Thermal Management for Advanced Electric Powertrain
Outline

- Tesla Motors Overview
  - The problem and Tesla Motors’ solution
  - Tesla Motors and its Technology
- Simulation Driven Design for Electric Vehicles
  - Project Dark Star Thermal Performance
  - Project White Star Product Profile Definition
The Problem: Oil

**U.S. Oil Demand**

- Residential: 4%
- Commercial: 2%
- Industrial: 23%
- Electric Generation: 3%
- Transportation: 68%

**Oil for Transportation**

- Passenger Cars/ Light Trucks: 51%
- Road Freight: 30%
- Air: 13%
- Rail: 2%
- Maritime: 2%
- Pipeline: 2%
If Not Oil Then Electric Cars

Whatever the resource, we must use it as efficiently as possible

Electric cars are by far the best choice
- The lowest resource consumption per mile
- The lowest carbon emissions per mile
- Complete & flexible elimination of petroleum usage

Fossil Fuels  “Clean” Energy  Bio Fuels

Oil  Natural gas  Coal
Nuclear Hydro  Geothermal  Solar  Wind
Methanol Bio-diesel
The Solution: Desirable Electric Cars

Cars for people who like cars

and also care about oil consumption

- Fun
- Performance
- Image

And

- The environment
- National security
The Company

Tesla Motors Inc.
San Carlos, California

Tesla Energy Group

Tesla Motors Ltd.
Norfolk, UK

Tesla Motors Inc.
Rochester Hills, Michigan

Tesla Motors Factory
Albuquerque, NM

Tesla Motors Taiwan Ltd.
San Chung City, Taiwan

Tesla Motors Customer Centers
Santa Monica Blvd
Los Angeles, California
(3 more coming soon)
Tesla Motors Technology

- 55 kWh Liquid-Cooled Energy Storage System (ESS)
- 185 kW AC Induction Motor
- 200 kW Power Electronics Module
- 2-Speed Gearbox with Electronic Shift
Simulation Driven Design

- Aero
- Rolling
- Vehicle Dynamics
- Vehicle Control
- Transmission
- Motor
- PEM
- ESS
- HVAC
- Cabin
- Assumptions
- B.C & I.C
- Drive Profile
- Output
Project Dark Star: Vehicle Thermal Performance
Steady State Thermal Models

Motor

PEM

ESS
Steady State Thermal Limits

Dark Star Thermal Limit

- Motor SS
- PEM 20 sec
- PEM 60 sec
- PEM SS
- Motor 10 min

Torque (N.m)

Speed (rpm)
Transient Thermal Models

Motor Transient Simulink Model
Thermal Performance Case I: Flat Ground WOT 40C

D* speed flat ground WOT

xxx mph @40C (PEM limited)

xxx mph @40C (motor limited)
Thermal Performance Case II: Freeway Climb

Freeway Elevations

- Tejon Pass: 4183 feet
- Donner Pass: 7200 feet
- Grapevine (Steepest grades)

http://seamless.usgs.gov/
Thermal Performance Case II: Grapevine climb, 65mph, 40C

Grapevine Climb

Motor under Max temp

<table>
<thead>
<tr>
<th>Speed 2nd</th>
<th>MotorTemp 2nd</th>
<th>Speed 1st</th>
<th>MotorTemp 1st</th>
<th>Elevation</th>
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<tr>
<td>0-1000</td>
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Project White Star

sleek/ sexy/ tech
Project White Star: Product Profile Definition

- **EPA Range:**
  - How far can one drive?
- **0-60 mph**
  - How fast can one accelerate?
- **Top Speed**
  - How fast can one drive?

**FUNCTION**

- **Vehicle Simulation**

**FORM**

- Is the vehicle beautiful?
- Is the vehicle comfortable?
- How many car-seats?
- How many cup-holders?

**DESIGN TARGET**

- Aero Target
- Tires and wheels
- Weight and weight distribution
- Motor
- Gear Ratio
- … …

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Range Trade-off [250 miles EPA combined]
CdA Design Target

Whitestar C03 Best Friction 3,500lbs - range from 65kWh at 65mph

- Cd = 0.235
  - A = 2.25 m²

- Cd = 0.245
  - A = 2.35 m²

- Cd = 0.258
  - A = 2.35 m²
Weight and Grade Sensitivity

65 mph SS Range vs Weight and Grade

- Weight Sensitivity
- Grade Sensitivity

Graph showing range in miles vs grade percentage, with different lines indicating varying weight sensitivities.
Hill Climb
Sacramento to Reno Benchmark
Hill Climb
Sacramento to Reno Benchmark

65 mph constant speed
40 degC, no thermal limit
HVAC ON (5 kW capacity)

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<th>Specification</th>
<th>Value</th>
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<td>Climbing Energy Consumption</td>
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<td>Cruising Energy Consumption</td>
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<tr>
<td>HVAC Energy Consumption</td>
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<td>Total Energy Consumption</td>
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<tr>
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<td>HVAC Power Consumption</td>
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<tr>
<td>Average Total Power Consumption</td>
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<tr>
<td>Peak Total Power Consumption</td>
<td>58,394 W</td>
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Gear Ratio and Tyre Trade-off: I

Zero to Sixty Contour Plot (s)

TRACTION LIMITED

TORQUE LIMITED
Baseline is torque AND traction limited making 6s unachievable.

Gear ratio increase (lower top speed) AND stickier tyres required to achieve 6s.
Questions/Discussions

Thank you.