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Reducing Fuel Consumption through Semi-Automated Platooning with Class 8 Tractor Trailer Combinations

Michael Lammert and Jeffrey Gonder
National Renewable Energy Laboratory

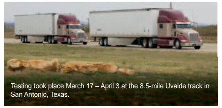
Project Objective

The objective of this project is to evaluate the fuel savings potential of semi-automated truck platooning. Platooning involves reducing aerodynamic drag by grouping vehicles together and decreasing the distance between them through the use of electronic coupling, which allows multiple vehicles to accelerate or brake simultaneously.

The U.S. Department of Energy's interest in platooning stems from the opportunity to reduce petroleum consumption. This study addressed the need for data on American-style line-haul sleeper cabs with modern aerodynamics and over a range of trucking speeds common in the United States. Other organizations may be looking into additional benefits and concerns—such as safety, road congestion reduction, and public and driver acceptance—which were not addressed in this study.

Test Vehicles

- Two platooned SmartWay tractors
- One SmartWay control tractor
- All tractors had 53-ft van body trailers with side skirts

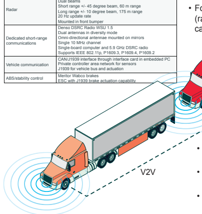

Testing took place March 17 – April 3 at the 8.5-mile Uvalde track in San Antonio, Texas.

Demonstration System Specifications

Category	Demonstration Platooning System Description
Manufacturer/integrator	**Peloton Technology Inc.**
Radar	Delphi Electronic Scanning Radar: Dual beams Short range +/- 45 degree beam, 60 m range Long range +/- 10 degree beam, 175 m range 20 Hz update rate Mounted in front bumper
Dedicated short-range communications	Denso DSRC Radio WSU 1.5 Dual antennas in diversity mode Omni-directional antennae mounted on mirrors Single 10 MHz channel Single-board computer and 5.9 GHz DSRC radio Supports IEEE 802.11p, P1609.3, P1609.4, P1609.2
Vehicle communication	CAN/J1939 interface through interface card in embedded PC Private controller area network for sensors J1939 for vehicle bus and actuation
ABS/stability control	Meritor Wabco brakes ESC with J1939 brake actuation capability

Enabling Technologies for Semi-Automated Platooning

- Forward object detection (radar, laser, stereo cameras, etc.)
- Dedicated short-range communications
- Vehicle-to-vehicle communications (V2V)
- Vehicle braking and torque control interface



Track Testing Plan

Data Collected

- SAE Type II fuel economy track testing to quantify fuel consumption reduction in a controlled setting
  - Ten constant-speed tests at 55 mph, 65 mph, and 70 mph
  - One variable speed test
  - 20 - 75 ft vehicle gaps (note: 65 mph = 95 ft/second)
  - 65,000 lb and 80,000 lb gross vehicle weight (GVW) loading tests
- Gravimetric fuel economy is primary data gathered using weigh tanks
- J1939 data collection, including some Peloton channels
  - Coolant temperature and "fan on" time to assess lowered ram air cooling effects
  - Vehicle following distance
  - Driver position error

	Test Conditions				
Trailing Distance	55 mph, 65,000 lb	65 mph, 65,000 lb	70 mph, 65,000 lb	Variable Speed, 65,000 lb	65 mph, 80,000 lb
20 ft		X			
30 ft	X	X	X		
40 ft		X			
50 ft	X	X	X	X	X
75 ft		X			

Test Truck Specifications

Van Specification	Lead Tractor Trailer	Trailing Tractor Trailer	Control Tractor Trailer
Manufacturer	Peterbilt	Peterbilt	Peterbilt
Model	386	386	579
Model year	2011	2011	2013
Engine manufacturer	Cummins	Cummins	PACCAR
Engine model	ISX-15 450	ISX-15 450	MX-13 475
Engine model year	2010	2010	2010
Emissions equipment	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR
Transmission	Eaton Fuller 10-speed	Eaton Fuller 10-speed	Eaton Fuller 10-speed
Retarder/regenerative braking	Engine brake	Engine brake	Engine brake
Tires	Michelin XDA Energy	Michelin XDA Energy	Goodyear Fuel MAX
Trailer configuration	53' van trailer with angled side skirts; 13'6" tall by 102" wide	53' van trailer with angled side skirts; 13'6" tall by 102" wide	53' van trailer with angled side skirts; 13'6" tall by 102" wide
Trailer side skirt	Freight Wing AeroFlex	Freight Wing AeroFlex	DuraPlate AeroSkirt

SAE J1321 Type II Fuel Consumption Test Method

- Track testing to quantify fuel consumption in a controlled setting with removable weigh tanks on each vehicle
  - Warm-up runs ensure all trucks at stable operating temperatures
  - Baseline configuration runs with all vehicles in isolation
  - Test configuration runs with test trucks (lead truck and trailing truck) in platoon formation
    - Measurements are a test to control ratio (T/C)

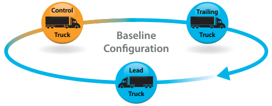
$$T/C \text{ ratio} = \frac{\text{Fuel used by test vehicle}}{\text{Fuel used by control vehicle}}$$

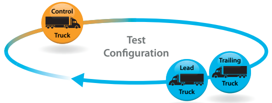
Lead vehicle T/C ratio = T_L/C

Trailing vehicle T/C ratio = T_T/C

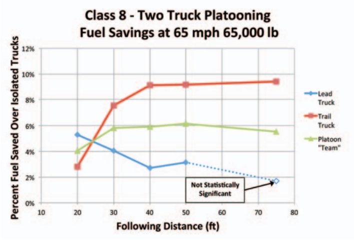
Team T/C ratio = $(T_L + T_T)/C$

  - Baseline ratio is compared to test ratio to calculate a percent change in fuel consumption for the test condition
  - Atmospheric changes from run-to-run are accounted for
    - Control truck is in isolation during baseline and test configuration runs
    - Test trucks isolated during baseline runs and in platooning formation during test runs





Fuel Savings Results



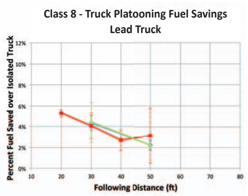
- Team fuel savings ranged from 3.7% to 6.4%
- Percent savings at 70 mph were lower than at 55 mph and 65 mph
- Higher GVW negatively impacted fuel-saved percent
- Closer following distances caused the engine fan on the trailing truck to engage, negatively impacting fuel savings
- Magnitude is currently being investigated

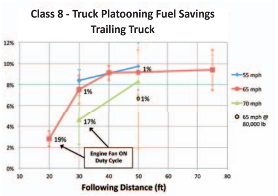
	Percent Fuel Saved (Gravimetric)					
	Lead Truck		Trailing Truck		Team	
Test Conditions	Nominal	95% CI	Nominal	95% CI	Nominal	95% CI
55 mph, 65k, 30'	4.33%	0.70%	8.38%	1.03%	6.38%	0.28%
55 mph, 65k, 50'	2.22%	0.49%	9.72%	2.24%	6.01%	1.33%
65 mph, 65k, 20'	5.28%	0.34%	2.81%	0.71%	4.04%	0.52%
65 mph, 65k, 30'	4.06%	1.19%	7.53%	1.33%	5.80%	1.26%
65 mph, 65k, 40'	2.69%	0.99%	9.10%	0.71%	5.91%	0.84%
65 mph, 65k, 50'	3.14%	2.65%	9.17%	2.11%	6.15%	2.37%
65 mph, 65k, 75'	*1.69%*	*2.35%*	9.39%	1.93%	5.53%	2.12%
70 mph, 65k, 30'	4.42%	1.92%	4.62%	2.33%	4.52%	2.12%
70 mph, 65k, 50'	2.23%	0.35%	8.36%	1.44%	5.31%	0.90%
VAR, 65k, 50'	*2.70%*	*8.32%*	*4.22%*	*6.82%*	*3.45%*	*7.56%*
65 mph, 80k, 50'	*0.55%*	*3.58%*	6.67%	4.84%	3.68%	2.07%

*Pink cells indicate results are not statistically significant at 95% confidence interval (CI).

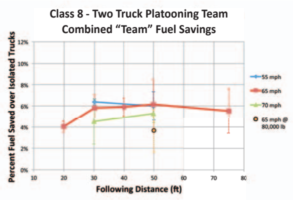
Fuel Consumption Results: Individual Fuel Savings

- 2.2% to 5.3% savings @ 65,000 lb GVW
- Shorter following distances demonstrated a reduction in fuel use for the lead tractor
- Trailing truck saw savings from 2.8% to 9.7%
- Tests with no "fan on" time had savings of 8.4% to 9.7%
- Fan duty cycle as high as 19%
- Engine coolant temperatures on the trailing truck generally increased as following distances decreased





Fuel Consumption Results: Team Fuel Savings



Proposed Future Work

There are many questions still to be answered about the fuel savings potential from platooning of Class 8 tractor trailers.

Future research needs under consideration:

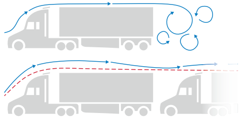
- More data points/test sets to confirm the trends seen here and to add greater following distances to clarify the optimum configuration
- Incorporate direct aerodynamic study into track testing (truck-mounted anemometer, smoke trails, etc.)
- Computational fluid dynamics modeling
- Test platoons of more than two tractor trailer combinations
- Identify what percent of national line-haul miles would be conducive to platooning
- Design aerodynamic aids specific to platooning to address the loss of cooling airflow over the radiator for the trailing tractor

Key Findings

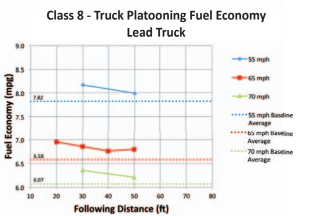
- Opportunity exists for significant fuel savings through platooning technology in line-haul applications
  - Tests demonstrated fuel savings for both the lead (up to 5.3%) and trailing (up to 9.7%) trucks
  - The demonstrated "team" savings of 6.4% could be an attractive return on investment for a fleet
  - Engine coolant temperature needs to be monitored/addressed for the trailing vehicle
  - Atmospheric conditions may play a strong role in the savings attainable due to the loss of ram air on the trailing vehicle; optimum following distance may be dependent on ambient temperature
- Heavy payloads affect the percent savings from platooning, but still result in substantial fuel savings
- SAE conference paper will be published at COMVEC in October 2014 (2014-01-2438)
- NREL technical report will be published in late 2014

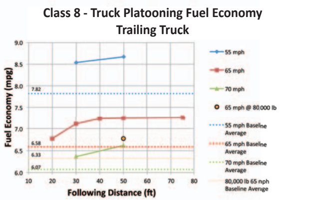
Fuel Economy Results

- Baseline mpg is the test distance of 59.4 miles divided by an average of all baseline run fuel consumption results from both test trucks for each speed and load condition
- Platooning mpg is calculated by applying the SAE procedure calculated percent fuel savings to the baseline fuel consumption average
- Platooning improved fuel economy at all speeds and conditions
  - Best mpg overall was platooning at 55 mph
- Baseline condition tests show effect of speed on mpg
  - 7.82 mpg @ 55 mph
  - 6.58 mpg @ 65 mph
  - 6.07 mpg @ 70 mph
- Baseline condition tests show effect of mass on mpg
  - 6.58 mpg @ 65 mph and 65,000 lb
  - 6.33 mpg @ 65 mph and 80,000 lb

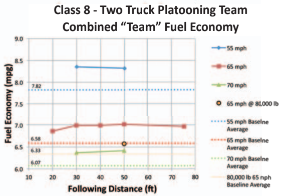


Fuel Economy Results: Individual MPG





Fuel Economy Results: Team MPG



Acknowledgements

This work was supported by the U.S. Department of Energy (DOE) Advanced Vehicle Testing Activity through Intertek Testing Services, North America, and would not have been possible without the generous donation of time and vehicles from Peloton, Inc. The authors wish to thank Lee Slezak and David Anderson at DOE and Josh Switkes at Peloton for their support.