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Experimental Fuel Consumption Results from a Heterogeneous Four-Truck Platoon

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Abstract

Platooning has the potential to reduce greenhouse gas emissions of heavy-duty vehicles. Prior platooning studies have chiefly focused on the fuel economy characteristics of two- and three-truck platoons, and most have investigated aerodynamically homogeneous platoons with trucks of the same trim. For real world application and accurate return on investment for potential adopters, non-uniform platoons and the impacts of grade and disturbances on a platoon's fuel economy must also be characterized. This study investigates the fuel economy of a heterogeneous four-truck platoon on a closed test track. Tests were run for one hour at a speed of 45 mph. The trucks used for this study are two 2015 Peterbilt 579's with a Cummins ISX15 and a Paccar MX-13, and two 2009 Freightliner M915A5's, one armored and the other unarmored. Many analysis methodologies were leveraged to describe and compare the fuel data, including lap-wise and track-segment analysis. The methodology for dividing the data into laps is described in detail. The influence of other factors beyond the aerodynamics of platooning is discussed. CAN fuel rate analysis showed excellent agreement with previous experimental trends for two and three-truck platoons. In general, the indicated fuel economy benefits in this study were 5-11% for following vehicles and 0-4% for the lead vehicle in platoon relative to their baseline fuel consumption. On a cumulative basis, all platoons saved fuel, ranging from 6% to 8% versus the sum of the standalone trucks' fuel consumption. The practical implications of the fuel economy results are discussed, as well as avenues for future research.

Introduction and Motivation

Platooning is controlled coordination of two or more vehicles in a convoy, sometimes called CACC (Coordinated or Cooperative Adaptive Cruise Control). The distance between vehicles in a platoon can be controlled tightly at no additional fatigue to the driver. Platooning vehicles can also respond quickly to braking events of the leader, much more quickly than the typical human driver's reaction time of 1-1.5 s [1]. Therefore, vehicles in a platoon can follow each other much more closely than would usually be considered a safe following distance under human operation. It is implied that under very close following conditions, platooning technology must be extremely robust before it is safe for wide-scale implementation.

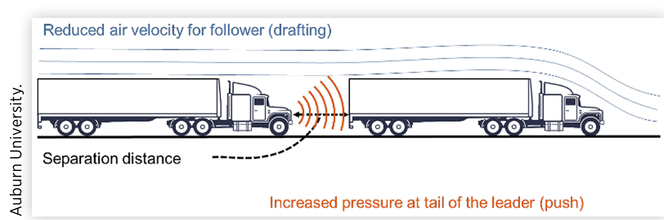
Platooning is under investigation as a fuel-saving technology. Close-following significantly reduces aerodynamic drag for both leading and trailing vehicles. According to the NRC in 2010, aerodynamic drag represents roughly half of a Class-8 truck's on-highway fuel usage, meaning a 20% reduction in drag roughly equals a 10% reduction in fuel usage, if all other sources of energy loss remain equal (i.e. accessory, rolling resistance, drivetrain, braking) [2]. It is by aerodynamics that platooning saves fuel. At risk of oversimplifying the aerodynamics, following (or trailing) vehicles experience reduced wind velocity due to shielding, and the leading vehicles experience an increased aft pressure, especially at distances closer than 75' (23 m). Figure 1 provides a visual of these effects.

For platoons of three vehicles or more, vehicles in the middle of a platoon experience a quasi-superposition of leader and follower aerodynamic benefits, which is demonstrated in [3,4].

The three primary motivations of platooning are greenhouse gas (GHG) reduction, reduced operating costs, and development of self-driving and V2V transportation systems for safer roadways.

From a global GHG reduction perspective, heavy duty trucks account for roughly 15% of the total transportation greenhouse gases in the US, despite the fact that passenger

FIGURE 1 Aerodynamic effects of platooning



vehicles far outnumber heavy duty vehicles on roadways [5]. This number may be higher in recent times due to an increased road share of heavy-duty trucks during the pandemic.

From a monetary perspective, fuel is one of the most expensive operational costs of commercial trucking. According to the 2018 NACFE Fleet Fuel Study (formerly ATRI), for long-haul trucking fuel is either the most or the second-most expensive operational cost after driver wages [6]. It follows that even a small reduction in fuel consumption in heavy-duty trucks creates significant savings.

Finally, from an autonomy perspective, platooning is an accessible technology to push the frontier towards a fully self-driving transportation infrastructure. As a true V2V technology, it is extended beyond the production SAE level I and II systems that are available on passenger vehicles, the best-known example being Tesla's Autopilot system. As autonomous driving systems move beyond pure perception-based logic and begin to use V2V communications to enhance performance, platooning provides a safe, relatively low-risk test bed. Fully-realized and robust platooning could someday allow drivers to perform other tasks or even sleep while on the road.

In order to successfully bring platooning to the fiscally conscious commercial trucking market, a business case must be built with accurate ROI. To build the business case for platooning, the fuel savings must be well-characterized. Therefore, the body of platooning research has either focused on the "in-situ" fuel-savings of platooning or the wide view logistics of forming a platoon. With regards to the "in-situ" studies, prior research has only investigated two- and three-truck platoons [4,7-24]. In these studies, the trucks are often of an identical or similar trim with regards to both powertrains and aerodynamics, which we will call a homogeneous platoon. Real world platooning would involve many different trucks and trailers, so there is a need to research heterogeneous platoons and platoons of four trucks or more.

Experimental Methods

Trucks and Control System

The trucks used for this study are two 2015 Peterbilt 579s utilizing different engines, a Cummins ISX15 and a Paccar MX-13. The remaining trucks are two 2009 Freightliner M915A5s, each with a Detroit Diesel S60, where one vehicle is armored and the other unarmored. A summary of the trucks is presented in Table 1. Note that the Paccar-engine Peterbilt truck is denoted as A1, the Cummins-engine Peterbilt truck is denoted as A2, the armored M915 is denoted as T13, and the unarmored M915 is denoted as T14.

The Auburn University platooning system uses a variety of sensors and algorithms to enable robust on-road performance. For the Vehicle to Vehicle (V2V) communication network, a Dedicated Short Range Communications (DSRC) radio is used. For range measurement, a combination of GPS, radar, and transmitted wheel-speed measurements are used as the inputs to an estimator. Control of the trucks is accomplished via sending commands over the vehicles' Controller Area Networks (CAN) using the architectures in place for Adaptive Cruise Control (ACC). A central, stand-alone computer running Robotic Operating Software (ROS) unites all of the sensors and systems and runs the control and estimation algorithms. For safety, there are redundant shut-off mechanisms including a hard-wired emergency stop that reverts the truck back to manual driving mode. The trucks are also equipped with electrically-assisted steering wheels to enable level II autonomy, although for this testing the trucks were manually steered. For more details on the Auburn University CACC system, please refer to [20,21,25-27].

TABLE 1 Specifications of the trucks used in this study

Truck ID	A1	T14	T13	A2
Manufacturer	Peterbilt	Freightliner	Freightliner	Peterbilt
Model	579	M915A5	M915A5	579
Model Year	2015	2009	2009	2015
Engine	Paccar MX-13	Detroit Diesel IV S60	Detroit Diesel IV S60	Cummins ISX15-415ST2
Peak Torque @ RPM	1750 ft.lbs @ 1000	1650 ft.lbs @ 1200	1650 ft.lbs @ 1200	1650 ft.lbs @ 1000
Rated Horsepower	430 hp	500 hp	500 hp	415 hp
Truck & trailer gross weight	35660 lbs	37996 lbs	46947 lbs	38020 lbs

FIGURE 2 NCAT test track, a 1.7 mile (2.7 km) oval

Test Procedure

The testing occurred at the National Center for Asphalt Technology's (NCAT) 1.7 mile (2.7 km) oval test track in Opelika, Alabama, shown in Figure 2. The trucks were warmed up for 1 hour prior to running an official test, and downtime between tests was limited to 30 minutes maximum. Strict warmup and downtime requirements limit the influence of transient parameters, such as: tire pressure, tire temperature, engine coolant temperature, driveline friction, etc. Rain or high winds were considered grounds for invalidating a test run. The Appendix describes the weather during the test campaign. All tests began on the south straight of NCAT. The test duration was 26 laps, or roughly 1 hour at the track speed limit of 45mph.

All trailers were of the dry-van type and unloaded in an effort to emphasize aero benefit over rolling resistance. For the trucks equipped with diesel particulate filters, the active regen was disabled for during the tests. Engine fans were turned on full-time to eliminate the possibility of switching on and off at close distances.

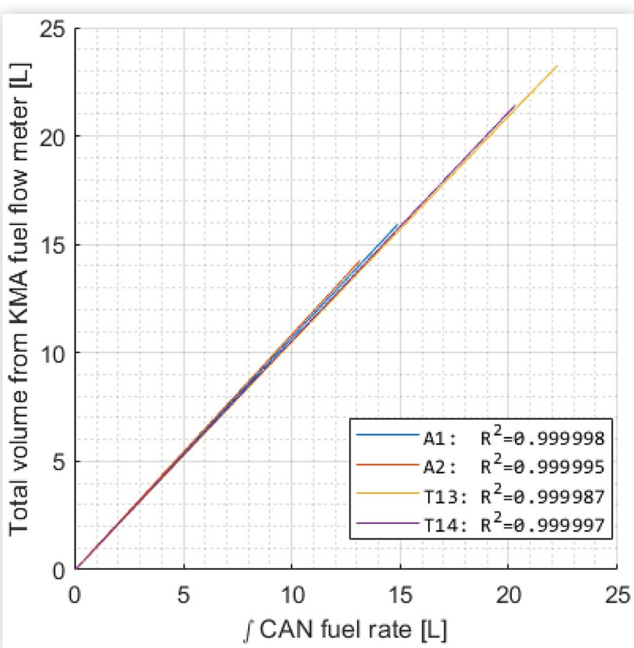
Fuel Measurement

As this study's key thrust is to characterize the fuel economy of trucks in a variety of conditions, accurate fuel measurement was of the utmost importance. Some platooning studies have made use of the SAE fuel measurement standard for heavy duty vehicles, SAE J1321 Type II Fuel Testing [28], colloquially known as Type II fuel testing. Type II fuel tests have strict requirements, including a control truck at all times, a strict warmup period, minimal downtime between tests, test periods of an hour or greater, and a host of environmental stipulations regarding wind intensity, temperature, humidity, and precipitation. Unfortunately, with only four available test trucks, there was no way to have a control truck on track during the four-truck testing, but the guidelines for warmup period, downtime, test duration, and environmental conditions were incorporated as guidelines for the test procedure.

In this study, the CAN fuel rate signal was used as a standalone fuel measurement. Indeed, several studies have justified using the CAN rate for fuel usage analysis [4,20,21,29].

To investigate to accuracy of the CAN fuel rate signal, data from an AVL KMA fuel flow meter was compared to the integrated CAN fuel rate on all four trucks. The KMA fuel flow meters were in calibration, with an accuracy of ±0.1%of the measured volume. Figure 3 shows that the CAN fuel rate

FIGURE 3 Correlation of integrated CAN fuel rate and data from AVL fuel flow meter for all four trucks



provides a very consistent measurement of the fuel used, if slightly conservative; on average the KMA fuel volume is 6.64% higher than that of the integrated CAN fuel rate. The trucks were run under the same conditions and for the same amount of time as the tests presented in this study. Since fuel economy gains will be measured for each vehicle relative to its own operational baseline (solo operation on the NCAT track), the absolute offset of the CAN data from the KMA data will not affect the results.

Test Matrix

The test matrix was designed to emphasize heterogeneity. Figure 4 show the different configurations that were studied. Additionally, runs were performed in which a passenger vehicle cut into the middle of the four-truck platoon, temporarily separating it into the two two-truck platoons. Analysis of the constituent two-truck platoons and cut-in runs is outside of the scope of this paper.

The order of the trucks in the four-truck platoon is Peterbilt (A1), unarmored M915 (T14), armored M915 (T13), Peterbilt (A2). Several factors influence this decision:

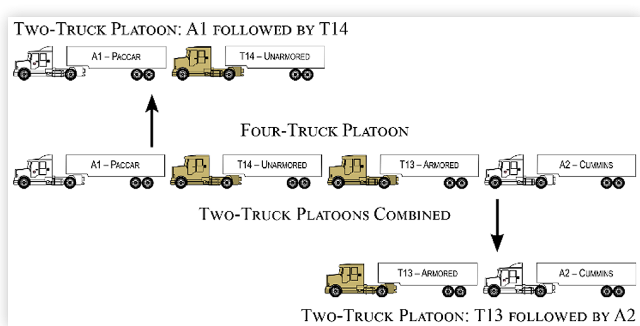
1. Having one platoon led by an M915 truck, which are less aerodynamic, and one by a Peterbilt, which are more aerodynamic, gives two aerodynamic configurations, which is important in a study aimed at heterogeneous platoons.
2. Putting the armored truck in the third position maximizes the disruption during cut-in tests due to the increased mass of the armored truck. Higher disruption increases the measurability.

The spacings chosen for this study were 100', 50', and 35' (in meters 30.48 m, 15.24 m, and 10.67 m, time gaps are 1.515 seconds, 0.758 seconds, and 0.53 seconds). Previous studies have seen a reduction in benefit for the final truck in both two- and three-truck platoons at spacings of 50-30' (15-9 m) throughout CFD, wind tunnel and experimental test-track studies [3,4,8,10,15,20,29].

Data Processing

The use of CAN data for fuel results enables great flexibility in the processing of the results. Track position was calculated

FIGURE 4 Three platoon configurations were studied but only four truck results are presented herein



using GPS data and the winding number. The steps taken to do so were:

1. Locate a point roughly in the center of the track.
2. Rotate the track such that the starting point of the test lies on the x-axis.
3. Calculate the vector from the center of the track to a truck's position over the course of the run, as shown in Figure 5.
4. Calculate the arctangent of the vector by Equation (1)

$$\theta_i = \operatorname{atan}\left(\frac{y_i}{x_i}\right) \quad (1)$$

where x and y are the truck's position

5. Use the periodicity of θ to indicate the start of a new lap, shown in Figure 6. Include hysteresis to reject the chattering that sometimes occurs due to noise in the GPS position signal.

FIGURE 5 Drawing vectors from the center of the track to a truck's position for use in lap segmentation

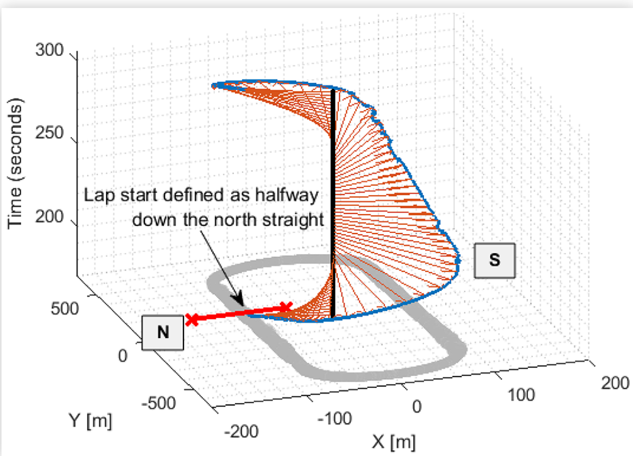
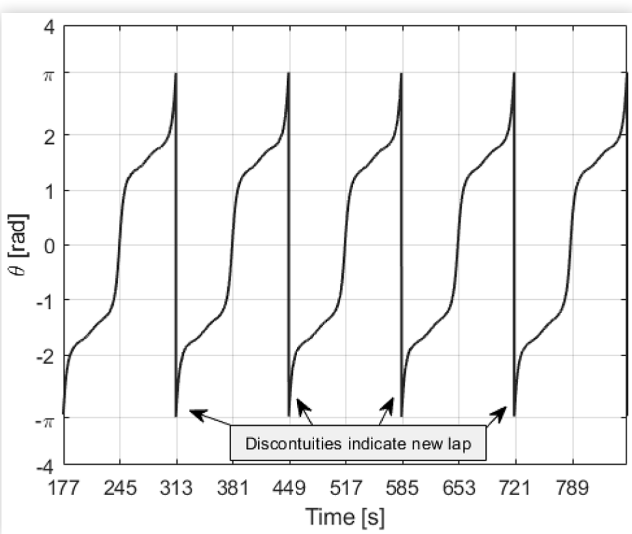


FIGURE 6 Using θ periodicity to divide data into laps



6. Because θ is nonlinear, integrate the wheelspeed signal over the course of the lap to arrive at a linear position metric. Use the theta discontinuities to divide the integrated wheelspeed into laps, shown in Figure 7.
7. Create a correlation between θ and the position by integrated wheelspeed. This step was necessary because some runs had faulty wheelspeed data recording. The correlation is shown in Figure 8.

Laps were then validated in terms of:

- Compliance with the commanded headway
- The gear during the run
- The engine fan state and DPF regen state on the applicable trucks

FIGURE 7 Creating a linear lap position signal from wheelspeed and θ periodicity

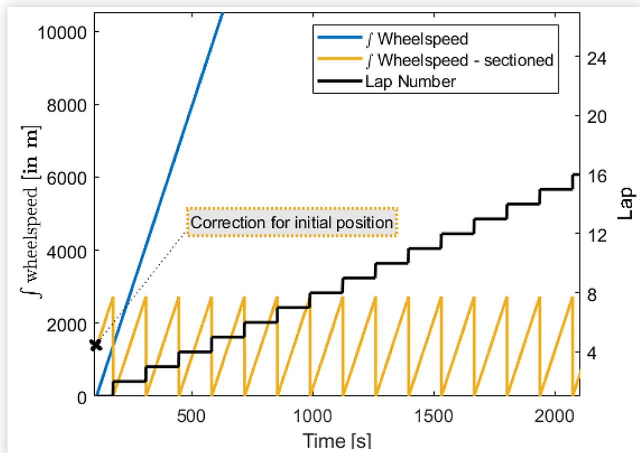


FIGURE 8 Correlation between theta and non-dimensional lap position

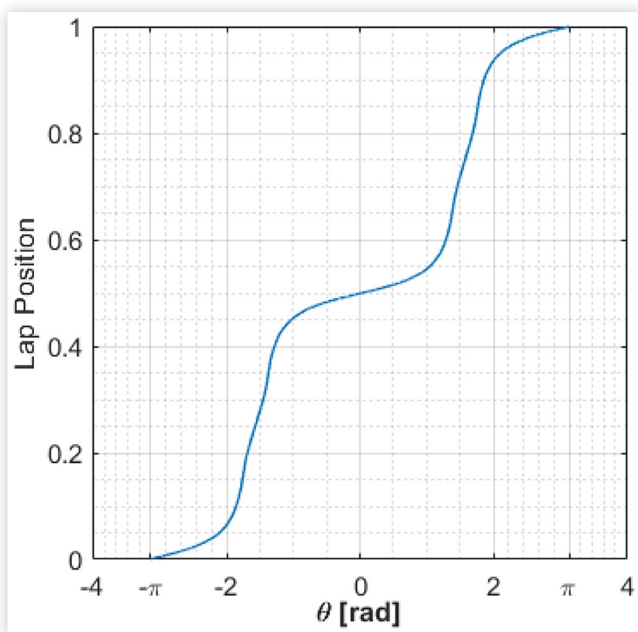
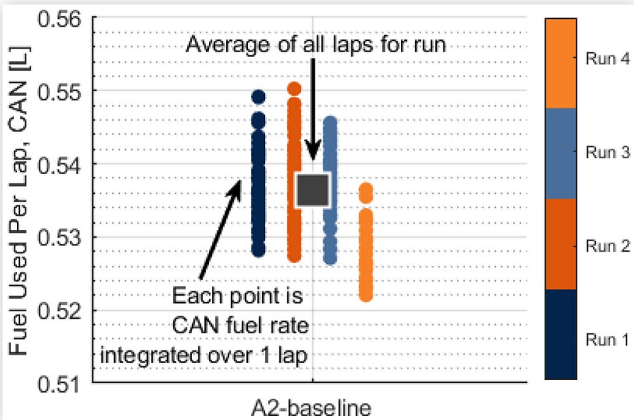


FIGURE 9 Sample CAN fuel by lap result, showing individual runs and laps



The variance of the headway and cumulative fuel were calculated for every lap, and any laps falling outside of 1.5× the Interquartile Range (IQR) were invalidated. Then laps could be plotted individually, as shown in Figure 9, along with the average.

Results and Discussion

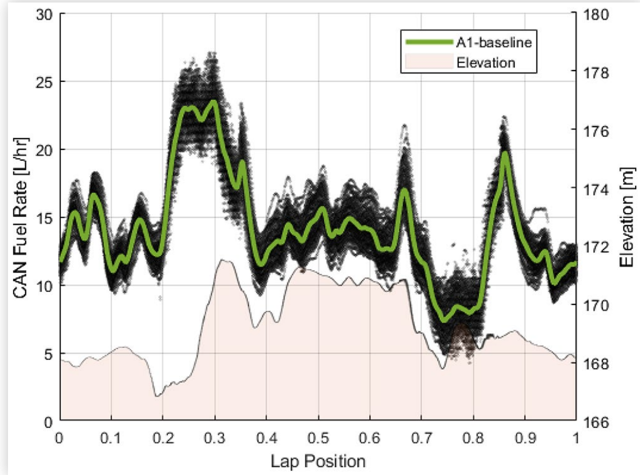
The key aim of this study is identify a reduction in fuel consumption due to decreased aerodynamic drag. It is believed that the benefit of platooning is solely due to lower drag. However, there are other factors influencing the fuel consumption that must be mentioned. The four loads resisting the forward motion of a truck are:

1. Rolling resistance (including drivetrain losses)
2. Aerodynamic drag
3. Grade (in the case of negative grade, the truck is positively accelerated)
4. Auxiliary loads (climate control, electrical draw)

At any given point in time, the balance between torque at the wheels and resistive forces on the truck in the form of grade, aerodynamic load, rolling resistance, and auxiliary loads determine the acceleration of the truck. This can be negative, positive, or zero. Ideally, for this study all variables except those impacted by platooning would be fixed, and the change in fuel use during platooning would be a true measure of aerodynamic benefit. However, there were many other factors coloring the results throughout the course of the tests. There are slight but non-negligible grade changes at the NCAT test track. Figure 10 shows the moving averaged fuel trace for an A1 baseline test (solo operation) with elevation overlaid. The influence of grade on the resulting fuel trace is especially noticeable.

Crucially, platooning impacts the dynamics that a truck experiences. A truck in a platoon "inherits" the dynamics of the truck in front of it, whose dynamics depend on the disturbances of the environment and the control strategy of the platoon. Figure 11 shows the normalized CAN fuel rates for

FIGURE 10 A1 moving-averaged CAN fuel rate with elevation data and individual lap data overlaid

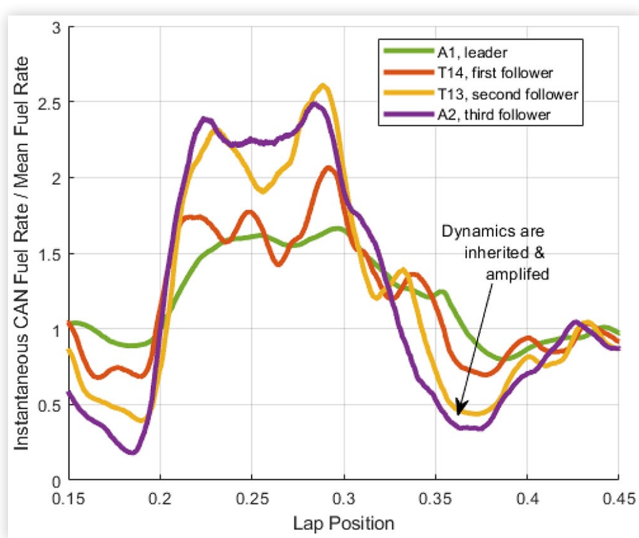


the four-truck (4T) 100' platoon, where all 4T 100' runs are being ensemble averaged at each lap position. The ensemble-averaging is demonstrated in Figure 10 and normalization is to the mean fuel use of each truck. Clearly, the dynamics of each truck is being amplified in the trucks that follow, which has motivated ongoing control enhancements.

Cumulative Fuel Results

As discussed in the previous section, an ideal platooning test for fuel economy would perfectly isolate the aerodynamic benefit of platooning. Hypothetically, the entire fuel trace would be at a lower rate. This is not the case in practice with the present control formulation. However, despite the amplified dynamics experienced during platooning shown in Figure 11, the trucks still benefitted significantly on a fuel basis while platooning.

FIGURE 11 Normalized CAN fuel rates from a four-truck platoon at 100′ headway



Results for the first truck in the four-truck platoon A1 are tabulated in Table 2, and in Figure 12. It is expected that the leader of a four-truck platoon would experience the same trends as if it were a two-truck platoon. At 100', there was slightly higher average fuel use as compared to baseline. At 50' and 35', A1 benefits appreciably. As the results are presented below, the A1 benefit is -0.9%, 1.7%, and 4.0% **at** 100', 50' and 35', respectively. The negative result at 100' is likely due to measurement uncertainty and not a physical phenomenon.

Baseline run #1, depicted in Figure 12, was left in the data intentionally for two reasons:

1. There is question about the equivalence of fuel energy content. The second, third, and fourth runs were conducted after the main onsite tank was refilled. Figure 13 plots the same data as Figure 12 but denotes the fuel source change. The 100' runs support this hypothesis, but the 35' and 50' runs do not.
2. The third and fourth baseline were run concurrently with the other trucks, with trucks spaced ~90 degrees out of phase on the track. This corresponds to 2200 feet (~670m), which, at the time of test matrix design, seemed to be enough distance to prevent any 'background platooning' impacts. Figure 14 shows the distance to the preceding vehicle hit a minimum of 202m during A1's third baseline, which had the lowest consumption of all A1 baselines. The decreasing distance over the course of this run is due to slight cruise-control velocity differences between the trucks. Figure 15 shows the distances to the vehicle ahead for all vehicles on track during the fourth A1 baseline run, where A1 reached a minimum of 432m to the

TABLE 2 Percent benefit for lead truck, A1, in a four-truck platoon

Distance	35 feet	50 feet	100 feet
Time Gap	0.530 s	0.758 s	1.515 s
Percent Benefit	4.0%	1.7%	−0.9%

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FIGURE 12 Lead truck CAN fuel results by lap for all four-truck configurations versus the baseline, each point represents a lap of data

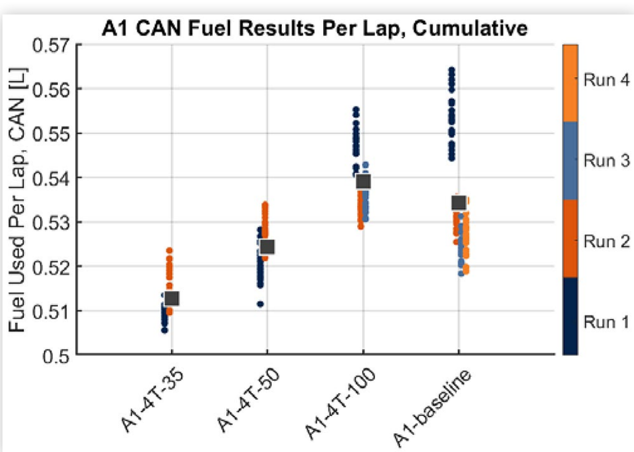

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FIGURE 13 Lead truck CAN fuel results for all four-truck platoons and the baseline with onsite main fuel tank refill denoted

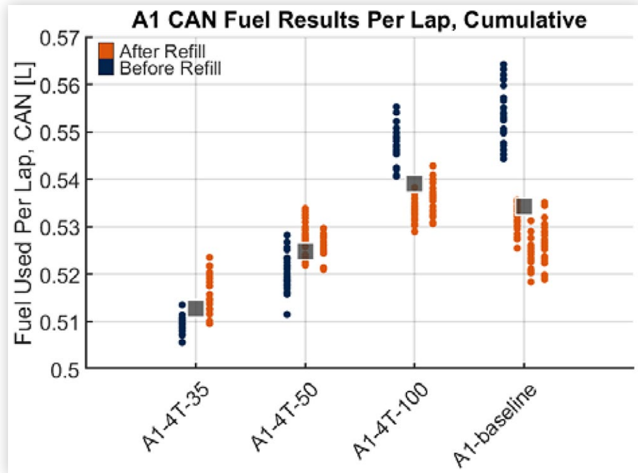

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FIGURE 14 Distance to the vehicle in front on track for A1 Baseline run #3, showing close distances for a baseline run

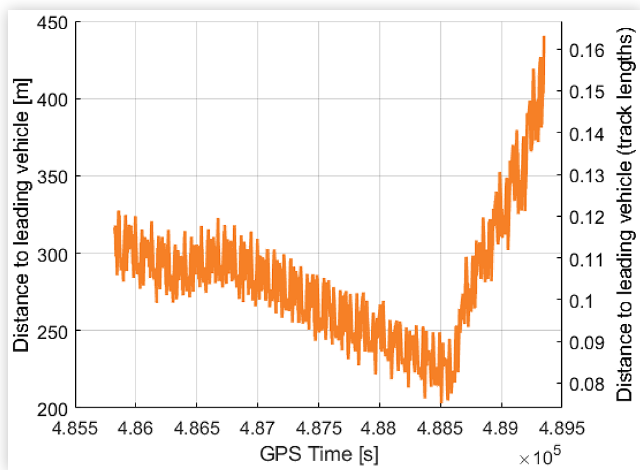

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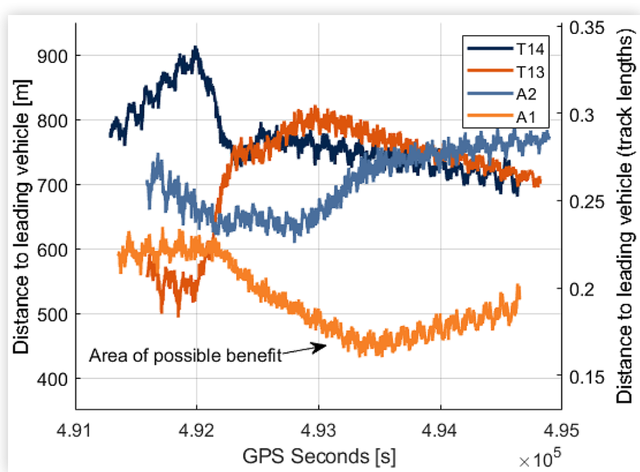
FIGURE 15 Distances for all four vehicles running concurrent baseline, including run #4 for A1



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forward vehicle. While the distances are much larger the platooning headways under study, it may have benefitted A1 slightly, causing the baseline fuel consumption to be artificially low during those runs. These distances were calculated using GPS time in conjunction with the lap position metric described earlier in this paper.

Results for the second truck, T14, are tabulated in Table 3, and shown in Figure 16. Prior three-truck platoon studies are a good reference for the T14 results, with the key difference being the non-uniformity of the trucks. To put it another way, the second truck in a four-truck platoon most probably experiences similar drag reduction as the second truck in a three-truck platoon. The results of this study indicated that at 100' T14 benefits up to 11.4%**.** There were less data runs for 35' and 50', and the indicated benefit on those runs is less than that of the 100' run at 10.2% and 7.7% respectively. The reason for this result is not clear, as it is expected that the truck should benefit more at closer headways.

Results for the third truck, T13, are tabulated in Table 4, and shown in Figure 17. As the third truck in a four truck platoon, it is expected to benefit more aerodynamically than the trucks ahead of it, but it also has more difficult control demands. Moreover, T13 is the heaviest truck, which means that for a given acceleration, it will require more fuel than the other trucks, all other things being equal. Finally, the two baselines shown for T13 were both run concurrently with the three other trucks on the track; so they may display slightly lower fuel consumption than if only T13 had been on track. The baseline consumptions of T13 were indeed 4% lower than those of T14, despite the weight difference in favor of T14. Even still, T13 benefitted considerably from platooning with an indicated **5.6%, 9.5%, and 9.5%** benefit for **100', 50' and 35'**.

TABLE 3 Percent benefit for 2nd truck, T14, in a four-truck platoon

Distance	35 feet	50 feet	100 feet
Time Gap	0.530 s	0.758 s	1.515 s
Percent Benefit	10.2%	7.7%	11.4%

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FIGURE 16 Second truck CAN fuel results by lap for all four-truck configurations versus the baseline

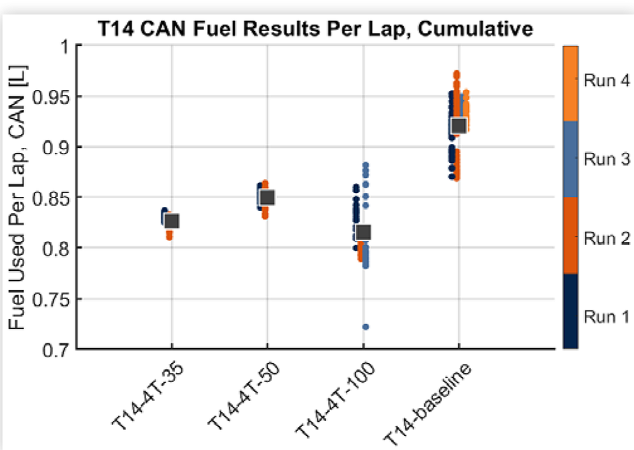

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TABLE 4 Percent benefit for 3rd truck, T13, in a four-truck platoon

Distance	35 feet	50 feet	100 feet
Time Gap	0.530 s	0.758 s	1.515 s
Percent Benefit	9.5 %	9.5 %	5.6%

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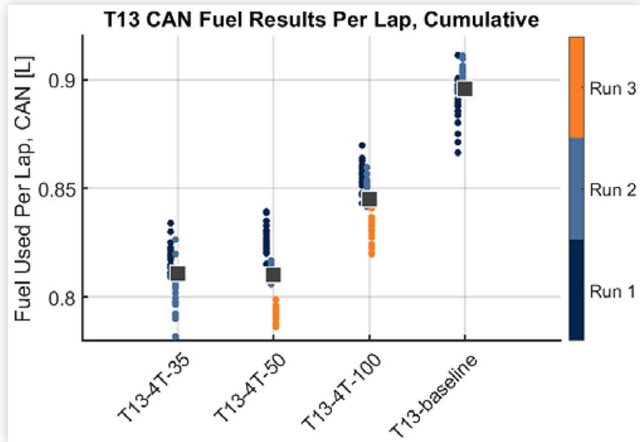
FIGURE 17 Third truck CAN fuel results by lap for all four-truck configurations versus the baseline



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A2, the last truck in the four-truck platoon, was expected to exhibit the same trends as the last vehicle in a three-truck platoon, with some additional benefit due to the larger wake of three trucks leading. Results for A2 are tabulated in Table 5, and shown in Figure 18. Many experimental, wind tunnel, and simulation studies have shown that the last truck in a platoon experiences a reduction in fuel economy benefit at

TABLE 5 Percent benefit for last truck, A2, in a four-truck platoon

Distance	35 feet	50 feet	100 feet
Time Gap	0.530 s	0.758 s	1.515 s
Percent Benefit	7.4%	7.8%	6.3%

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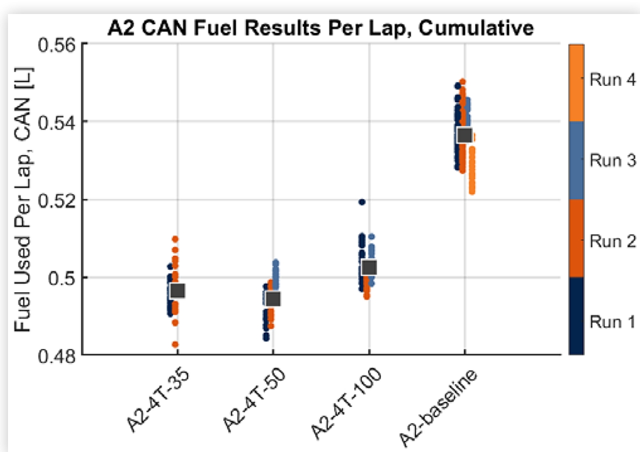
FIGURE 18 Last truck CAN fuel results by lap for all four-truck configurations versus the baseline



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close following distances. The available data indicates 6.3%, 7.8%, and 7.4% **benefit for** 100', 50' and 35'. A reduction in benefit does occur in the present data (7.8% vs. 7.4%), although it is very slight and within the experimental and methodology error.

The results for the entire platoon on a percent difference basis are summarized in Figure 19. In general, the second and third trucks T14 and T13 benefited the most on percent basis, followed by the final truck A2, then distantly by the lead vehicle A1. There are several potential reasons why the fourth truck is not benefitting the most out of all trucks:

- The fourth truck is more aerodynamic than the second and third trucks, and therefore it has less potential for drag reduction.
- The fourth truck, with its engine fan on full time and a larger cab for the climate control to cool, sent a larger fraction of power to accessories than the second and third truck. As the accessory power draw increases relative to the power used to overcome aerodynamic drag, the observed fuel economy benefit from platooning decreases on a percent basis. This is because platooning only decreases aerodynamic drag, with no effect on auxiliary loads or rolling resistance.
- Middle trucks are subject to both reduced wind velocity from shielding and to increased aft pressure, effects which correspond to trailing and leading respectively. The fourth truck is only a follower, therefore it experiences the shielding effect only.

Because the platoon in this study consists of disparate trucks with vastly different powertrain efficiencies, fuel use on an absolute basis is important for highlighting the potential ROI on a commercial platooning system. Figure 20 shows the average fuel use of each truck in each configuration over the run length of 26 laps. It is worth noting that the military trucks, T13 and T14, consume up to 67% more fuel than the

FIGURE 19 Summary of fuel consumption results for the entire four-truck platoon across all spacings

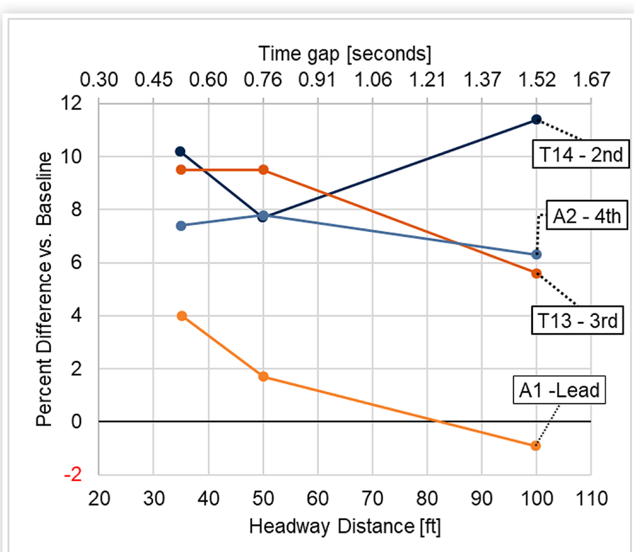


FIGURE 20 Average CAN fuel consumption over the course of an entire run, divided by truck then spacing

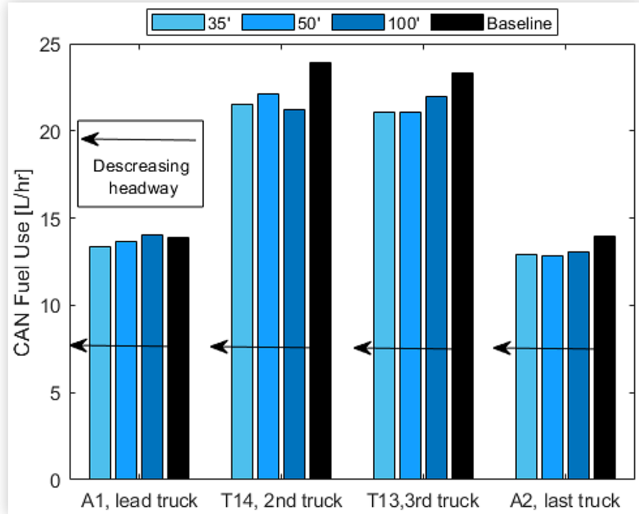
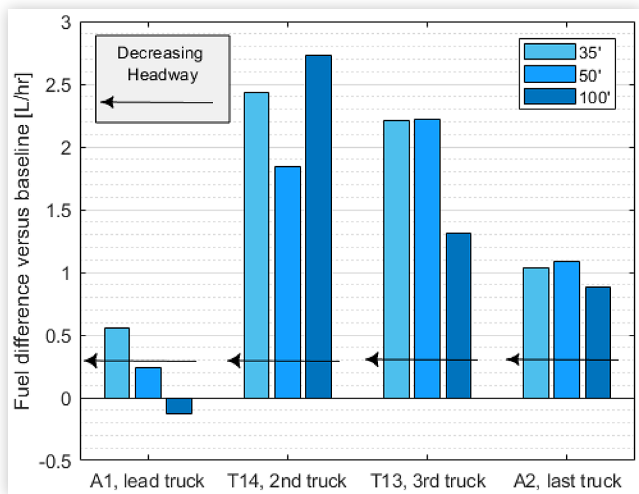


FIGURE 21 Difference between the average CAN consumption during baseline and each platoon configuration for each truck

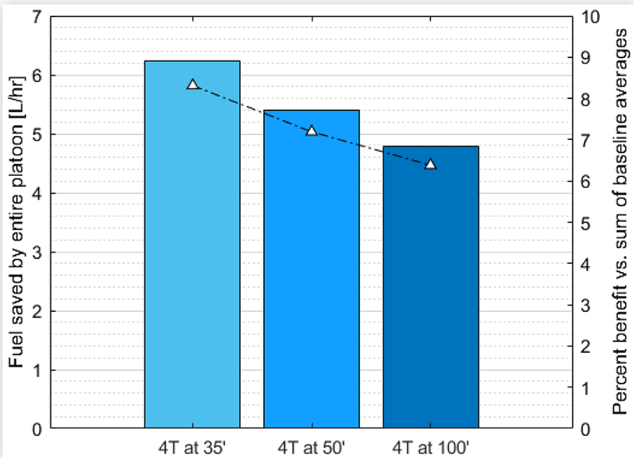


Peterbilts, A1 and A2. Also the slightly higher fuel use of A1 at 100' becomes trivial in the light of the other trucks' benefits. Figure 21 shows the difference between the baseline average fuel consumption and platoon averages. Figure 22 shows the average savings of the entire platoon. All platoons save fuel on a cumulative basis, and the fuel savings increase with decreasing headway.

Conclusions

To the authors' knowledge, the results presented herein are the first published experimental four-truck platoon fuel results in literature. Four trucks were platooned at 35', 50', and 100' headway spacings on a closed test track. In all but one headway spacing for one truck, every truck consumed less fuel than its

FIGURE 22 Total fuel saved versus baseline by summing entire platoon fuel consumption in each case



baseline average at every headway spacing. The case with a higher indicated platooning fuel consumption was a lead truck at 100 feet, a condition where prior research has indicated there is little to no aerodynamic benefit to for the lead truck in platoon [8]. The authors can state the following with confidence:

- The four-truck platooning results are in good agreement with prior studies of two- and three-truck platoons.
- The fuel economy benefit of the lead vehicle was modest. However, there were several external factors influencing its baseline data.
- Fuel economy of the second and third platooning trucks benefitted the most. Their relatively poor aerodynamics may be a factor in this, emphasizing the need for continued heterogeneous platoon research.
- The fourth truck saw the most consistent fuel economy benefit across all headway spacings.
- Because these tests were conducted at the test track speed limit of 45 mph, the results in this study likely underestimate the benefits that would be seen at highway speeds with no disturbances.

In the future, there is work to be done optimizing CACC platoons for grade and disturbances. The NCAT track lacks challenging elevation changes, and further investigations are planned at the more dynamic American Center for Mobility (ACM) test track, which has much more demanding elevation changes. These tests serve as a baseline reference case for those tests.

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Definitions/Abbreviations

ACC - Adaptive Cruise Control

ATRI - American Transportation Research Institute

AVL - Anstalt für Verbrennungskraftmaschinen List

A1 - 2015 Peterbilt 579 in lead position of platoon

A2 - 2015 Peterbilt 579 in fourth position of platoon

CACC - Cooperative Adaptive Cruise Control

CAN - Controller Area Network

CFD - Computational Fluid Dynamics

DSRC - Dedicated Short Range Communications

GHG - Greenhouse Gases

GPS - Global Positioning System

IQR - Interquartile Range

KMA - Kraftstoffe Messanlage

NACFE - North American Council for Freight Efficiency

NCAT - National Center for Asphalt Technology

NRC - National Research Council (American)

ROI - Return on Investment

ROS - Robotic Operating Software

SAE - Society of Automotive Engineers

T13 - 2009 M915A5 in third position of platoon

T14 - 2009 M915A5 in second position of platoon

V2V - Vehicle to Vehicle

Appendix

The weather during the test was consistent, with only two days showing high winds.

Time	Temperature (° F)			Dew Point (° F)			Humidity (%)			Wind Speed (mph)			Pressure (Hg)			Precipitation (in)
Sep	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Total
16	74	69.3	67	69	65.9	62	97	89.2	71	26	18.9	13	29.6	29.4	29.3	0.01
19	74	70.8	66	67	62.3	57	84	74.3	66	14	8.5	0	29.8	29.7	29.6	0
20	75	66.8	60	57	52.8	50	73	61.6	46	23	12	6	29.8	29.8	29.7	0
23	79	70.5	64	65	60.5	57	80	71.1	56	8	4	0	29.7	29.6	29.6	0
24	74	70.5	66	71	67.5	61	96	90	76	14	8.4	3	29.6	29.5	29.4	0
25	80	73.9	69	71	69	66	97	85.3	64	10	5.3	0	29.6	29.5	29.5	0.22
26	84	72.3	64	66	64	62	100	78.2	49	8	1.9	0	29.6	29.6	29.5	0
27	81	74.6	69	71	68	65	90	80	68	14	6.3	0	29.6	29.5	29.5	0
Oct	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Total
2	73	63.5	53	48	42.5	36	72	49.4	27	12	6.3	0	29.7	29.7	29.6	0
3	75	62.6	48	49	46	44	86	57.6	34	12	4.4	0	29.8	29.7	29.7	0
4	75	64.3	53	56	51.1	48	87	64	44	9	3.2	0	29.8	29.7	29.6	0

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