University of Wisconsin
SAE Snowmobile Team

University of Wisconsin Madison

2008 SAE Clean Snowmobile Challenge

Electric Sled Design Presentation

Presented by:

Nick Rakovec

Brian Olenski

Clean
Quiet
FAST

University of Wisconsin
SAE Snowmobile Team

Bucky EV – Redefining Electric!

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Design Emphasis

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)	**Primary**
Noise	None	Primary (300 points)	Secondary (225 pts effectively random)

University of Wisconsin
SAE Snowmobile Team

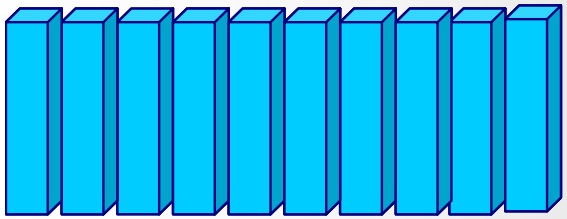
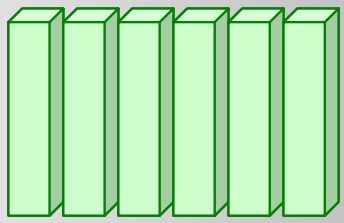
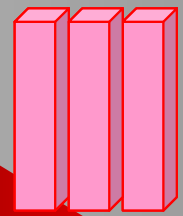
Clean
Quiet
FAST

Specific Design Goals

Parameter	Competition Goal	UW Goal	UW Achieved
Range	≥ 16 km (10 mi)	≥ 32 km (20 mi)	30 km (18.6 mi)
Top Speed (IC goal)	≥ 70 km/hr (45 mph)	≥ 140 km/hr (90 mph)	≥ 122 km/hr (76 mph)
Acceleration (150 m)	≤12 s	≤10 s	6.9 s
Emissions	Zero	Zero	Zero
Weight		≤ 340 kg (750 lb)	313 kg (691 lb)
Drawbar Pull		≥ 250 kgf (550 lbf)	250 kgf (550 lbf)
Noise (IC)	≤ 78 dB	≤ 60 dB	56 dB

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Battery Selection

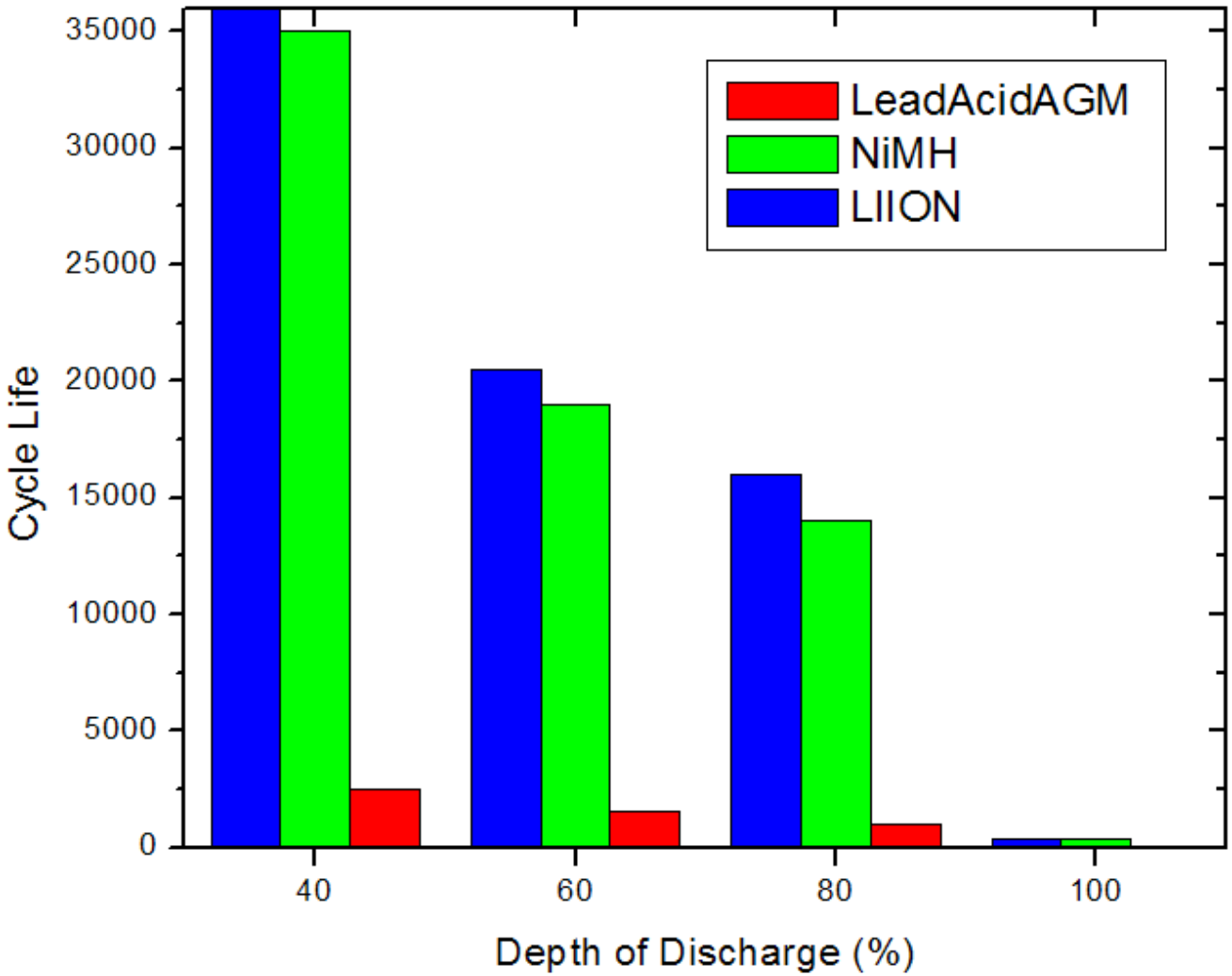




Nickel Metal Hydride	Lead Acid	Lithium-Ion
1.25 Volts/Cell	2.12 Volts/Cell	4.00 Volts/Cell
12.5 V → 10 Cells	12.5 V → 6 Cells	12.0 V → 3 Cells

University of Wisconsin
SAE Snowmobile Team

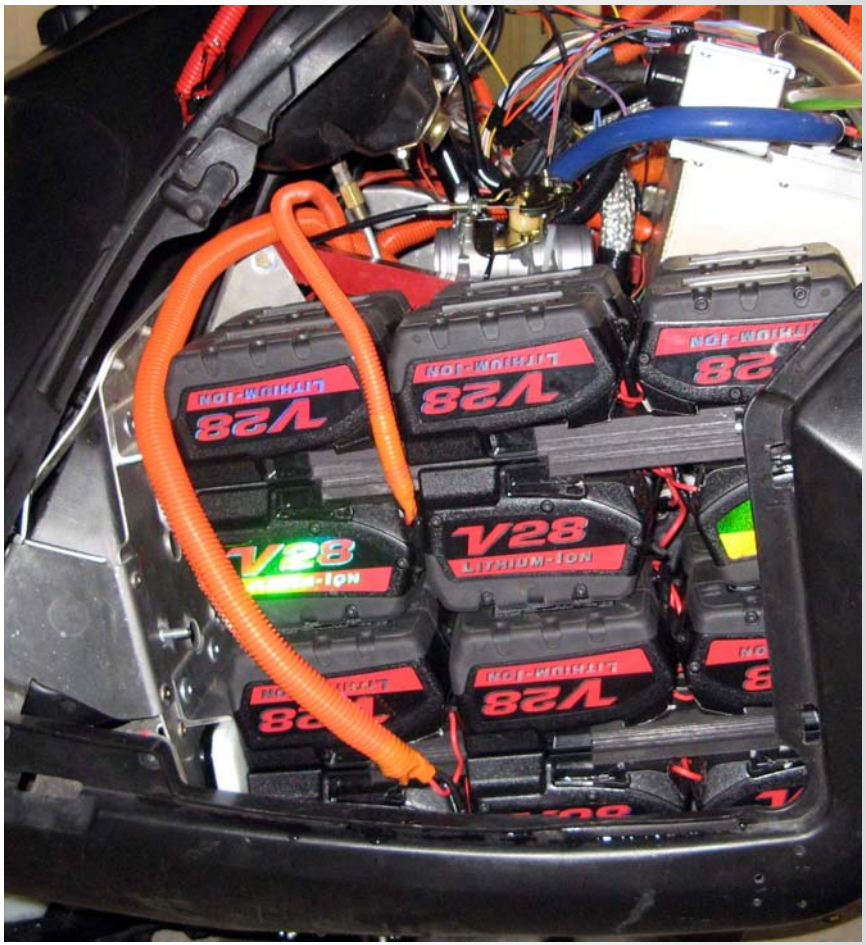
Clean
Quiet
FAST

Battery Selection



University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Battery Mounting



7 strings x 2.8 A-hr = 19.6 A-hr
84 cells x 4 V/cell = 336 $V_{nominal}$

84x Milwaukee Tool V28 Li-Ion Battery Modules

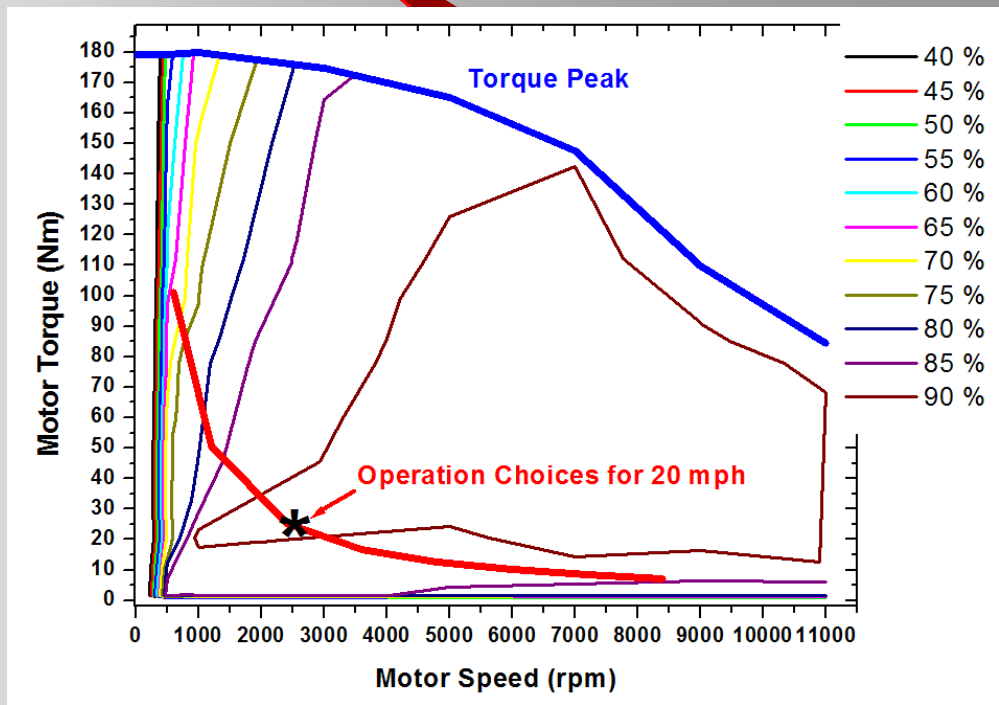
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Delphi EV1 Motor

105 kW continuous

AC Induction

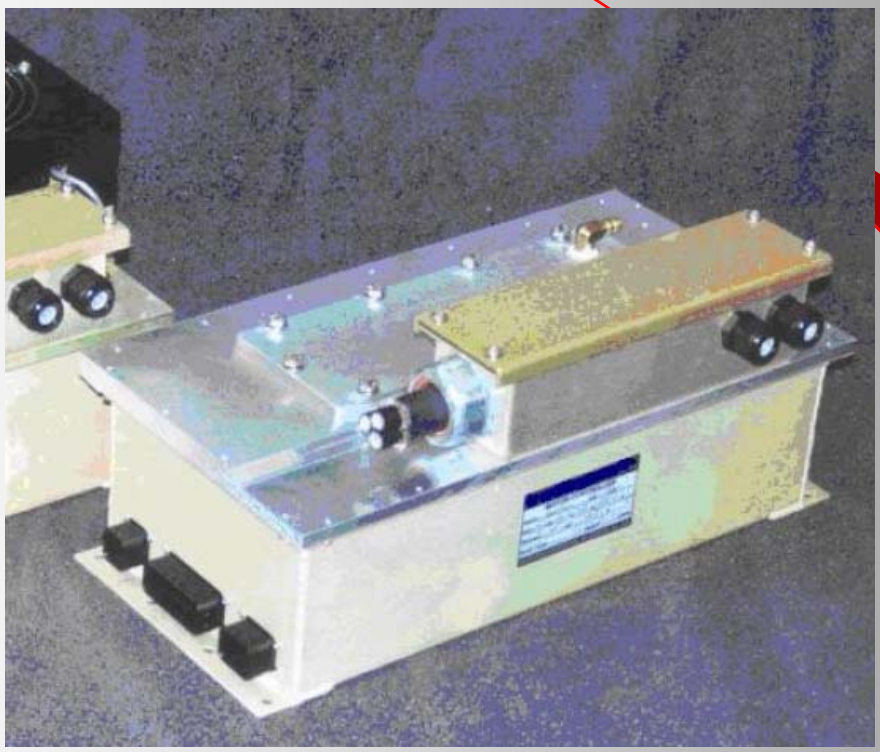


≥ 90% efficient

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Motor Controller



Azure DMOC445 Motor Controller

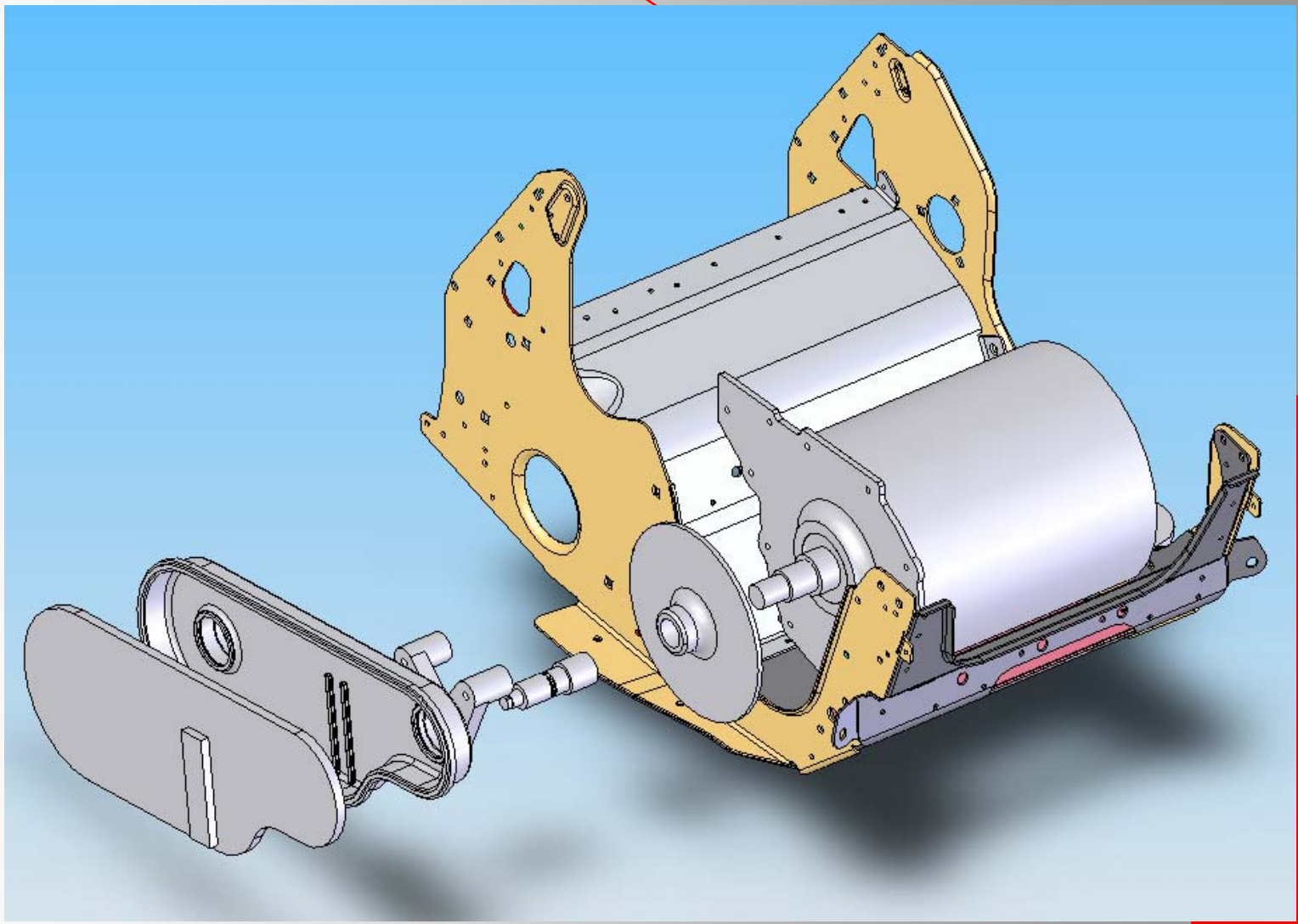
University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Powertrain Implementation

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

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Powertrain Implementation



University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Powertrain Integration

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

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

-40° to 130 ° C
18 g Shock Load
Immersion to 3 m underwater
Matlab Simulink Control Models
MotoHawk Automatic Code Gen

Clean
Quiet
FAST

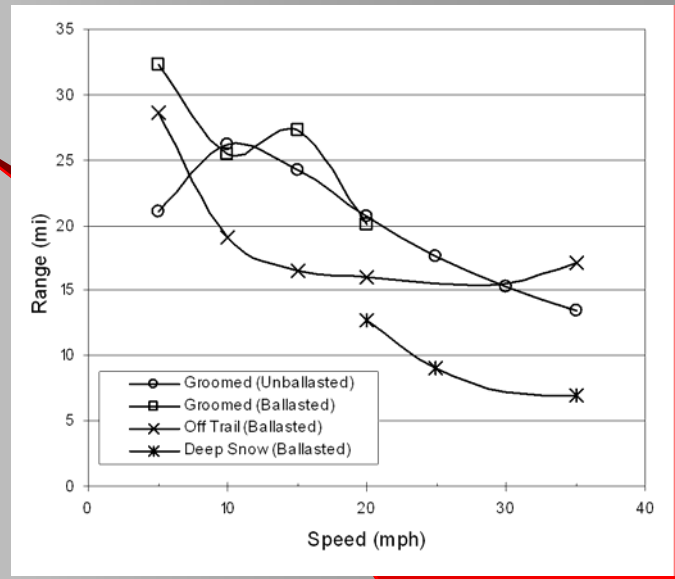
University of Wisconsin
SAE Snowmobile Team

Bucky EV – Redefining Electric!

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Range Predictions



- Pack Capacity
  - 19.6 A-hr = 6.6 kW-hr
- Road load
  - Initial model [Auth] – 4.6 kW at 20 mph
  - Testing (reduced pack and ballast)
    - 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)
    - **Extremely** variable based on snow conditions (and speed)
- Predicted range
  - ≤1 hr at 20 mph
  - 20 mi absolute maximum (optimal conditions, full discharge)
  - 15 mi practical range (typical conditions, limited discharge)

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Range Testing

- Pre-competition testing
  - Snow conditions: 8” snow with 3” track depth
  - 13.7 mi at 20 mph
  - Estimated battery depth-of-discharge: 70-90% (hadn’t yet been calibrated)
- Competition testing
  - Snow conditions: Snow-covered road (optimal)
  - Range according to snowmobile odometer: 18.4 mi
  - Very close to goal of 20 mi
- What we learned from competition range test
  - Road load
    - 6 kW typical
    - 24 N-m flat, 35 N-m on incline, 20 N-m descending
  - Target pack depletion: 97%
  - Actual charge removed: 96% (18.8 A-hr / 19.6 A-hr)
  - SoC estimation algorithm very successful!

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Bucky EV – Redefining Electric!

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

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

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

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Acceleration

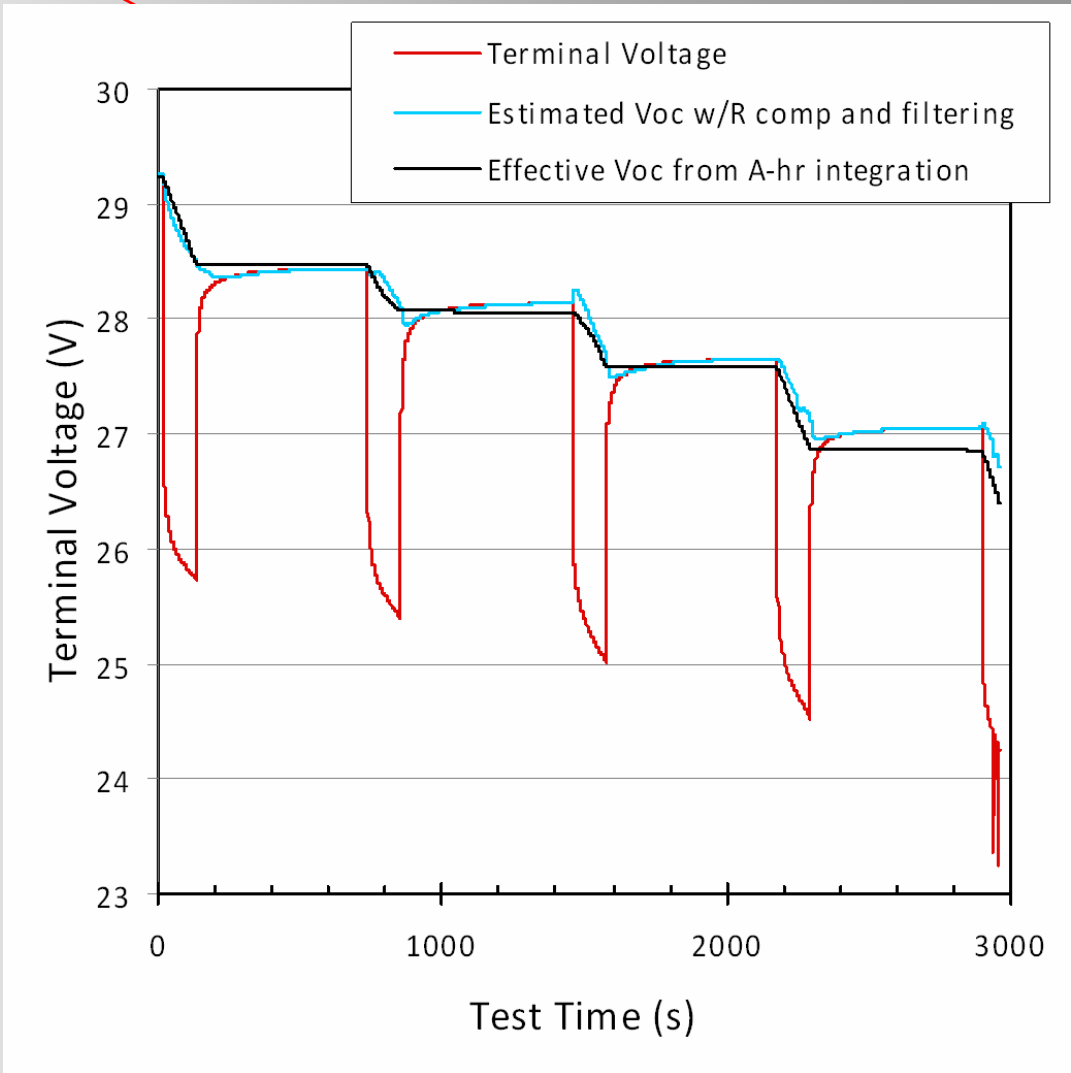
Beats competition IC minimum of 12 s to 500 ft

University of Wisconsin
SAE Snowmobile Team

Battery Management

Estimate state-of-charge (SOC)

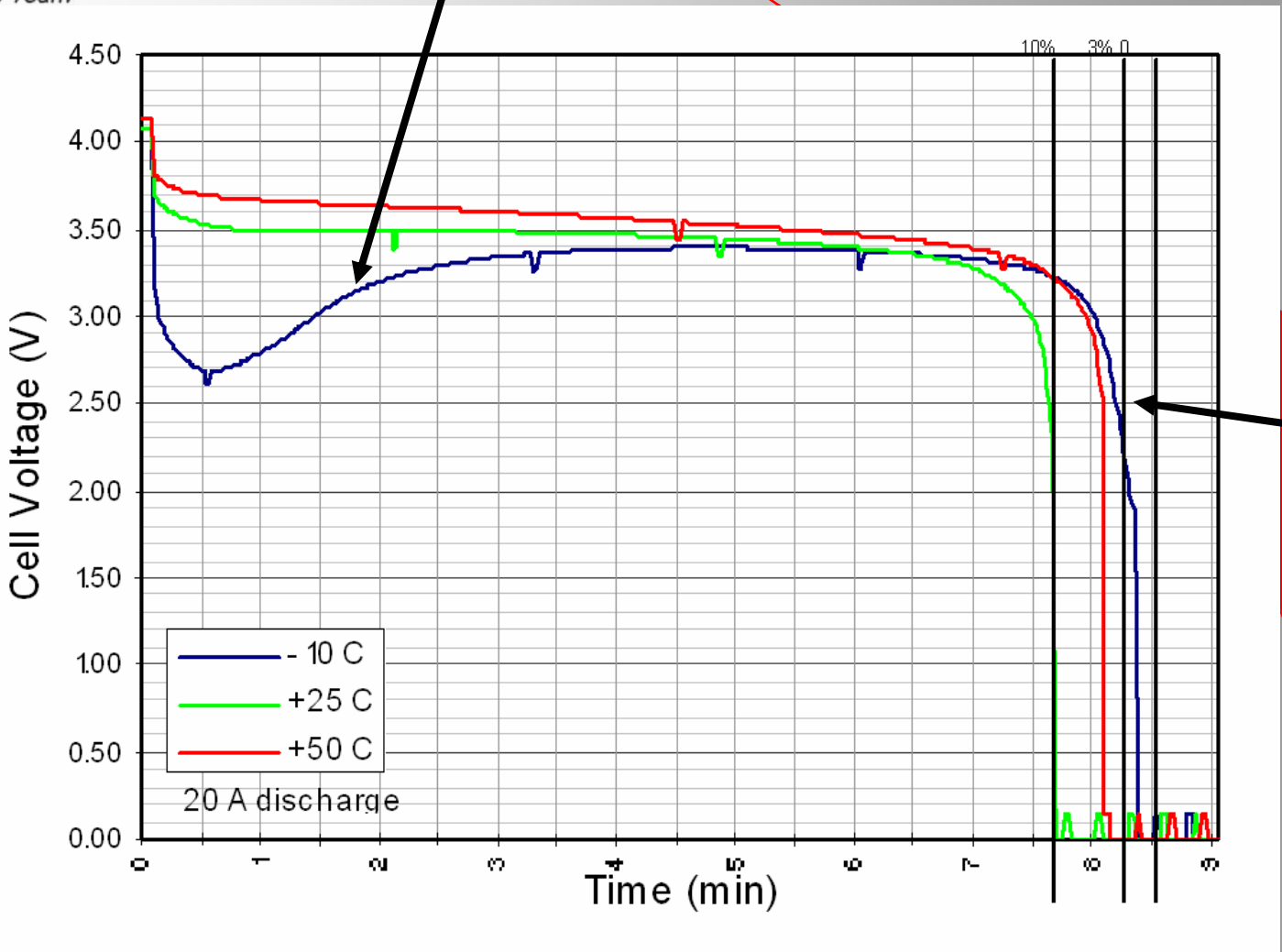
- Battery terminal voltage model
  - Voltage source
  - Series resistance
    - R based on temperature
  - Series RC element
    - τ,R based on temperature
- Estimate SOC based on
  - $V_{terminal}$
  - $I_{instantaneous}$, I_{LPF}
  - Battery temperature
- Outputs
  - SOC, DTE indications
  - Warn rider at 10%
  - Terminate operation at 3%



University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Cold Performance

90% power available within 105 s



Nearly full capacity available

Rated by manufacturer at -10°C

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Goal Recap

Parameter	Competition Goal	UW Goal	UW Achieved
Range	≥ 16 km (10 mi)	≥ 32 km (20 mi)	30 km (18.6 mi)
Top Speed (IC goal)	≥ 70 km/hr (45 mph)	≥ 140 km/hr (90 mph)	≥ 122 km/hr (76 mph)
Acceleration (150 m)	≤12 s	≤10 s	6.9 s
Emissions	Zero	Zero	Zero
Weight		≤ 340 kg (750 lb)	313 kg (691 lb)
Drawbar Pull		≥ 250 kgf (550 lbf)	250 kgf (550 lbf)
Noise (IC)	≤ 78 dB	≤ 60 dB	56 dB

Clean
Quiet
FAST

University of Wisconsin
SAE Snowmobile Team

Questions?

University of Wisconsin
SAE Snowmobile Team
Clean
Quiet
FAST

Drive Shaft