasis
Range	Primary	Primary (100 points)	**Primary**
Towing Capacity	Primary	Primary (100 points)	**Primary**
Weight	Secondary	Secondary (100 points)	Secondary
Handling	Minor (safety only)	Secondary (100 points)	Secondary
Acceleration	None	Minor (50 points)	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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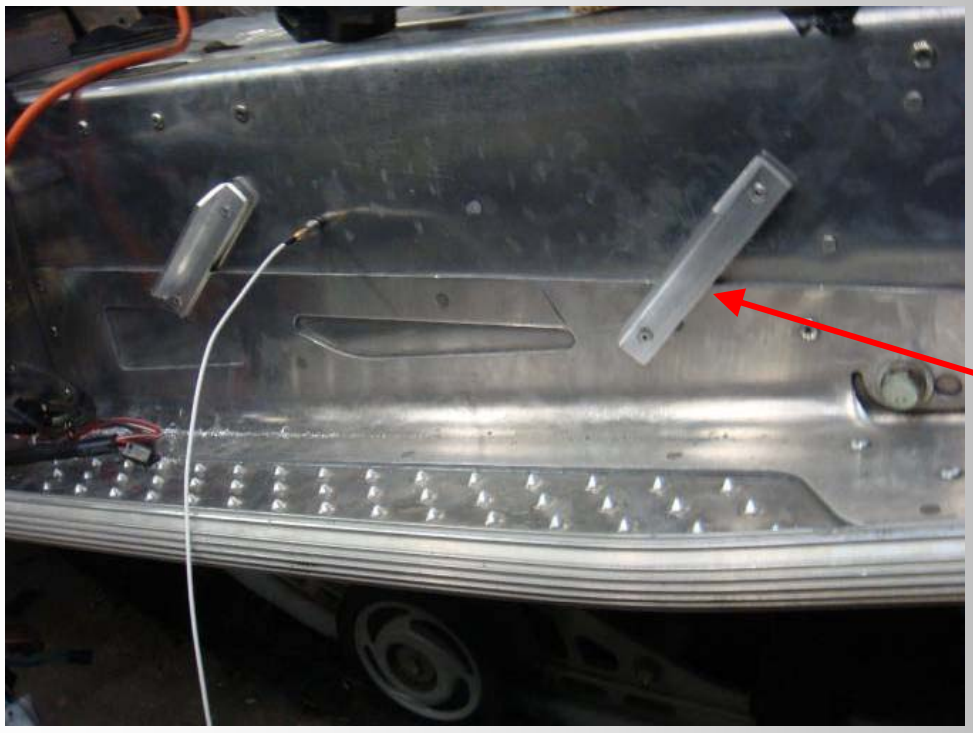
Quiet
FAST

Sound Reduction

Chassis



Tunnel Stiffeners

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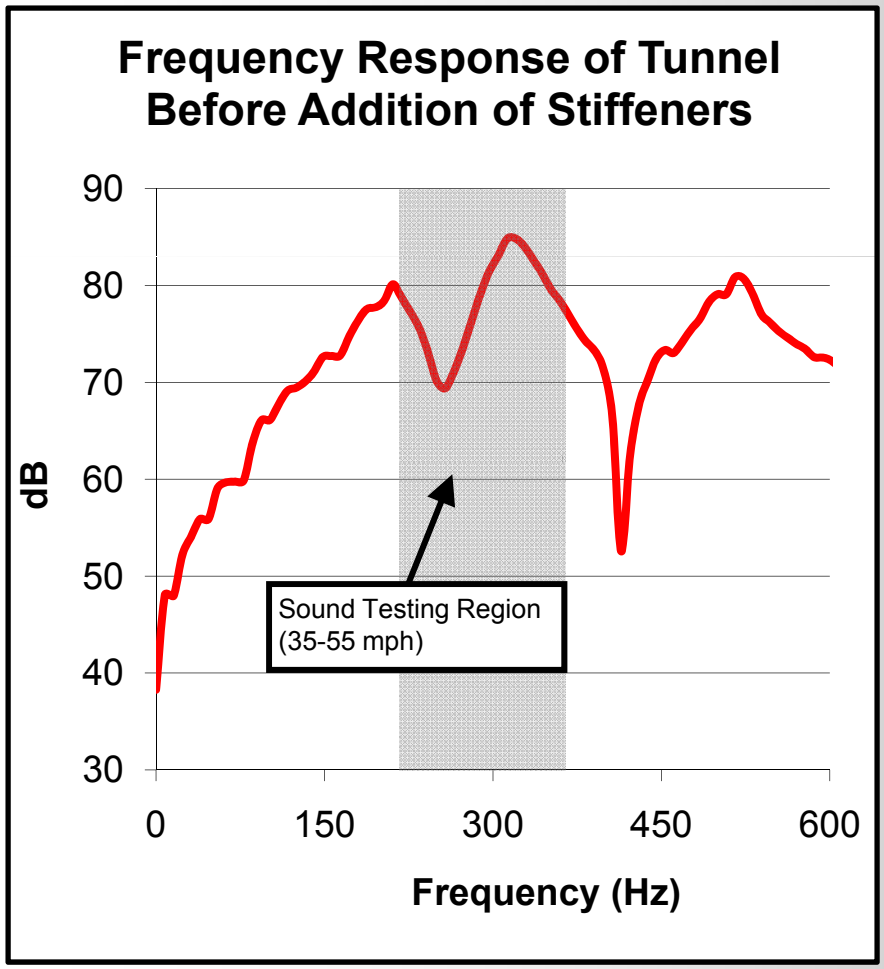
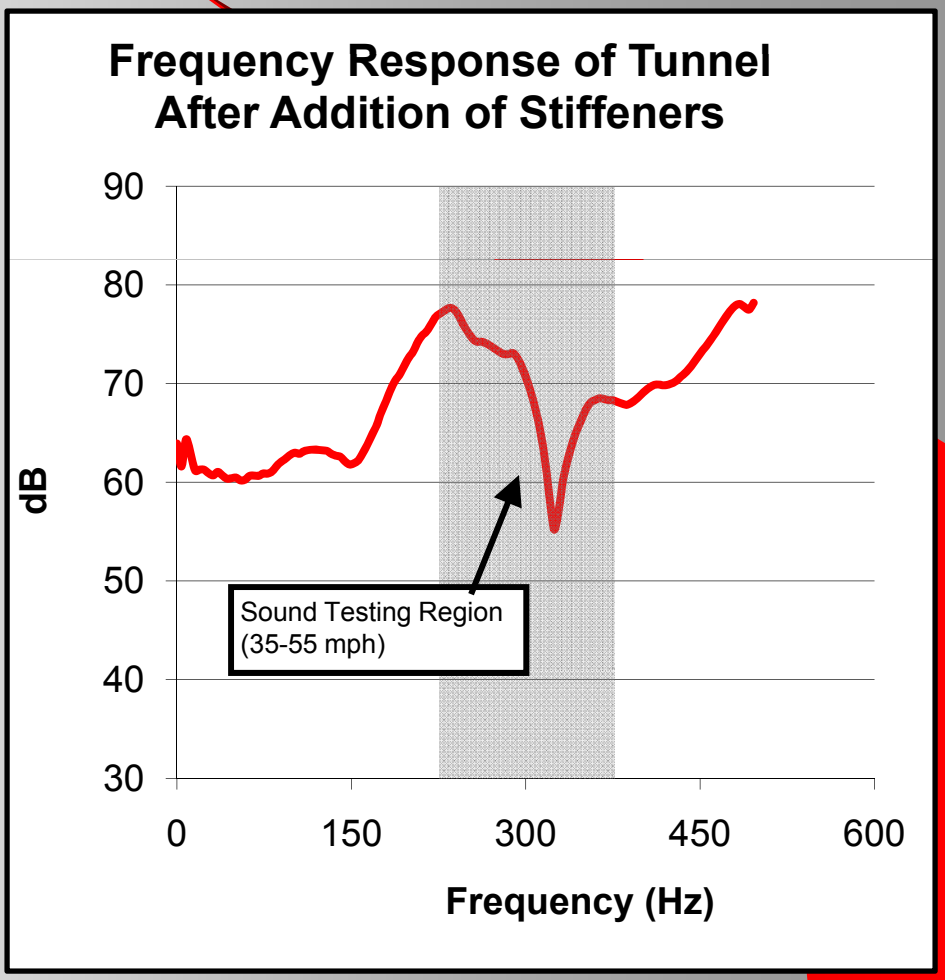
Resonance of Tunnel





Greenland Summer ’08 Trial

Clean
Quiet
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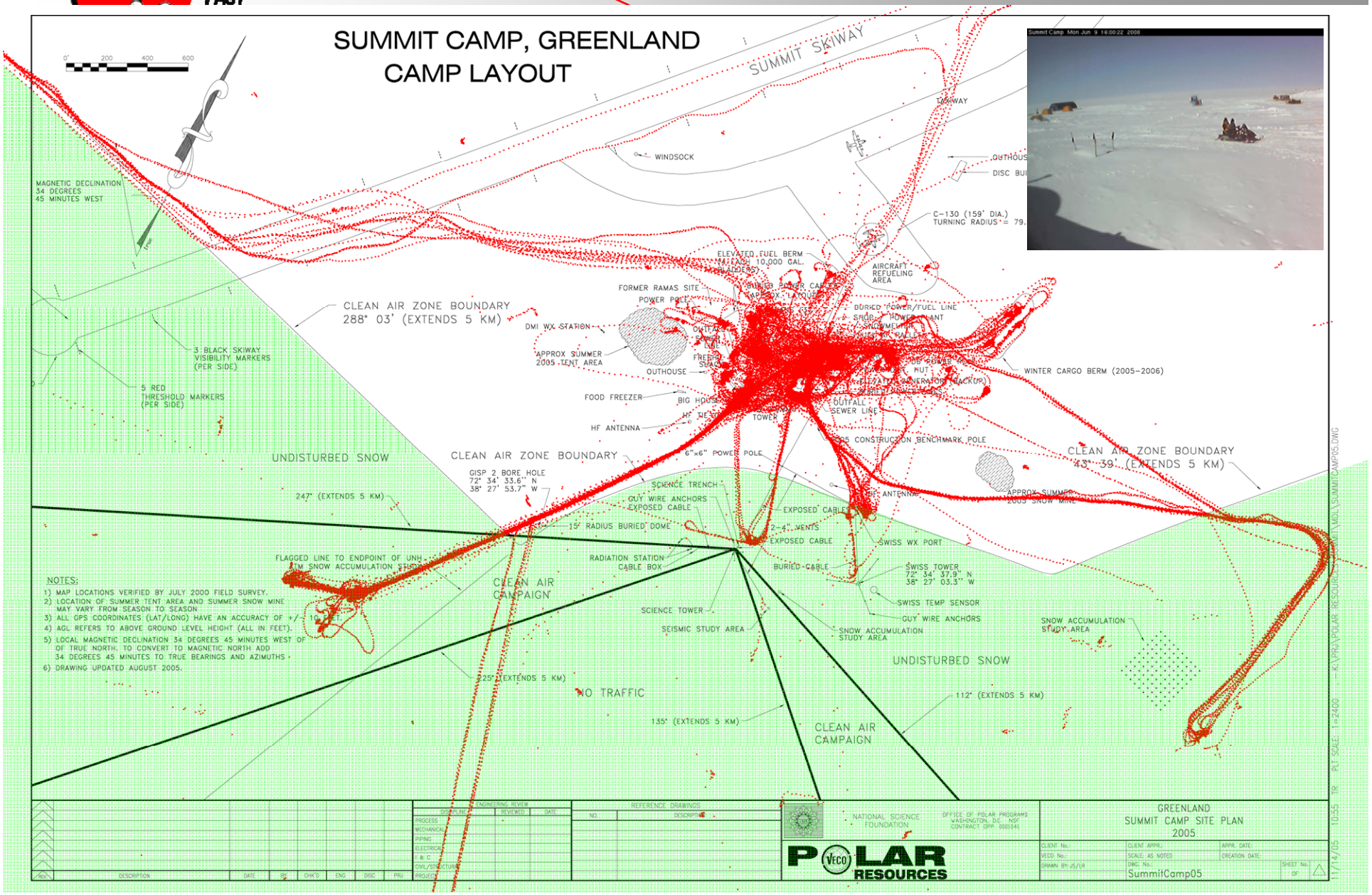

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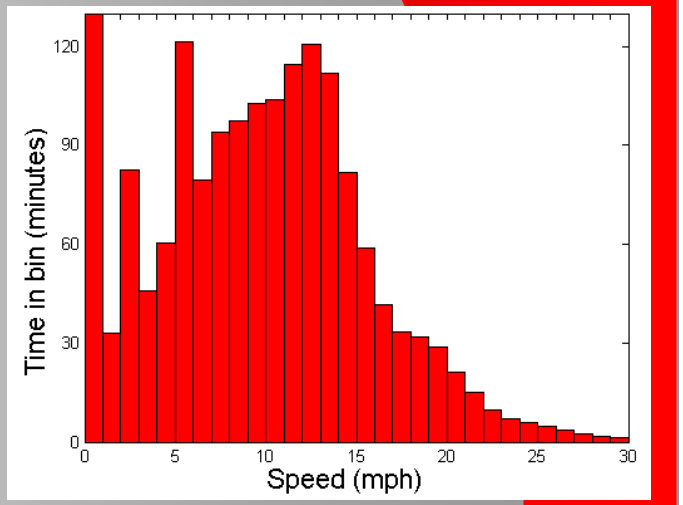
Greenland 2008/2009 Summary

- Total usage
  - 948 km (589 mi) in ~120 days (5 mi daily average)
  - 26 hr of operation in 2008 (non-zero speed)
  - Average speed 13 km/hr (8 mph) in 2008
- 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
- 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 Achieved	UW 2011 Goal
Range	≥ 16 km (10 mi)	14.2 km (8.8 mi)	≥ 40 km (24 mi)
Top Speed (ZE goal)	≥ 70 km/hr (20 mph)	122km/hr (76 mph)	≥ 96 km/hr (60 mph)
Acceleration (150 m)	≤12 s	8.7 s	≤7 s
Weight		289 kg (637 lb)	≤ 313 kg (650 lb)
Drawbar Pull		275 kgf (607.0 lbf)	≥ 400 kgf (880 lbf)
Noise (IC)	≤ 78 dB	64 dB	≤ 60 dB

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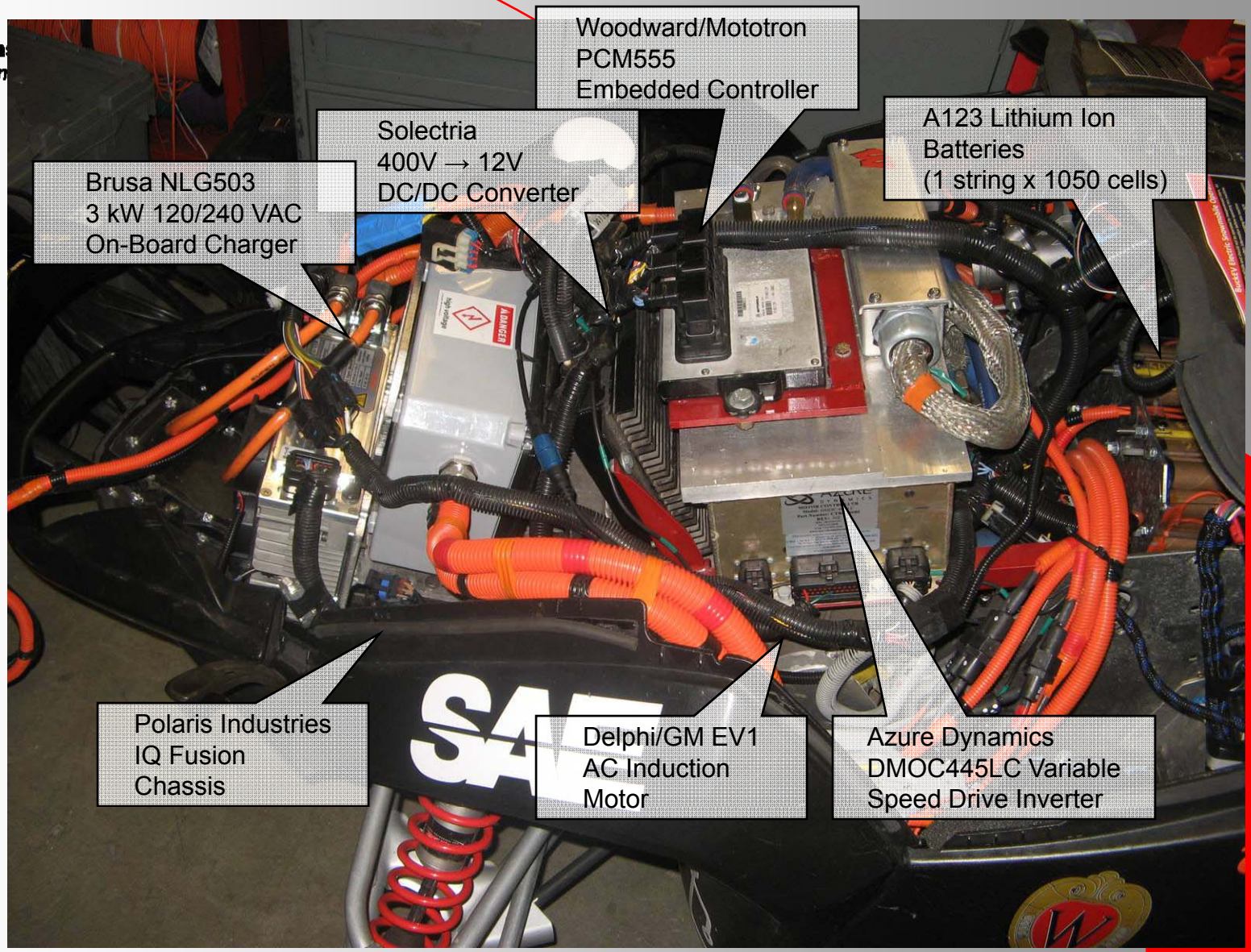
Design Overview



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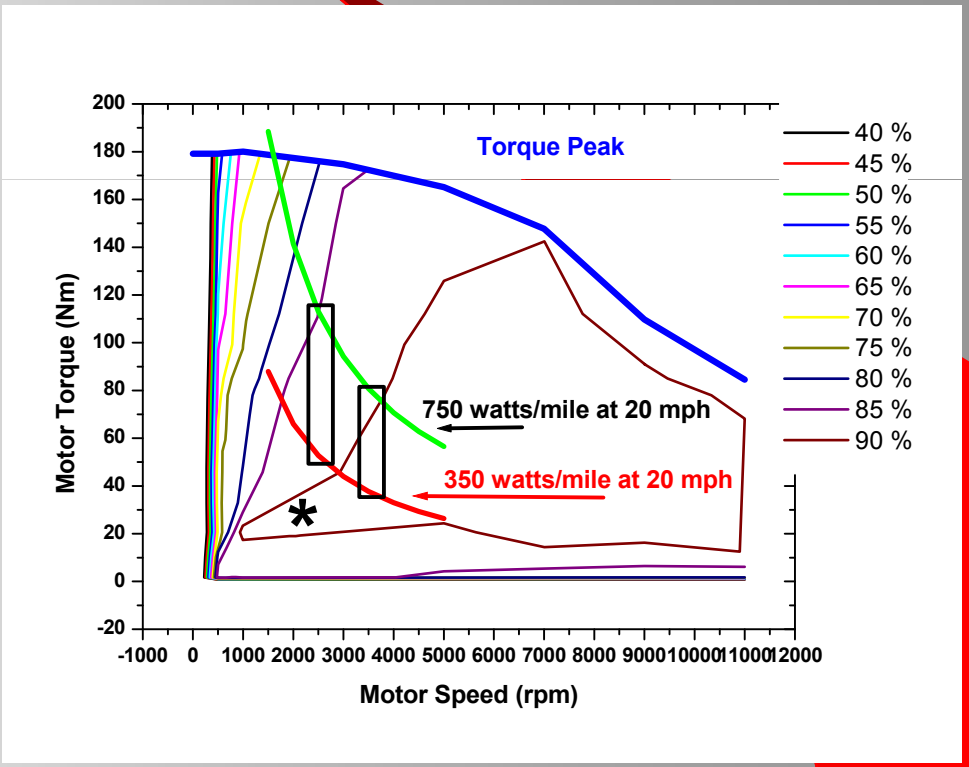
Delphi EV1 Motor

AC Induction



100 kW continuous

≥ 90% efficient

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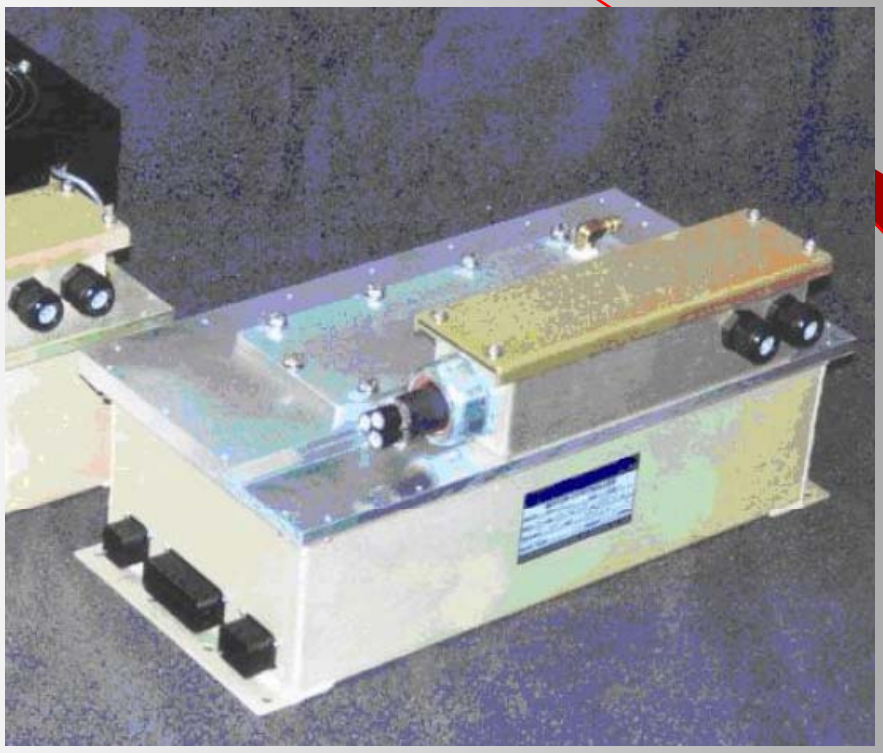
Motor Controller



Azure DMOC445LC Motor Controller

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Powertrain Implementation

2011 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

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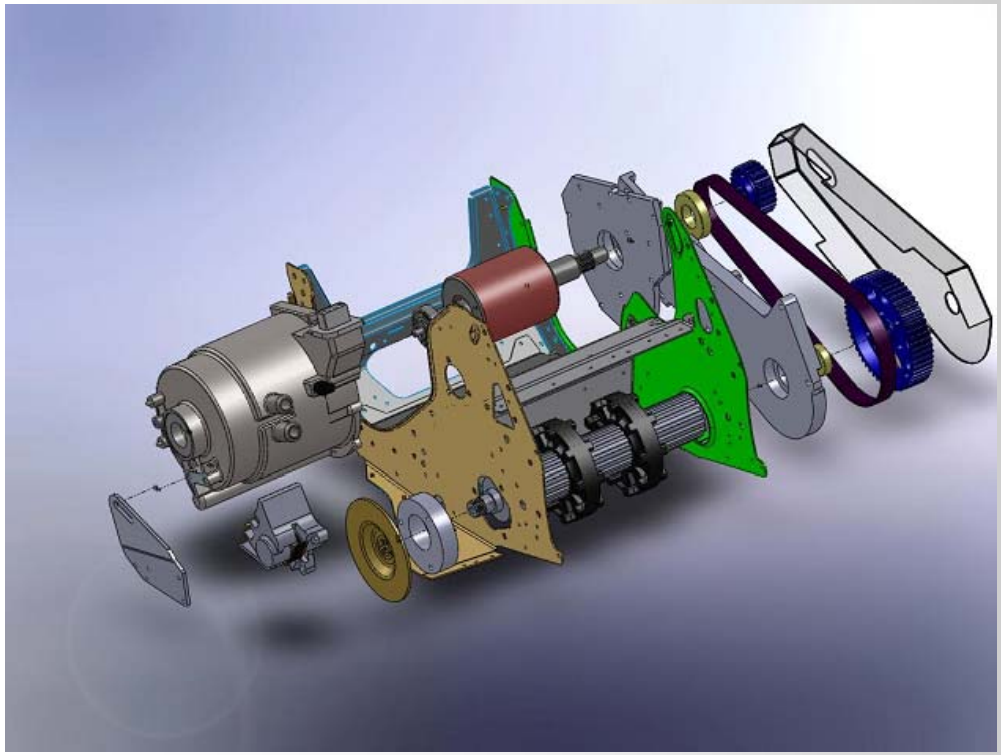
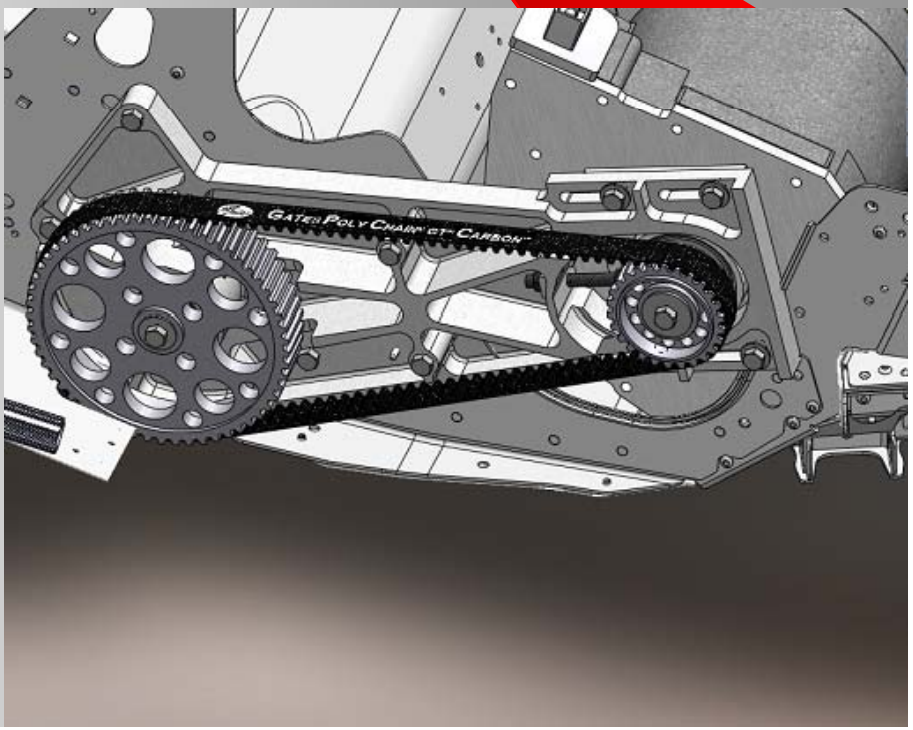
2011 Gen2 Drivetrain





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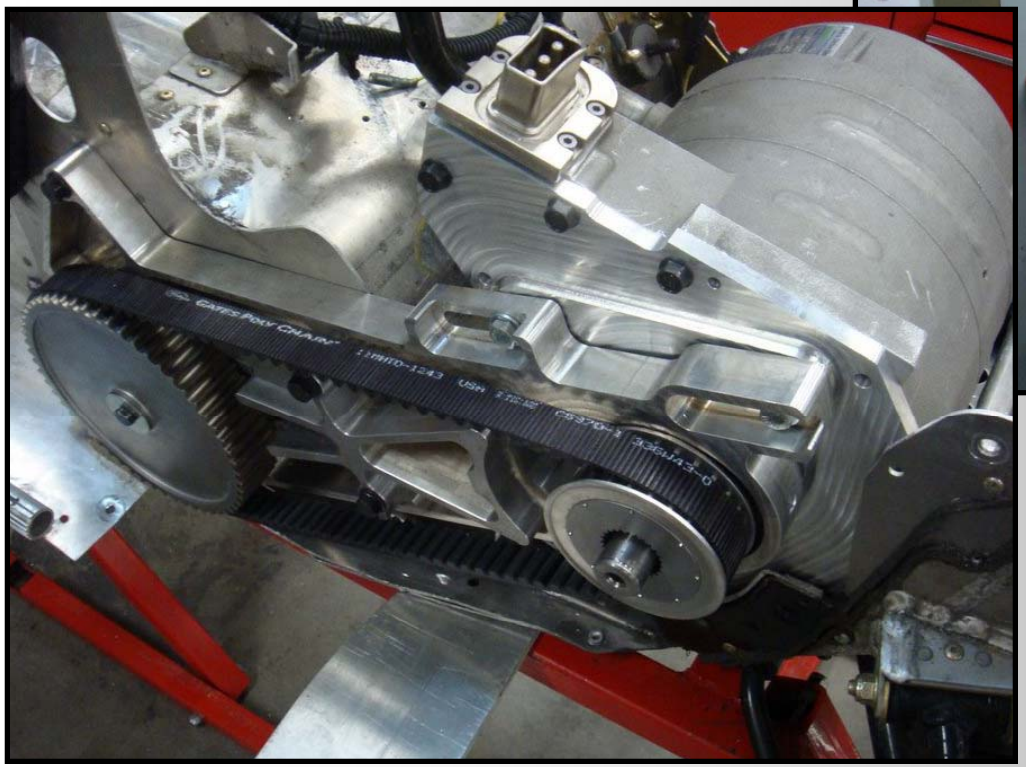
2011 Gen2 Drivetrain Implementation



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Battery Chemistry Comparison

	Pb-Acid	NiMH	Li-Ion	Petrol
Energy Density (Gravimetric) (Wh/kg)	30-40	40-120	100-180	12000
Energy Density (Volumetric) (Wh/L)	60-75	140-400	200-300	9000
Power Density (W/kg)	180	300-1000	1000-5000	
Cycle efficiency (% charge/discharge)	70-92%	65-80%	95-99%	
Cycle life (total cycles)	500-800	500-1000	500-15000	1
Self-discharge (%/month)	3-20%	~30%	5-10%	
Current cost ($/Wh)	0.15-0.30	0.30-0.60	0.50-2.50	<0.0001

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2011 Battery Pack

- Pack built with A123 batteries
  - 347 $Volts_{nominal}$
  - 10 parallel cells, 23 A-hr
  - Integrated BMS
    - Monitor and equalize cells
  - ½ ” Polycarbonate Shell
- Pack Capacity
  - 7.97 kW-hr
- Predicted range
  - Optimal conditions: 42 km (26 mi)
  - Expected competition conditions: 32 km (20 mi)

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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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Control System

CAN Hub

INPUTS

Key Switch

Accelerator Position

Brake Switch

Kill Switch

OUTPUTS

Coolant Pump

Speedometer

Torque Gauge

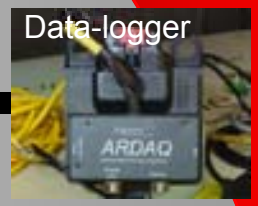
Malfunction Indicator Light

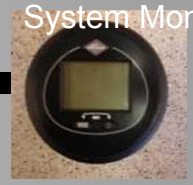
Reverse Indicator Light

Low Battery Indicator Light

Brake Lights

Accessory Power Driver





Diagnostic Port

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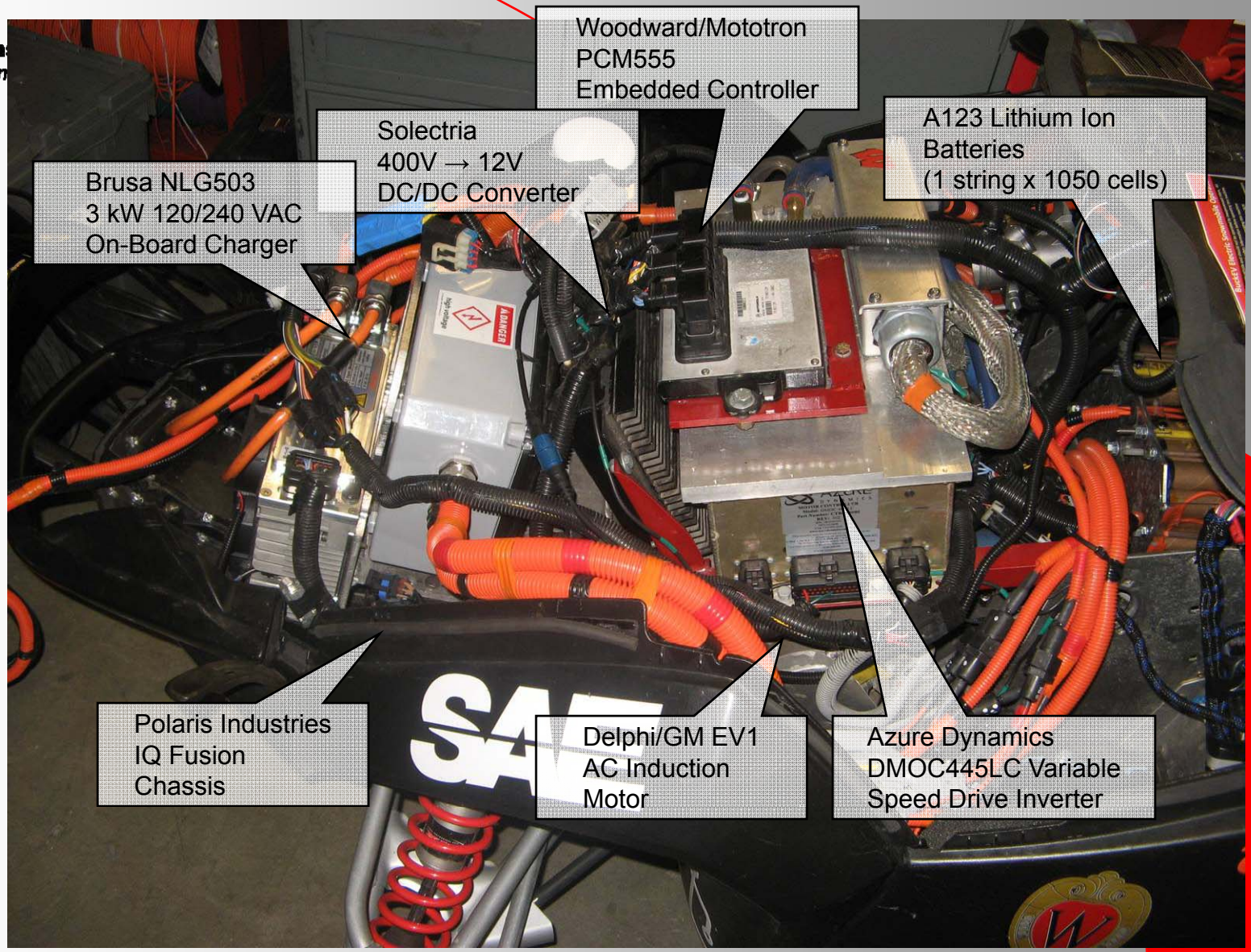

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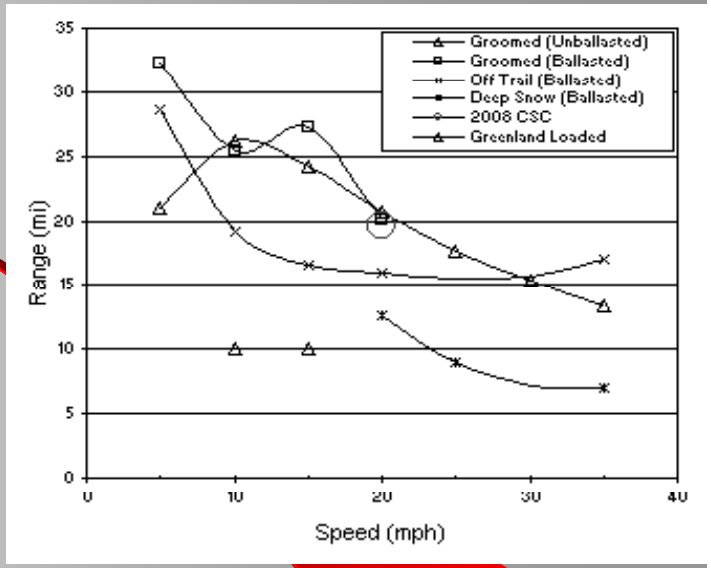
2011 Range



- Pack Capacity
  - 7.97 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
  - 42 km (26 mi) absolute maximum (optimal conditions, full discharge)
  - 32 km (20 mi) practical range (typical conditions, limited discharge)
- Achieved range
  - 20.8 mi (20 mph on hard packed snow)

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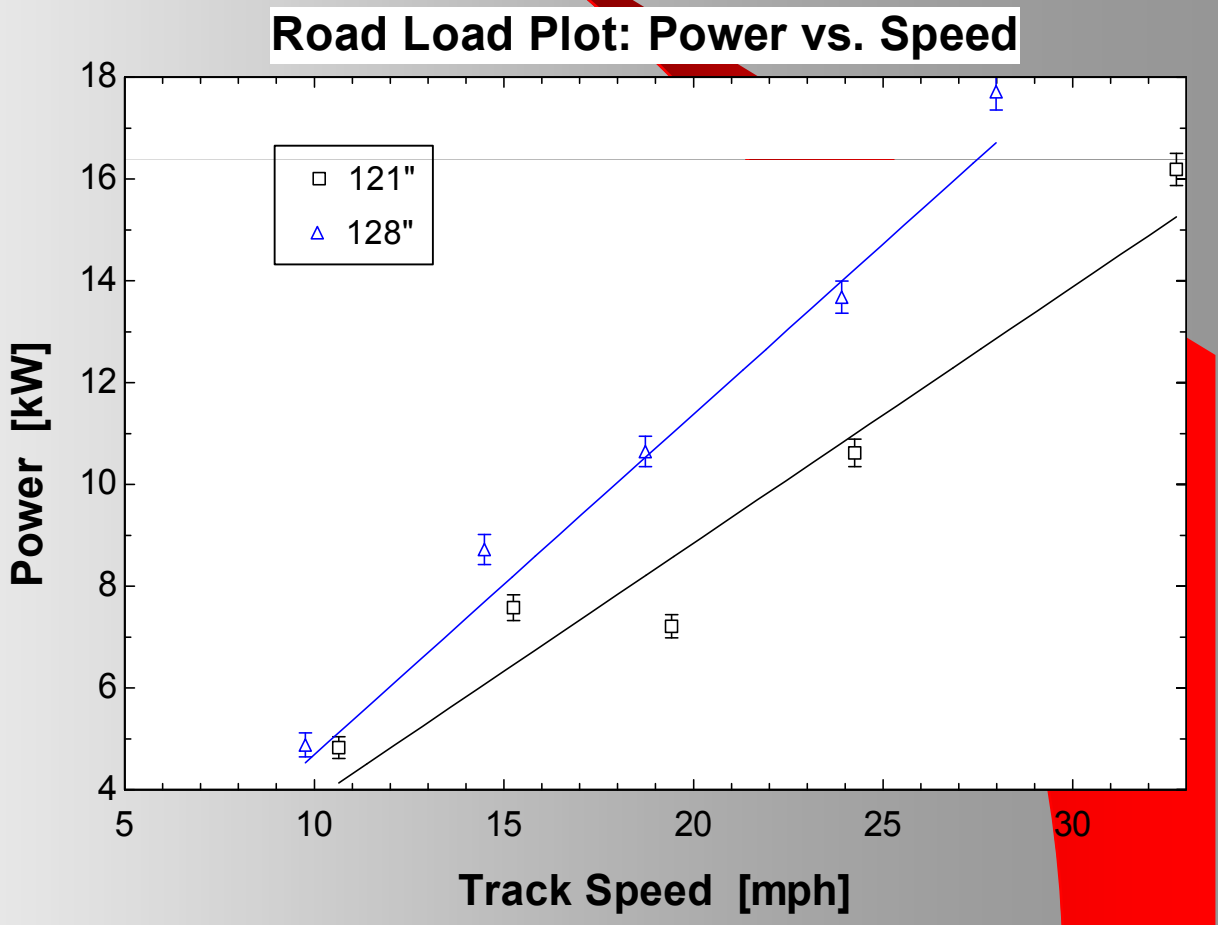
Driveline Efficiency Testing

- 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



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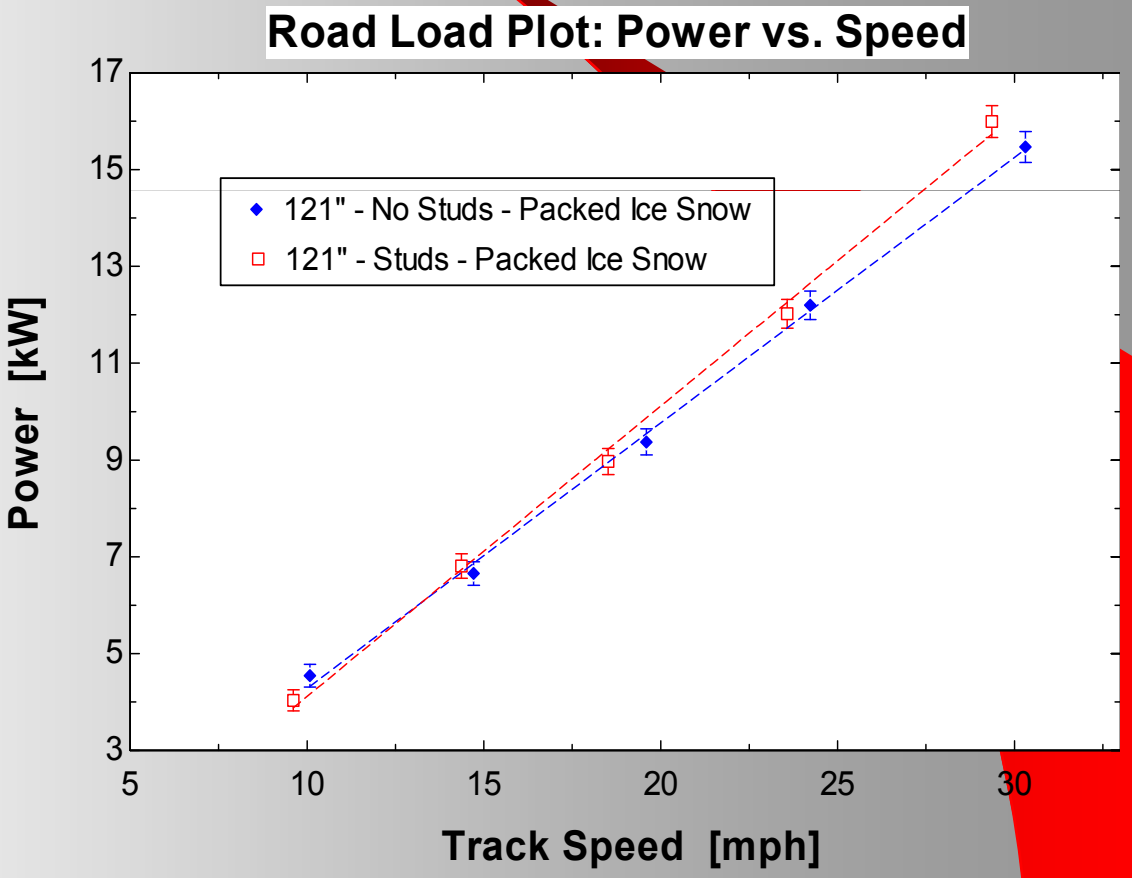
Effect of Studs

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



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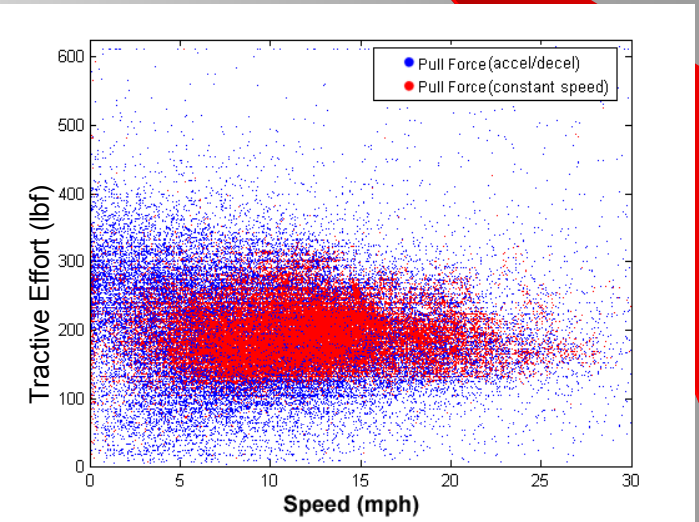
Towing Capacity

- Traction dominated
  - 2008 scores ordered by weight
  - 2009 switched to studded track (won event)
- Increase tractive effort
  - Continued using studded track
  - Shifted batteries back
  - Geared motor down



- Maximum tractive effort of electric drive
  - ~900 lbf at yesterday's draw bar pull event
  - Maintained up to 20 mph (unlike DC motor solutions)

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Handling

2010 results

- 16.99 s faster than any other E-sled (objective handling)
- Second fastest snowmobile overall (objective handling)

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Goal Recap

Parameter	Competition Goal	UW 2011 Goal	UW 2011 Achieved
Range	≥ 16 km (10 mi)	≥ 42 km (26 mi)	33.5 km (20.8 mi)
Top Speed (ZE goal)	≥ 70 km/hr (20 mph)	≥ 96 km/hr (60 mph)	?
Acceleration (150 m)	≤12 s	≤10 s	?
Emissions	Zero	Zero	Zero
Weight		≤ 300 kg (650 lb)	320 kg (707 lb)
Drawbar Pull		≥ 400 kgf (880 lbf)	410 kgf (900 lbf)
Noise (IC)	≤ 78 dB	≤ 60 dB	?

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Questions?

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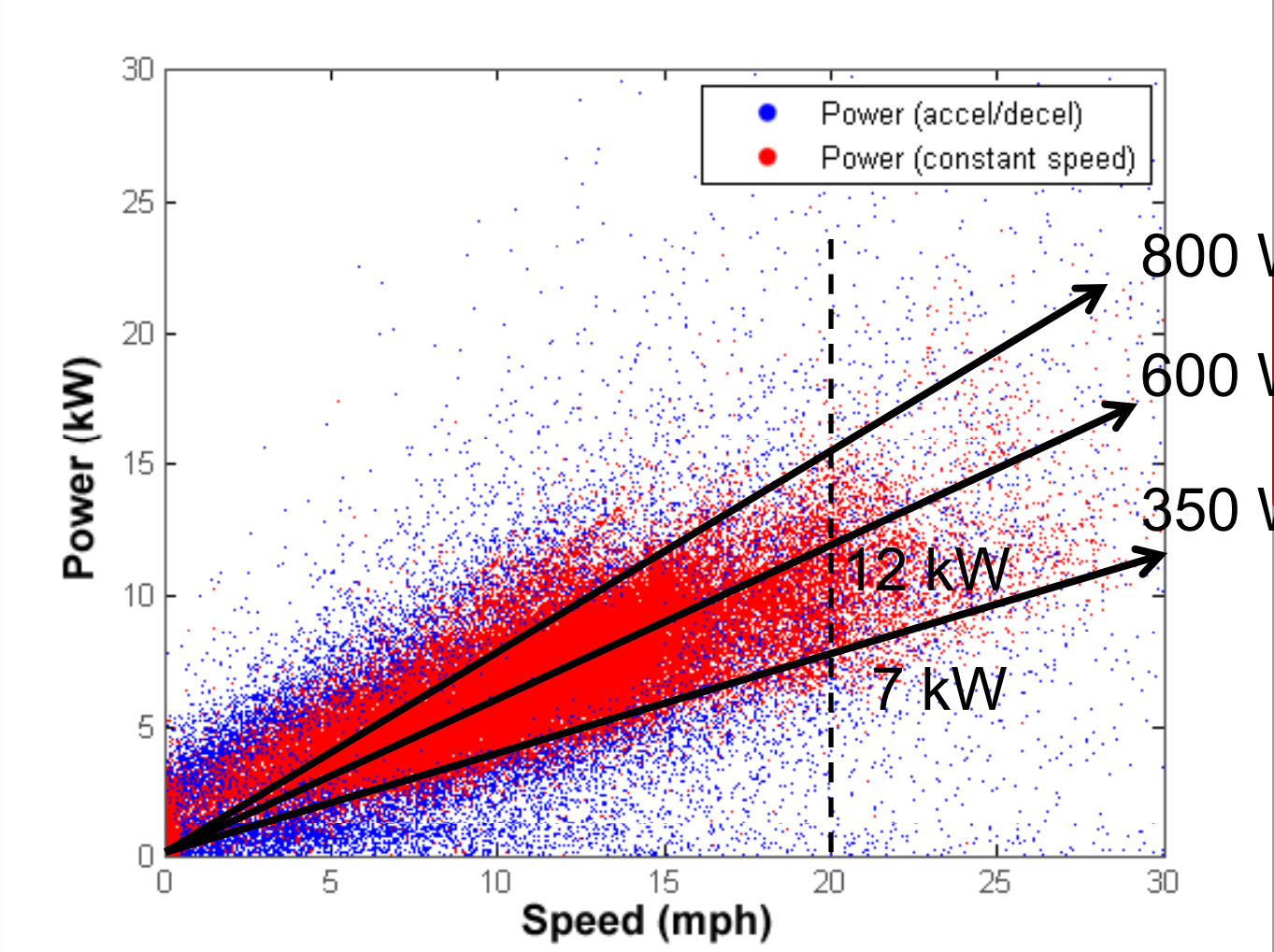
Greenland Road Load Measurement



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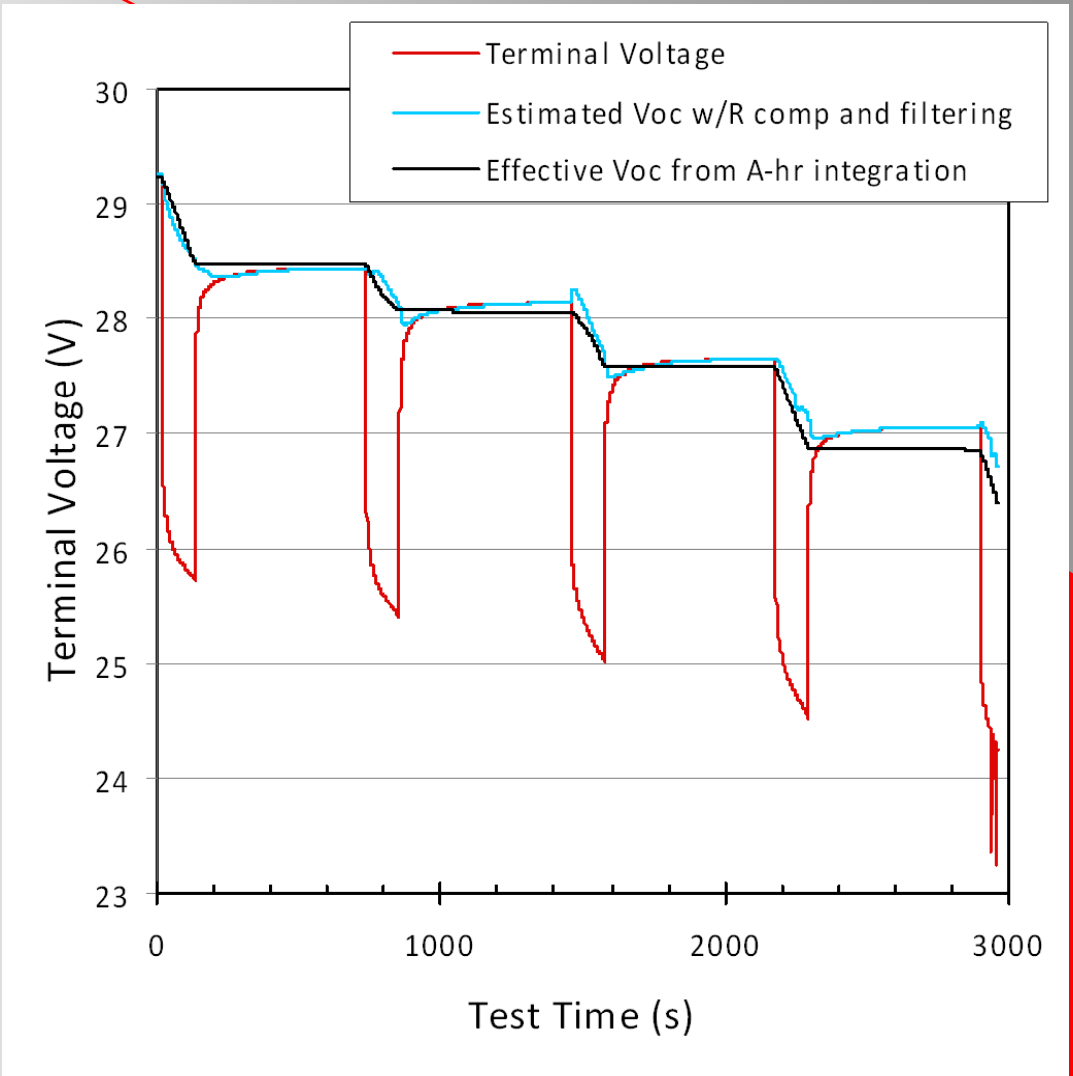
Battery Management

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

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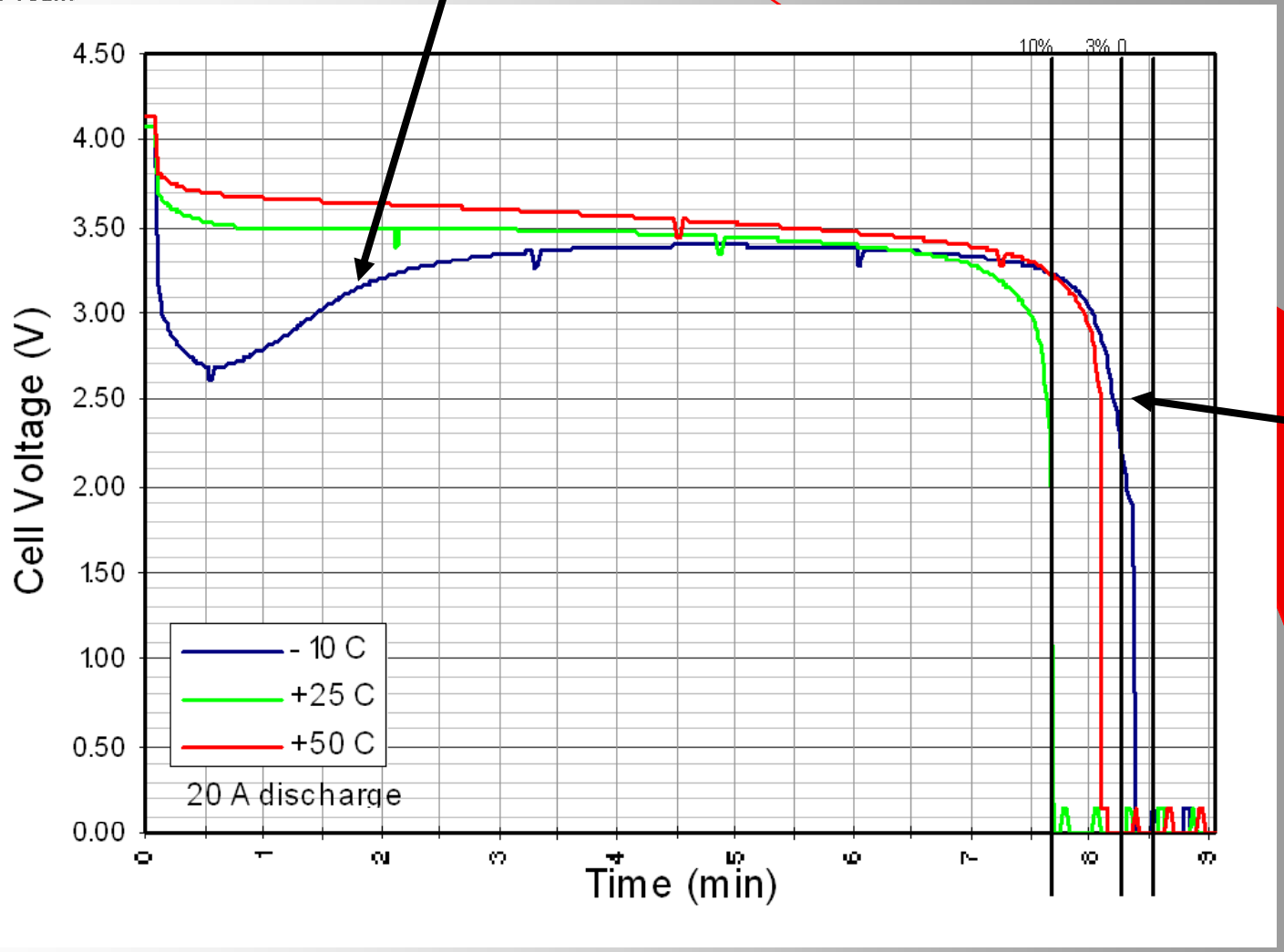
Cold Performance

90% power available within 105 s



Nearly full capacity available

Rated by manufacturer at -10°C

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Fuel Savings Analysis

- Gasoline-Powered Snow Machine
  - Estimated 10 mpg
  - 0.1 gallon/mile
- Electric Snow Machine
  - 350-500 W-hr/mi
  - Diesel generator efficiency
    - 15 kW-hr/gallon
  - 0.02-0.05 gallon/mile
- Savings over 200 mi
  - 10-20 gallons
  - @ 6 lbs/gallon → weight of sled in ~5-10 years
- Other benefits
  - Diesel genset also provides building heat, snow melting
  - Reduced emissions → Enhanced research platform
    - Stationary source instead of mobile source pollution
    - Improved after-treatment possible on genset
- Alaska