Modeling the Hybridization of a Class 8 Line-Haul Truck

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Introduction

- Hybridization already in commercial vehicles: pick-up, delivery, bus, garbage… but little development for a class 8 tractor-trailer!
- Class 8 truck: 20% of US truck use
- Very high use means quicker payback time for any fuel saving technology; even small improvements can be viable.
- This study: to quantify and analyze the benefits of hybridization using modeling and simulation:
  - Assumptions (sizing, models, etc.)
  - Fuel savings on duty cycles
  - Fuel savings on roads with grades
Baseline Truck Specifications

- **Engine**: 317 kW (425 hp) Cummins ISX 14.9 L
- **Transmission**: 10 speed (Eaton FRO, 11.06 to 0.75)
- **Final Drive**: 2.64:1
- **Tires**: 0.515 m radius (P295/75R22 Bridgestone M720)
- **Mechanical accessories**: 5.2 kW
- **Electrical Accessories**: 1 kW
- **Mass**: 36,300 kg (100% load) / 26,000 kg (50% load)
Mild Hybrid Configuration: Starter-Alternator

- Baseline + 50 kW Motor + 2.5 kWh Battery
- Accessories electrification: 3 kW elec. / 1 kW mech. (vs. 0.3 / 5.2 for the conv.)
- Start/Stop: engine is OFF when the truck idles and battery is not depleted
- Torque assist, regenerative braking (limited)
- No shifting time reduction
Full-Hybrid Configuration: Series-Parallel

- Baseline + 200 kW Motor (MG1) + 50 kW Motor (MG2) + 25 kWh Battery
- Accessories electrification: 3 kW elec. / 1 kW mech. (vs. 0.3 / 5.2 for the conv.)
- Start/Stop, EV capability at low speeds
- Torque assist, regenerative braking
- Shifting time reduction
Argonne’s PSAT Is Used for Simulation

- **PSAT = Powertrain System Analysis Toolkit**
- Primary DOE modeling software for *21st Century Truck*
- >700 users, >130 companies
- Interfaces with Matlab/Simulink
- Forward-looking model
- Hot conditions
Fuel Savings on Standard Drive Cycles

- In percentage of fuel saved, hybridization is most beneficial on urban cycles.
- Full HEV gets higher fuel savings.

*Repeated 5 times for Charge balance*
Regenerative Braking and Engine Efficiency Are the Main Factors Behind Fuel Savings

- Smaller motor on the mild HEV reduces regen braking
- Longer shifting times on the mild HEV also reduces regen braking

- Mild HEV has no EV capability: at low speeds, engine must be ON, and then works in inefficient areas

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Driving without Stops Reduces the Fuel Savings of the Hybrid

- Full HEV loses half of its fuel savings “improvement” when the cycle does not include stops!
- HEV has no benefits when cruising: less transients means less advantage for the HEV
Using Rolling Hills To Study Impact of Grade

- **Driving scenario:**
  - Constant speed (60 mph) target
  - “Rolling hills”: sinusoidal shape
  - Maximum grade varies from 0 to 4%
  - Hill Period = horizontal distance from valley to valley
    
    \[ = 2 \times \text{horizontal distance from bottom to top of the hill} \]
    
    \[ = 1, 2 \text{ or } 3 \text{ km} \]

![Sectional view of the road](image)

(max grade: 3%)
Hybrid Control on Grades Needs Grade-Specific Tuning to Ensure SOC Balance

- 1%: no braking in downhill
- 2%: some regen braking, but not enough to compensate for the electrical accessory load. No torque assist for uphill.
- >2.5%: regenerative braking provides energy for the electrical accessory load and uphill torque assist.
- Level of torque assist needs to be tuned for each grade level to ensure battery charge-balancing.
Conventional Vehicle Does Not Perform the Same Duty!

- Hybrid can follow the trace more often than the conventional
- Without electric assist, conventional vehicle loses speed
- Grade is time based → the distance uphill will be shorter than planned if the speed is below the target

- As a result, it is as if the conventional drives on a different hill:
  - Shorter uphill (both in elevation and distance), same downhill
  - After the hill, vehicle is at lower elevation: -7 m after 30 km (4% grade, hill period = 1 km)

- Solution: use a distance-based driver (future work)
Fuel Savings on Grade Suggest Grade Should Be Considered for Hybridization Impact Evaluation

- Up to 8% savings for a mild hybrid, 16% for a full hybrid
- Full HEV gets higher fuel savings, thanks to higher regen capacity and torque assist capability.

Fuel savings of hybrids truck w.r.t. a conventional truck

Mild HEV

Full-HEV

100 % Load
Conclusion

- Mild HEV offers good fuel savings with limited investment, thanks to Start/Stop and moderate regen levels
- Full-Hybrid offers best fuel savings, thanks to high power electric system
- Best savings in urban driving: 20-40 % (full-HEV), ~10% (mild-HEV); a few percents on a highway driving
- Grade: up to 16% savings (full-HEV), ~8% (mild-HEV)
- Future work
  - Optimize hybrid configuration and sizing
  - Use real-world routes/cycles instead of standard cycles or theoretical routes
  - Use distance-based driver to remove time-based duty cycle bias
  - Implement torque-assist control with road profile look-ahead
- Future studies will use Autonomie, Argonne’s next generation model-based design environment
Acknowledgements/ Contact

- PSAT development was funded by Lee Slezak (US DOE)
- This study was done to support the National Academy of Science Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles

- Other Argonne Papers at SAE COMVEC 2010:
  - Validation of a Line-Haul Class 8 Combination Truck (2010-01-1998) [CV 406]
  - Plug-and-Play Software Architecture to Support Automated Model-Based Control Process (2010-01-1996) [CV406]
  - Impact of Advanced Technologies on Medium-Duty Trucks Fuel Efficiency (2010-01-1929) [CV 306]

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