Improving Transportation Efficiency Through Integrated Vehicle, Engine, and Powertrain Research - SuperTruck II

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Jeff Girbach, Principal Investigator, Powertrain
June 13, 2019

Daimler Trucks

Project ID: ACE100

This presentation does not contain any proprietary, confidential, or otherwise restricted information
Overview

Timeline

- Start: January 1, 2017
- End: December 31, 2021
- Status 6/2019 = 50% Complete

Barriers

- Our first prototype component integration is underway on the A-Sample Truck, but making all the systems work together is the biggest challenge.
- Prototype controls integration on top of series controllers remains a difficult task.

Budget

- Project Total: $40Mil

<table>
<thead>
<tr>
<th>Share</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Share</td>
<td>$20,000,000</td>
</tr>
<tr>
<td>Michelin</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>ORNL</td>
<td>$500,000</td>
</tr>
<tr>
<td>NREL</td>
<td>$203,254</td>
</tr>
<tr>
<td>Detroit Share</td>
<td>$12,468,918</td>
</tr>
<tr>
<td>DTNA Share</td>
<td>$5,827,829</td>
</tr>
</tbody>
</table>

2018 Summary

- Total: 2018 Planned - 12,270,352, 2018 Actual - 9,334,148
- DTNA: 2018 Planned - 2,668,167, 2018 Actual - 2,488,671
- DDC: 2018 Planned - 9,004,185, 2018 Actual - 6,845,477

Project Partners

- Schneider National
- Strick Trailer
- Michelin
- Oak Ridge National Labs
- National Research Energy Laboratory
- University of Michigan
- Clemson University
Objectives – Project Phases

### Phase 1
- Simulation
- Goal Setting
- Main Path & Stretch Path Defined

### Phase 2
- Main Path Design
- A-Sample Design Release
- Bench Testing
- Wind Tunnel Testing

### Phase 3
- A-Sample Build & Test
- System Integration
- Stretch Technology Go/No Go

### Phase 4
- Final Demo Design
- Integration Development

### Phase 5
- Final Demo Build
- Final FE Test
- Final Report

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**Program status**

**Main Path Technologies**

**Stretch Technologies**

<table>
<thead>
<tr>
<th>Phase 2</th>
<th><strong>Aero Tinker Truck Assembled</strong></th>
<th>100%</th>
<th>April 2018</th>
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</thead>
<tbody>
<tr>
<td></td>
<td><strong>Prototype DD13 Engine Delivered to DTNA</strong></td>
<td>100%</td>
<td>Sept 2018</td>
</tr>
<tr>
<td></td>
<td><strong>A-Sample Design Release</strong></td>
<td>100%</td>
<td>Dec 2018</td>
</tr>
<tr>
<td>Phase 3</td>
<td><strong>A-Sample Assembled</strong></td>
<td>100%</td>
<td>June 2019</td>
</tr>
<tr>
<td></td>
<td><strong>A-Sample FE Validation Test Complete</strong></td>
<td>30%</td>
<td>Dec 2019</td>
</tr>
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</table>
Approach – SuperTruck 2 Roadmap Update

**Phase 1:** Goal setting via simulated conceptual FE targets

**Phase 2:** Simulation of designed systems (ie, CFD, rolling resistance, etc.)

**Phase 3:** Validation of physical prototypes (A-Sample testing)

**Expected reduction of FE going from conceptual to designed components**

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2009 Cascadia

On road (Portland-Pendleton) validation to determine starting point between SuperTruck “baseline” to 2017 New Cascadia @65k lbs combined gross vehicle weight

Freight Efficiency %

Phase 1 Conceptual Goal Targets
Phase 2 Design Simulated Status
Phase 3 Prototype Validation
Technical – Aerodynamic & Exterior Development

Pathway to Reach Aerodynamic Target

Computational Fluid Dynamics

Physical Validation

Input for Design (40% Clay)

Final Check (100% Clay)

A-Pillar Treatment

Updated SuperTruck 1 Fairings

95% Defined
Technical – Chassis Developments

Prototype Tires

Michelin tire will be optimized for clutched rear axle – “Detroit Long Haul Tandem Concept”

Operates like a 6x2 at hwy speeds

1. Low Rolling Steer Tire
2. High Mileage/Low Rolling Drive
3. Low Rolling Tag Tire

Thermal Configuration

• High efficiency engine needs new cooling concept
• Allows for 48V system cooling
Replace alternator with 48V motor generator:
- Pull power off the engine in place of the alternator.
- Consume battery power as an e-motor to assist powertrain.
- Allows for energy recovery “mild hybrid”.

A-Sample System Layout

12V Starter @55 °F 1.5 Sec
48V Starter @55 °F 1.2 Sec
20% Faster @Warm Temps

New proposed belt routing

DOE Annual Merit Review | Daimler Trucks North America | SuperTruck 2 | June 13, 2019
Collaboration: First Prototype Integration
A-Sample Truck

- Aero
- Transmission
- Controls & Wiring
- 48V Systems
- Engine
- Cooling
- Axles

A-Sample
## Summary of Technical Investigations

<table>
<thead>
<tr>
<th>Phase 2 Simulated &amp; Design Status</th>
<th>Phase 3 Prototype Validation</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Main Path</strong></th>
<th><strong>Stretch Items</strong></th>
<th><strong>Investigation Topics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aero</strong></td>
<td>• Aero front</td>
<td>• Under hood airflow</td>
</tr>
<tr>
<td></td>
<td>• Improved tractor-trailer gap mgmt</td>
<td></td>
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<tr>
<td></td>
<td>• Improved wheel treatments</td>
<td></td>
</tr>
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<td></td>
<td>• Aero windshield</td>
<td></td>
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<tr>
<td></td>
<td>• Mirror cameras</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Improved aero seals</td>
<td></td>
</tr>
<tr>
<td><strong>Engine</strong></td>
<td>• Down-sped, high BMEP DD13 engine</td>
<td>• In-cylinder thermal barrier coatings</td>
</tr>
<tr>
<td></td>
<td>• High peak firing pressure</td>
<td>• Additional WHR heat sources</td>
</tr>
<tr>
<td></td>
<td>• Heat loss &amp; friction reduction measures</td>
<td>• Real-time predictive powertrain control</td>
</tr>
<tr>
<td></td>
<td>• Active drivetrain fluid temperature control</td>
<td></td>
</tr>
<tr>
<td><strong>Chassis &amp; Powertrain</strong></td>
<td>• High FE Tires (Michelin)</td>
<td>• High FE gear oil</td>
</tr>
<tr>
<td></td>
<td>• Thermal system</td>
<td>• AC Condenser w/electric fan</td>
</tr>
<tr>
<td></td>
<td>• Advanced axle system</td>
<td></td>
</tr>
<tr>
<td><strong>Energy Management</strong></td>
<td>• 48V Mild Hybrid</td>
<td>• 48V Water Pump</td>
</tr>
<tr>
<td></td>
<td>• 48V Power Steering</td>
<td>• 48V HVAC Compressor</td>
</tr>
<tr>
<td></td>
<td>• Improved pHVAC system (NREL)</td>
<td>• Higher capacity battery systems</td>
</tr>
<tr>
<td></td>
<td>• 48V Water Pump</td>
<td>• Clutched Air Compressor</td>
</tr>
<tr>
<td><strong>Vehicle Controls</strong></td>
<td>• Pairing</td>
<td>• Intelligent Controls</td>
</tr>
<tr>
<td></td>
<td>• Eco Roll 2.0</td>
<td>• HMI for new systems</td>
</tr>
<tr>
<td></td>
<td>• Mechatronics System Integration</td>
<td></td>
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<tr>
<td><strong>Mechatronics System Integration</strong></td>
<td>• Intelligent Controls</td>
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<td><strong>HMI for new systems</strong></td>
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Approach – Powertrain Research Components

- Designed and analyzed a number of BTE improvement measures
- Experimental evaluation on-going
- Two primary test platforms in Detroit
  - Dedicated Tinker Truck vehicle
  - Engine test cell

**Downspeeding enablers**
- Two stage turbocharging
- Interstage cooling
- High hydraulic flow injectors

**Faster combustion enablers**
- High compression ratio
- Higher peak cylinder pressure
- Redesigned bowl shape
- Thermal barrier coating

**Air System**
- Miller cycle valve timing
- Long loop EGR
- Two stage EGR cooling

**Controls**
- Model predictive controls
- Transient calibration optimization

**Parasitics**
- Oil flow reduction
- Low viscosity oil
- Higher oil temperature
- Active piston cooling jets
- Liner surface conditioning
- Variable speed water pump

**Waste Heat Recovery**
- Phase Change Cooling WHR

**Aftertreatment**
- Close-coupled SCR

**Fluid Temperature Management**
- Split Cooling System
- Transmission temp. management
Technical – Collaboration with ORNL

- Developed ST2 DD13 Combustion & conjugate heat transfer (CHT) CFD model
- 3-D CHT on piston, 1-D CHT on liner
- Technical investigations
  - Miller Cycle (late IVC) with low-pressure EGR
  - Thermal barrier coating (TBC)
- CFD is coupled with Daimler’s cycle simulation model
- Analysis results
  - Demonstrated reduced pumping losses/lower BSFC (1% at road load)
  - Demonstrated TBC’s potential for reduced heat loss

- New engine installed at ORNL
- Initial firing and baseline planned for April
- Full performance and emissions evaluation capabilities
- Proposed efforts include
  - Friction pack evaluation
  - Intake conditioning studies

- Power pack testing at ORNL’s Vehicle System Integration (VSI) laboratory
- Hardware-in-the-loop drive-cycle testing
- Component level to full HD powertrain
- Repeatability typically within 0.3% CoV
- Advanced transmission design evaluation
- Efforts planned for summer 2019
Technical – Thermal Barrier Coating Development

Performance variables
- IMEP
- Thermal Efficiency
- Emissions Estimates
- Surface Heat Flux
- Surface Temperature
- Heat Release Rate
- Heat Flux

Three major enablers
- Analysis
- Plasma spray
- On-engine validation

Spray Technology
- SST developing advanced plasma spraying process for thermal spray of advanced oxide TBC onto steel piston
- Plasma spray process optimized for complex geometry
- Coatings demonstrate uniform, smooth coverage over entire piston crown
- Initial durability assessment of coatings in progress

High Fidelity Single Cylinder CFD Model
Composite TBC/Piston FEA
Cycle Simulation

Analysis

Single Cylinder Engine
Multi Cylinder Engine
Experimental Evaluation
Technical – Phase Change Cooling (PCC) Waste Heat Recovery (WHR)

Objectives
- Recover high quality waste heat in the cylinder head and engine block
- Deliver on 3.5% BTE potential

System description

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Water – ethanol mix (60%/40%)</th>
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</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>50 bar</td>
</tr>
<tr>
<td>Temperature</td>
<td>305°C</td>
</tr>
<tr>
<td>Vapor Power</td>
<td>159 kW</td>
</tr>
</tbody>
</table>

Status
- Finalizing coolant core design
- Experimental evaluation scheduled to start Q4 2019
Technical – Waste Heat Recovery (WHR)

<table>
<thead>
<tr>
<th></th>
<th>Refrigerant Based System</th>
<th>Ethanol Based PCC System</th>
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<tbody>
<tr>
<td>Complexity</td>
<td>🗿 🗿 🗿 🗿</td>
<td>🗿 🗿 🗿 🗿</td>
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<td>Performance</td>
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<td>Condenser Requirements</td>
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<td>🗿 🗿 🗿 🗿</td>
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<tr>
<td>System Cost</td>
<td>🗿 🗿 🗿 🗿</td>
<td>🗿 🗿 🗿 🗿</td>
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<tr>
<td>Development Challenges</td>
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<td>🗿 🗿 🗿 🗿</td>
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- Significant added complexity in both cases
- PCC system eliminates the need for a coolant circuit
- PCC requires extensive engine re-design
- Refrigerant based system poses significant heat rejection challenge
Technical – Model-Predictive Powertrain Controls

Objectives

- Real-time engine & aftertreatment control optimization with high fidelity on-board models exercised over a receding horizon

Status

- Engine systems fully characterized
- Aftertreatment system modeling on-going
- Experimental evaluation in progress
Remaining Challenges & Barriers

Technical

• We are now beginning to receive updated heat loads for the final demonstrator engine based off of test cell data. We need to re-run the thermal simulation data to check that we have enough heat rejection without raising the charge air cooler temperature.
• We are beginning the packaging studies for the ST2 Final Demonstrator, the twin turbo charger setup is large and due to proximity, could present a heat issue for the HVAC air intake system.
• First engine prototypes with the new technology are being installed in test bays. Validation of the designs and optimization of the new technologies will begin.

Resources

• In April, our Mechatronics Integration person left the company, right before A-Sample key on. We are shifting controls resources to cover the immediate need, getting A-Sample up and running
## Summary and Future Work

<table>
<thead>
<tr>
<th>Phase</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>-</td>
</tr>
<tr>
<td>Phase 2</td>
<td>-</td>
</tr>
<tr>
<td>Phase 3</td>
<td>- Continued Aero Tinker Truck Validation Testing, A-Sample Build Complete, 40% Exterior Clay development, Mechatronics Integration and Bug Fixing, On-Road Testing</td>
</tr>
<tr>
<td>Phase 4</td>
<td>-</td>
</tr>
<tr>
<td>Phase 5</td>
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### Timeline

**Scope Definition**
- Baseline to NGC defined, Goal Setting, TRL Handover and Scope Defined

**Concept Creation & Theoretical Analysis**
- Aero Analysis & Design
- Super Truck Main Path Defined

**A-Sample (Development Truck)**
- A-Sample Design Release
- A-Sample Complete
- A-Sample Optimization

**Target System Optimization**
- Mule Truck Arrives
- Chassis Modifications
- Shakedown Testing
- A-Sample FE Test
- Long Lead Item Design Release
- Design Complete

**Super Truck Buildup**
- Final FE. Tests
- DDC Final 13L Powertrain Integration
- Final FE Test
- Shakedown Testing

**Final Report**
- 1st Draft of Final Report
- Submit Final Report

**Project Phases**
- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5

**ST2 Demonstrator Complete**
Responses to Previous Year Reviewer‘s Comments

<table>
<thead>
<tr>
<th>Comment</th>
<th>Response</th>
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</thead>
<tbody>
<tr>
<td>Start-Stop was not in the primary pathway. Predictive engine and drive systems seem to also have been removed.</td>
<td>We evaluated start-stop from a 48V perspective, but since ST2 is an on-road, long haul vehicle, the benefits to the program would be negligible. DTNA continues to develop predictive systems, and the latest updates will be in the final ST2 demonstrator, but there was no need for additional ST2 funds to be used to develop this topic.</td>
</tr>
<tr>
<td>There are still big gaps to achieve the program goal of a 55% BTE demonstrator engine. It casts doubts if this can be achieved</td>
<td>New simulation results on engine technologies are now showing that we should be on a good path to reach the 55% BTE. Next steps is building and validating the performance to hit the program goal.</td>
</tr>
<tr>
<td>Questioned why single wide based tires would be abandoned at such an early stage when there is a clear advantage</td>
<td>Yes, wide based single tires have a rolling resistance advantage, but most of the market uses duals, so we wanted to tackle the tougher problem. Improving the dual solution in both rolling resistance and tire life.</td>
</tr>
</tbody>
</table>
## SuperTruck 2 Partnerships and Collaborations

<table>
<thead>
<tr>
<th>US National Labs</th>
<th>Universities</th>
<th>Industry</th>
<th>Fleet</th>
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<tbody>
<tr>
<td>Oak Ridge National Laboratory</td>
<td>University of Michigan</td>
<td>Michelin</td>
<td>Schneider</td>
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<tr>
<td>NREL</td>
<td>Clemson University</td>
<td>Johnson Matthey</td>
<td>Atkinson LLC</td>
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<td>Solution Spray Technologies</td>
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<td></td>
<td></td>
<td>Yinlun TDI LLC</td>
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<td></td>
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<td>Strick Gate</td>
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Daimler AG
Questions?