SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Vehicle Systems

DOE Contract: DE-EE0003303
NETL Project Manager: Ralph Nine
Program Investigator: Dennis W. Jadin, Navistar

DOE MERIT REVIEW
WASHINGTON, D.C.
May 17th, 2012
Outline

• Program Overview
• Barriers and Technology Roadmap
• Approach
• Technical Accomplishments
• Future Work
• Summary
Program Overview

Goals and Objectives
- Demonstrate 50% improvement in overall freight efficiency of a combination Tractor-Trailer
  - 30/50% improvement achieved through tractor/trailer technologies
  - 20/50% improvement achieved through Engine technologies
- Attain 50% BTE Engine
- Demonstrate path towards 55% BTE Engine

Barriers
- Achieving 50% freight efficiency while balancing Voice of Customer Needs
- Packaging of hybrid drive unit and Waste Heat Recovery Systems
- Maintaining tractor weight while adding new systems
- Availability of Suitable Battery Technology

Budget
- DOE recently approved new budget periods / phases >>>>
- An increased level of resources planned in budget periods 2 & 3 will accommodate project deliverables in periods 4 & 5.

<table>
<thead>
<tr>
<th>Budget Period</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10/01/10</td>
<td>08/31/12</td>
</tr>
<tr>
<td>2</td>
<td>09/01/12</td>
<td>09/30/13</td>
</tr>
<tr>
<td>3</td>
<td>10/01/13</td>
<td>06/30/14</td>
</tr>
<tr>
<td>4</td>
<td>07/01/14</td>
<td>03/31/15</td>
</tr>
<tr>
<td>5</td>
<td>04/01/15</td>
<td>09/30/15</td>
</tr>
</tbody>
</table>

Total Project Funding:  
- DOE $37,328,933
- Prime Contractor $51,801,146

DOE Funding Received: $ 13,393,868
Partners (Collaboration and Coordination with Other Institutions)

Navistar  
Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing

Alcoa  
Lightweight Frame Structures & Wheel Materials

ATDynamics  
Trailer Aerodynamic Devices

Behr America  
Cooling Systems

Meritor  
Hybrid Powertrain, Axles

Michelin  
Low Rolling Resistance Tires

Wabash National  
Trailer Technologies

TBD  
Composite Material Structures (was TPI)

Argonne National Lab  
Hybrid Drive Simulation and Controls & Battery Testing

Lawrence Livermore National Lab  
Aerodynamic Testing
### Barriers (Challenges) and Technology Roadmap

<table>
<thead>
<tr>
<th>System Area</th>
<th>Barriers</th>
<th>Technology Roadmap</th>
</tr>
</thead>
</table>
| Engine & Vehicle | Achieving 50% freight efficiency while balancing Voice of Customer Needs | ✓ Seek and Prioritize Voice of Customer Inputs  
• Rely on analysis (tradeoff) to select technology |
| Vehicle     | Packaging of hybrid drive unit and Waste Heat Recovery Systems            | ✓ Redesign drive unit and batteries to achieve overall size reduction.             |
| Vehicle     | Maintaining tractor weight while adding new systems                      | • Optimize Body Structure Requirements for over the road usage.  
• Utilize Advanced Materials for Light Weighting (Polycarbonate Glazing, Composites, Alloys) |
| Hybrid Drive | Suitable batteries (rugged, affordable, powerful) are not commercially available Weight penalty affecting FE | ✓ Develop a detailed battery specification  
✓ Reach out world-wide to potential suppliers  
✓ Select new supplier  
• Collaborate to develop lighter SuperTruck batteries  
• Identify additional lightweighting opportunities |
Approach:
Vehicle Vs. Chassis Efficiency

% Fuel Economy Improvement

1. Aero Enhancements
   - Gap Reduction
   - Aero Drop at Highway Speed
   - Surrogate Camera Mirrors
   - Tractor Shapes
   - Trailer Shapes & Features

2. Lightweight
   - SMARTandem 6x2 axles
   - Composite Cab
   - Composite Trailer Structure
   - Next Gen Wide Based Singles and Wheels

3. Driveline
   - SMARTandem 6x2 Gears
   - Next Gen Wide Based Singles Tires
   - Tire Inflation Maintenance System
   - Opti Lube Level Axle Fill
   - Electronic Leveling Air Consumption

4. Hybrid
   - Dual Mode Hybrid Drive
   - Electrified Accessories
     - Power Steering
     - Air Compressor
     - AC Compressor
   - SMARTandem 6x2 axles
   - Composite Cab
   - Composite Trailer Structure
   - Next Gen Wide Based Singles and Wheels

30% Target
Approach:

Technology Roadmap - Vehicle

- Projection
- Completed

On-Road Demo and Initial Steady-State FE Results
Mule 1 Hybrid Highway and City FE Results
Mule 2 w/Hybrid, TuCo, Aero Trailer, etc.
Final SuperTruck Vehicle Demonstrator

Percent Freight Efficiency Improvement

Q1 '11 Q2 '11 Q3 '11 Q4 '11 Q1 '12 Q2 '12 Q3 '12 Q4 '12 Q1 '13 Q2 '13 Q3 '13 Q4 '13 Q1 '14 Q2 '14 Q3 '14 Q4 '14 Q1 '15 Q2 '15 Q3 '15 Q4 '15

Target

SuperTruck – Development and Demonstration of a Fuel Efficient Class 8 Tractor & Trailer
DE-EE0003303
Mule Truck #2 Build Status – Planned to do for freight efficiencies for 2012

- Dual Mode Hybrid
- Electric Turbo Compounding (TuCo)
- Active 5th Wheel
- Dynamic Ride Height (includes front air)
- Full Length Drive Wheel Skirts
- High-rise Roof Air Fairing
- ATDynamics Boat Tail
- Michelin Wide Based Single Tires (WBS Tires)
- Camera Surrogate Mirrors
- External LED Lighting, Including Headlights
- Meritor Air Disk Brakes
- Meritor SMARTandem 6x2 Axle System
- Power Steering Upgrades
- Wabash Light Weight Trailer

Mule #1 items
Mule #2 new technologies
### Vehicle Systems Technology Rollout (2011-2012)

<table>
<thead>
<tr>
<th>Technology Category</th>
<th>Area of Concentration</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aerodynamics</td>
<td>Advanced Tractor Shape - Speed Form Study</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Surrogate Rear View Mirrors - Initial Concepts</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Advanced Trailer Shapes - PIV - Particle Image Velocimetry</td>
<td>3Q 2011</td>
</tr>
<tr>
<td></td>
<td>Tire Skirting; Steer, Drive &amp; Trailer</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Tractor-Trailer Gap Reductions; Dyn. 5th wheel, Cab Extenders</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Cooling System Exhaust location Impacts on Aerodynamics</td>
<td>1Q 2012</td>
</tr>
<tr>
<td></td>
<td>Trade-off Studies of Cooling System Concepts</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Determine Thermal Management Configuration</td>
<td>3Q 2012</td>
</tr>
<tr>
<td></td>
<td>Aero Drop, Electronic Suspension Leveling, Tractor &amp; Trailer</td>
<td>2Q 2012</td>
</tr>
<tr>
<td>2. Vehicle Lightweighting</td>
<td>Advanced Modular Chassis Construction</td>
<td>4Q 2012</td>
</tr>
<tr>
<td></td>
<td>Efficient Drive Axle, 6x2 Configuration</td>
<td>1Q 2012</td>
</tr>
<tr>
<td></td>
<td>Cab Architecture Downselection</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Cab Structural Design &amp; Material Selection</td>
<td>4Q 2012</td>
</tr>
<tr>
<td></td>
<td>Trailer Architecture Selection</td>
<td>4Q 2012</td>
</tr>
<tr>
<td></td>
<td>Trailer Structural Design &amp; Material Selection</td>
<td>4Q 2012</td>
</tr>
<tr>
<td>3. Driveline</td>
<td>Optimized Wide-Based Single Tires &amp; Wheel End Equipment</td>
<td>4Q 2011</td>
</tr>
<tr>
<td></td>
<td>Next Gen Wide-Based Single, Low Rolling Resistance Tires</td>
<td>4Q 2011</td>
</tr>
<tr>
<td></td>
<td>Tire Pressure Monitoring and Inflation</td>
<td>2Q 2012</td>
</tr>
<tr>
<td></td>
<td>Efficient Drive Axle, 6x2 Configuration</td>
<td>1Q 2012</td>
</tr>
<tr>
<td>4. Hybrid Drivetrain</td>
<td>Mule Vehicle #1</td>
<td>3Q 2011</td>
</tr>
<tr>
<td></td>
<td>Electrified Accessories; Power Steering, AC &amp; Air Compressors</td>
<td>3Q 2011</td>
</tr>
<tr>
<td></td>
<td>Mule Vehicle #2</td>
<td>3Q 2012</td>
</tr>
</tbody>
</table>
**Technical Accomplishments**

1. **Aerodynamics – Development Progress**

- **Boat tail and rear skirts design verification and optimization in collaboration with program partners ATDynamics**

- **Trailer skirts design evaluation & optimization in collaboration with program partners Wabash National**

- **Tractor shape development through 1/8th scale Wind Tunnel testing and CFD**

- **Evaluation of Trailer design modifications planned for upcoming tests**

- **Design & Testing of Tractor components such as drive wheel skirts, belly pans etc. for aero improvement**

- **Integration of steering axle and cooling flow with minimal impact on aerodynamics**
## 1. Aerodynamics – Status

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Measured</th>
<th>Normalized Cd%</th>
<th>Freight Efficiency Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProStar Short Sleeper (Baseline)</td>
<td>2010</td>
<td>100</td>
<td>0%</td>
</tr>
<tr>
<td>ProStar Long Sleeper</td>
<td>2007</td>
<td>94</td>
<td>3%</td>
</tr>
<tr>
<td>Aero Concept 2010-2011 (Tractor Only)</td>
<td>2010</td>
<td>88</td>
<td>6%</td>
</tr>
<tr>
<td>Aero Concept 2010-2011 (Tractor &amp; Trailer)</td>
<td>2010</td>
<td>75</td>
<td>12.50%</td>
</tr>
<tr>
<td>Best Tested Feb 2012 w/Steer Axle &amp; Cooling Flow Integrated</td>
<td>2012</td>
<td>60</td>
<td>20%</td>
</tr>
</tbody>
</table>
## Technical Accomplishments

### 2. Lightweighting

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>DESCRIPTION</th>
<th>SAVINGS (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle - Smart Tandem</td>
<td>Removes one drive axle (6 X 2 configuration)</td>
<td>-400</td>
</tr>
<tr>
<td></td>
<td>Light Weight rotor &amp; caliper yields 10#/ wheel end</td>
<td>-200</td>
</tr>
<tr>
<td>Brake System - Disc</td>
<td>Increased tube dia. with thinner wall</td>
<td>-70</td>
</tr>
<tr>
<td>Single Prop Shaft</td>
<td>Wide Based Singles with NG Aluminum Rims</td>
<td>-1000</td>
</tr>
<tr>
<td>Tires and Wheels</td>
<td>Composite / multi material panels</td>
<td>-500</td>
</tr>
<tr>
<td></td>
<td>Single one hundred gallon fuel tank</td>
<td>-110</td>
</tr>
<tr>
<td>Body - Cab</td>
<td>Second 100 gal. of fuel = 700 #</td>
<td>-700</td>
</tr>
<tr>
<td>Plastic Fuel Tank</td>
<td>Composite load floor</td>
<td>-500</td>
</tr>
<tr>
<td>Fuel</td>
<td>Weight reduced components</td>
<td>-220</td>
</tr>
<tr>
<td>Trailer</td>
<td>Weight reduced system</td>
<td>-200</td>
</tr>
<tr>
<td>Trailer Suspension</td>
<td>Less modules</td>
<td>-200</td>
</tr>
<tr>
<td>Chassis System</td>
<td>Modular style batteries</td>
<td>-600</td>
</tr>
<tr>
<td>Cooling Modules</td>
<td>Improved Power density</td>
<td>-895</td>
</tr>
<tr>
<td>Third Gen. Batteries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third Generation E motors</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Possible Reduction: -5595

Hybrid Incremental: 4700#

Net Reduction: -895

Proposed Target Weight Reduction for FE: 4000#

Lightweighting Gap: 3105#
### 3. Driveline - Wheel End Equipment Team

**New Wheel End Decision Matrix**
- Alcoa, Michelin, Meritor, Navistar
- 25 total people participating (some full time, others part time)
- 6 design choices plus current production
- 3 weighted major design considerations
  - 18 total categories

**Chose the Next Generation Wide Based Single Tire for driving and trailer use.**
- 1.5% FE savings from aero drag reduction
- Weight savings in axle and wheel ends
- Team developing new wheel end design spec.
- Michelin started tooling for new tire.

<table>
<thead>
<tr>
<th>Factors for Consideration</th>
<th>Weight</th>
<th>Subcategory Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>50%</td>
<td>310</td>
</tr>
<tr>
<td>Rolling Efficiency - Tires</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Aero impacts - i.e. tire size, wheel size, wheel covers, suspension ride height, overall height</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>System Weight</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Alignment Control / Vehicle Efficiency</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Bearing &amp; Seal Drag</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Brake Drag</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Design Feasibility</td>
<td>35%</td>
<td>550</td>
</tr>
<tr>
<td>Durability / Reliability</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>dFMEA</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>System Temperatures (Tires, Wheels, Brakes, Seals, Bearings) difficulty to control temperatures</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Development Time (to Demo units)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>SuperTruck investment within current planned budget</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>System Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Investment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Alignment Control / Tire Wear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercialization</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Commercial Applicability / Flexibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Servicability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation from Industry Standards - positive acceptance by industry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Technical Accomplishments

4. Hybrid Powertrain – Performance Modeling

• **Trade-Off Study of Electric Machine and Battery Size**
  – A range of hybrid machines and batteries have been studied
  – Final report expected April 1

First iteration of SuperTruck
Dual-mode hybrid is here

![Diagram showing trade-off between cost, fuel economy, and freight efficiency.](image-url)
Technical Accomplishments

4. Hybrid Powertrain – Real-World Testing

Ohio Transportation Research Center
- Fuel Economy Testing
- In progress

Michigan Proving Grounds
- Software and Calibration Development
- Summer, 2012

Navistar Proving Grounds
- Software and Calibration Development
- Fall/winter, 2012

Colorado
- Highway Testing
- Summer, 2012
Navistar’s “Kentucky Route” is commonly-used to quantify fuel consumption of class 8 vehicles
- Low traffic density for good repeatability
- Highway-type route (high speed)
- Large database to compare to
- 75% of the total weighting

The remaining 25% can be a test-track urban cycle, like CILCC or HHDDT Transient
## Technical Accomplishments

### 4. Hybrid Powertrain – Fuel Economy Testing

#### Fleet Test Vehicles

<table>
<thead>
<tr>
<th></th>
<th>Control Vehicle</th>
<th>Pre-Hybrid ProStar</th>
<th>Hybrid Powertrain Mule 1</th>
<th>Hybrid Powertrain Mule 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIN</td>
<td>E4173</td>
<td>E2933</td>
<td>E2941</td>
<td>E2933</td>
</tr>
<tr>
<td>Model Year</td>
<td>2009</td>
<td>2010</td>
<td>2010</td>
<td>2010</td>
</tr>
<tr>
<td>Transmission</td>
<td>10-Spd Manual</td>
<td>Eaton AutoShift</td>
<td>Dual-Mode Hybrid</td>
<td>Dual-Mode Hybrid</td>
</tr>
<tr>
<td>Tractor Weight</td>
<td>19,150</td>
<td>18,320</td>
<td>22,060</td>
<td>TBD</td>
</tr>
</tbody>
</table>

#### 55 mph Steady-State Test Results

<table>
<thead>
<tr>
<th></th>
<th>Tractor Weight Diff.</th>
<th>MPG</th>
<th>Freight Eff at Constant Freight Weight (Cubed-Out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid Relative to ’09 Control Truck</td>
<td>+2910</td>
<td>3.7% Better*</td>
<td>3.7% Better*</td>
</tr>
<tr>
<td>Hybrid Relative to ’10 Pre-Hybrid</td>
<td>+3760</td>
<td>7.1% Better*</td>
<td>7.1% Better*</td>
</tr>
</tbody>
</table>

*Results not complete. More runs required to achieve statistical validity*
<table>
<thead>
<tr>
<th>Vehicle Technologies</th>
<th>Target</th>
<th>Status</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Hybrid</td>
<td>Dual-mode Gen II w/EiG batteries</td>
<td>6%</td>
<td>3.7%*</td>
</tr>
<tr>
<td>3. Driveline</td>
<td>SMARTandem &amp; Opti Lube&lt;br&gt;Next Gen WBS Tires, Electronic Leveling&lt;br&gt;Electrified Accessories*</td>
<td>4%</td>
<td>-</td>
</tr>
<tr>
<td>2. Lightweight</td>
<td>SMARTandem, Ladder assembly&lt;br&gt;Next Gen WBS Wheels &amp; Tires&lt;br&gt;Composite Cab &amp; Trailer Structures</td>
<td>4%</td>
<td>-</td>
</tr>
<tr>
<td>1. Aero Enhancements</td>
<td>Dynamic 5th Wheel&lt;br&gt;Dynamic Ride Height&lt;br&gt;Surrogate Camera Mirrors&lt;br&gt;Tractor Shapes&lt;br&gt;Trailer Shapes &amp; Features&lt;br&gt;Reduced Height w/NG WBS Tires</td>
<td>16%&lt;br&gt;20%</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>30%</td>
<td>23.7%</td>
</tr>
</tbody>
</table>

* Electrified accessories are contained within the Hybrid system results.
** Next Gen WBS Tires provide improvement through reduced vehicle height and frontal area in Aero.
Future Work for 2012

- Complete steady-state and urban driving cycles to demonstrate 5-10% improvement in freight efficiency due solely to hybrid drive
- Commission the next-gen mule 2 truck and its upgraded technologies
  - Electric turbo-compounding
  - Aero improvements (tractor and trailer)
  - Smart tandem
  - Low-rolling resistance tires
  - Air suspension
  - Active fifth wheel
- Upgrade both hybrid drive units for improved shift reliability
- Demonstrate a 25% improvement in freight efficiency using the next-gen mule 2 truck and a trailer with add-on aero features
- Build and install Gen-3 hybrid drive units and re-engineered batteries in mule trucks
- Finish 1/8th and 1/3rd scale wind tunnel testing
- Finalize the demo truck concept
**Relevance:**
- The potential of a class 8 truck and trailer combination configured to save 9 billion gallons of diesel fuel per year, reduce our dependence on foreign oil and improve our environment by reducing green house gases has significant national and global interests.

**Approach:**
- Project focus is on assessing and developing both engine and vehicle technologies to improve freight efficiency while balancing voice of customer requirements in a class 8 truck and trailer integrated design.

**Technical Accomplishments:**
1. Several aerodynamic scale-models have been developed and evaluated in the wind tunnel. A significant improvement over the baseline has been observed.
2. The hybrid drive unit and battery pack has been redesigned. A weight reduction of approx. 1400 lbs is predicted.
3. Highly-efficient axles and tires have been selected and will be tested this year.
4. The dual-mode electric hybrid drive system has been demonstrated on-road and is generating fuel economy data.

**Partnerships & Collaborations:**
- Cross-functional and industry partnership teams are working well together. Good mix of skills and resources to address the technical tasks in this project.

**Future Directions:**
- Continue to progress towards a vehicle and engine demonstration of various efficiency improvement technologies.
Technical Accomplishments
1. Aerodynamics – Timeline of activities

Transition to new 1/8th scale, rolling-road wind tunnel facility—moving belt better simulates vehicle moving down the road

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Tunnel Tests (1/8th scale)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Tunnel Tests (1/3rd scale)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling Flow</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Phase I – Baseline model test
Phase II – Updated SuperTruck model test

Design verification and optimization as design evolves & details are added

Coast down testing for aero performance validation
Technical Accomplishments

1. Aerodynamic Analysis

Vehicle Thermal Management Systems

- 1-D System Simulation Goals
  - Improve system performance
  - Minimize energy usage of fans and pumps
  - Support waste-heat recovery systems
  - Decouple sub-system interactions

- Under-hood Airflow Analysis
Technical Accomplishments
1. Aerodynamics – Gap Reduction

Advantages of Reduced Tractor/Trailer Gap
• Projected 1.5% Highway Fuel Economy Improvement
• Systems can be independent of trailer
• Potentially better aerodynamic/fuel economy payback than trailer mounted devices for fleets with large trailer to tractor ratios

Aero Benefit vs Gap Closure
1. Aerodynamics - VTTI Camera Surrogate Mirrors

Cooperative Research Project with VTTI

- Formal kickoff meeting at Navistar being scheduled for April
- VTTI is researching suitable hardware / cameras / lenses
- Navistar arranging loan of test vehicle

Projected 1.5% FE potential savings

- Convex and Flat Mirror Replacements
- Door & Fender Camera Mounting Locations
**Technical Accomplishments**

4. Hybrid Powertrain – Gen -3 Hybrid Drive Unit

**Generator housing**

- Torsional Isolator
- Overdrive gear set
- Integrated with mid mount

- Simple planetary reduction 5:1 vs. compound 6.5:1 for gen-2
- Underdrive gear set vs. overdrive for gen-2
- Output shaft
- Driven oil pump
- Eliminated

**Key Features**

- New smaller inverter
  - Mounted under T.M. rather than Generator
- 1.6:1 for Gen & Engine
- Solid shaft
- Sealed Bearing
Technical Accomplishments

4. **Hybrid Powertrain – Touch-Screen Data Display**

- Critical system parameters are displayed and monitored in the cabin
  - Electric machine
  - Battery
  - Turbo-compounding
- Will be used to make certain calibration choices and monitor diagnostic messages

![Instrument Panel-Mounted Touch-Screen](image1.png)

![Typical Display Graphics](image2.png)