

Aerodynamic Drag and Engine Cooling Effects on Class 8 Trucks in Platooning Configurations

Matthew Ellis and Joaquin Ivan Gargoloff
Exa Corporation

Raja Sengupta
Volvo Trucks North America

ABSTRACT

The increasing importance of reducing greenhouse gas emissions and the ongoing evolution of vehicle-to-vehicle connectivity technologies have generated significant interest in platooning for commercial vehicles, where two or more vehicles travel in same traffic lane in relatively close proximity. This paper examines the effect of platooning on four increasingly aerodynamic tractor-trailer configurations, using a Lattice Boltzmann based CFD solver. Each platoon consisted of three identical tractor-trailer configurations traveling in the same lane at 65mph. Two different vehicle to vehicle gaps were studied, 5m and 9m, in addition to singleton (solitary) vehicles, representing an effectively infinite gap. Aerodynamic drag for the lead, middle, and trailing vehicle in the platooning configurations were compared to the corresponding single vehicle tractor-trailer configuration. Unlike similar investigations on platooning that solely focused on the potential fuel economy gain via aerodynamic drag reduction, this paper also highlights the adverse impact of platooning on the engine cooling performance in trailing vehicles, due to the reduction in ram air cooling caused by wake of the upstream vehicle. Since much of the fuel economy gain from aerodynamics could be at risk if the fan has to be engaged to meet engine cooling demand, this analysis should be an essential part of the cost-benefit consideration of platooning in the context of reducing fuel consumption and thereby, greenhouse gas emissions.

CITATION: Ellis, M., Gargoloff, J., and Sengupta, R., "Aerodynamic Drag and Engine Cooling Effects on Class 8 Trucks in Platooning Configurations," *SAE Int. J. Commer. Veh.* 8(2):2015, doi:10.4271/2015-01-2896.

INTRODUCTION

Improved fuel efficiency and reduced greenhouse gas emissions continues to be a critical goal for the heavy truck transportation industry. Fuel efficiency is key for end users in the freight industry such as fleets and individual owner-operators as it has a direct impact on operating costs. Improved fuel efficiency also has energy security implications. Reducing greenhouse gas emissions is a goal of regulatory bodies and environmentally conscious individuals and groups. In 2011, the first ever standards for medium and heavy duty trucks were released by the U.S. Department of Transportation and the Environmental Protection agency that went in to effect in 2014. These standards require many tractor-trailer configurations to achieve a 20% reduction in fuel usage and greenhouse emissions by 2018 [1].

Improved fuel efficiency of tractor-trailer systems, and thus reduced emissions, can be obtained with improvements or changes to several aspects of the vehicle design. Some examples are reduced rolling resistance, improved engine efficiency, and reduced aerodynamic drag.

Fleets that utilize tractor-trailers to haul freight need to consider many factors when choosing where to invest in fuel saving technologies. Tractor-trailers traveling on flat terrain at highway

speeds spend more than half of engine output overcoming aerodynamic drag [5]. Fleets also need to consider effective tractor-trailer gaps that minimize aerodynamic drag as well as ensure proper axle loading.

There have been many investigations on the effects of vehicle platooning. A summary of several of these studies has been detailed which shows a variety of government agencies and heavy vehicle manufacturers interested in benefits and challenges of this technology [2]. The goal of several of these studies has been to understand the energy savings of running in a platooning configuration that comes from shielding the trailing vehicles from free stream and, at a close enough following distance, pressurizing the trailer back face of the leading vehicle. Other goals of these investigations have been implementation of platooning operation, improved safety and reduced traffic congestion. These studies have investigated both mixed vehicle, cars and heavy vehicles, as well as strictly heavy vehicle platooning configurations. One of the projects that investigated a non-homogeneous platoon is the Safe Road Trains for the Environment program (SARTRE). Published material from this project shows a fuel economy savings for trailing heavy vehicles and automobiles for various gap distances in the platoon [3][4].

Patten et al. commented on the lack maturity of platooning for the Canadian infrastructure [5]. The concerns mentioned were dealing with integrating these vehicles into existing traffic patterns and developing proven systems to allow vehicles to communicate with each other to safely allow short separation distances where platooning has the largest aerodynamic improvement. These comments were specific to the Canadian market, but are real considerations for successful implementation of platooning.

More recent studies have shown successful testing of vehicle to vehicle communication systems on closed test tracks and public highways. Lammert et al. investigated various separation distances, vehicle speeds, and vehicle weights on a closed test track. Results showed that lead vehicle showed fuel savings between 2.7% and 5.3%, while trailing vehicle achieved between 2.8% and 9.7% fuel savings. This study also monitored engine cooling fan engagement and showed that when the fan did not engage to meet cooling needs for the trailing vehicle, the fuel savings was between 8.4% and 9.7%. This shows that maintaining enough ram air driven engine cooling flow is critical to achieving fuel economy benefits [6]. Fuel economy testing on a public highway with a 36 foot separation distance showed a fuel economy savings of a lead vehicle at 4.5% and trailing vehicle of 10.0% [7].

MOTIVATION AND ANALYSIS APPROACH

While platooning effects have been studied previously, there are considerations for platooning that have not been fully studied in controlled conditions. One such aspect is predicting when the engine cooling fan will engage on the trailing vehicle(s) due to lack of ram air flow in the wake of the leading vehicle. This effect is critical since the power to drive a heavy vehicle fan is significant and can impact fuel savings achieved from reducing aerodynamic drag on a trailing vehicle. Another aspect is measuring the impact of varying tractor and trailer aerodynamic content on the benefit of platooning. Both of these aspects are investigated in this paper.

Simulations using PowerFLOW, a commercially available computational fluid dynamics software based on a Lattice-Boltzmann Method, were used to assess aerodynamic and heat exchanger thermal performance of vehicles in platooning configurations. PowerFLOW uses a Very Large-Eddy Simulation (VLES) turbulence modeling approach utilizing Renormalization Group (RNG) $k - \epsilon$ equations and advanced boundary layer wall modeling [8]. The platooning configuration considered in these simulations comprised of three vehicles traveling in the same vehicle lane with the same tractor and trailer content. A three vehicle platoon is a good representation of arbitrarily sized platoons since the lead and last vehicles in any platoon are expected to have similar performances as the lead and last vehicles in a three vehicle platoon, while the intermediate vehicles are expected to behave similar to the middle vehicle in a three vehicle platoon.

Each platoon had the same separation distance (or gap) between each of the vehicles. Two gaps were evaluated in this study, 5 meters and 9 meters, in addition to singleton (single vehicle in domain) simulations representing an effectively infinite gap. A 9 meter gap has been tested with current technology [6], while achieving a 5 meter gap

may require significant advances in vehicle to vehicle communication technology, as well as active safety. The smaller gap was also used to determine if any additional fuel savings benefits (reduced aerodynamic drag and acceptable heat exchanger cooling flow) could be realized over a more feasible gap.

Four tractor-trailer configurations were evaluated to understand how current individual aerodynamic devices, such as trailer skirts and trailer boat tails, impact the performance in a platooning configuration. The base vehicle was a Volvo VNL 670 hauling a standard 53 foot van body trailer. The second vehicle configuration added standard trailer skirts about 7 meters in length to the base vehicle. The third vehicle configuration added improved trailer skirts, a trailer front fairing attached to the front of the trailer, and a standard boat tail installed at the rear of the trailer. The final configurations implemented the same trailer front fairing, advanced trailer skirts and boat tail, and fairings that fully covered the 2nd and 3rd axle tires. The simulation models incorporate fully detailed geometry including detailed underbody and chassis needed for both aerodynamic and heat exchanger flow accuracy. Images of these configurations are shown in [Figure 1](#).

On each vehicle, the same best practices used to achieve correlation to wind tunnel models were implemented [9][10]. These best practices conform to SAE J2966 which provides guidelines for heavy vehicle aerodynamic assessments [11]. Following these best practices, the number of fluid cells in the simulation domain for the single vehicle analysis was about 70 million and increased to 200 million with the simulations containing 3 separate tractor trailer configurations. In addition to the aerodynamic evaluation, the heat exchanger performance was also determined in the simulations. The setup for the heat exchanger analysis was the same as used in a previous correlation study that evaluated radiator and charge air cooler performance at highway speeds [12]. All heat exchangers were represented by a porous media that utilized supplier component data to define the air side resistance and thermal performance. Both the radiator and charge air cooler (CAC) inlet temperatures were fixed in the simulations, allowing the simulations to solve for radiator heat rejection and CAC out temperature. The same fluid cell resolution in the wake of the leading vehicle trailers was extended downstream to the tractor of the leading vehicle in order to best capture the flow behavior between each vehicle, similar to previous platooning simulations [13]. The aerodynamic and the heat exchanger performance evaluations were carried out in the same simulations.

Each of the platooning simulations was evaluated at a 0° yaw and a 5° yaw crosswind condition. The 0° yaw condition represented performance in very low wind while the 5° yaw condition represented performance in moderate wind conditions. The freestream velocity in the simulations was 65 MPH which represents a Reynolds number of about 5 million.

RESULTS

The following section presents the results of the simulations using the Volvo VNL 670 vehicle. 4 different vehicle variants were considered each with an additional level of aerodynamic performance package.

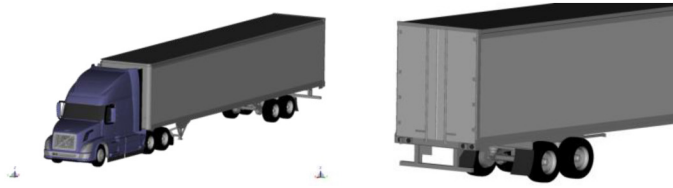


Figure 1a. Vehicle 1 Tractor and Trailer Configuration

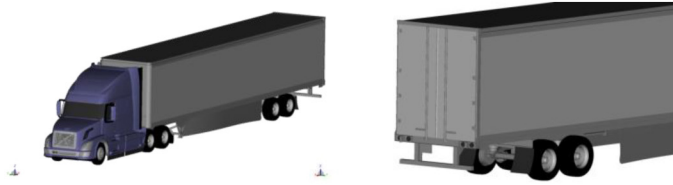


Figure 1b. Vehicle 2 Tractor and Trailer Configuration

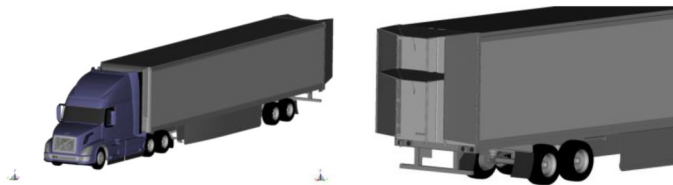


Figure 1c. Vehicle 3 Tractor and Trailer Configuration

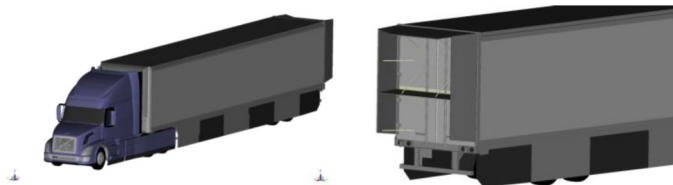


Figure 1d. Vehicle 4 Tractor and Trailer Configuration

The following chart shows the normalized drag for each one of these 4 vehicles, assuming one single stand-alone vehicle (no platooning). Drag is normalized with respect to Vehicle 1:

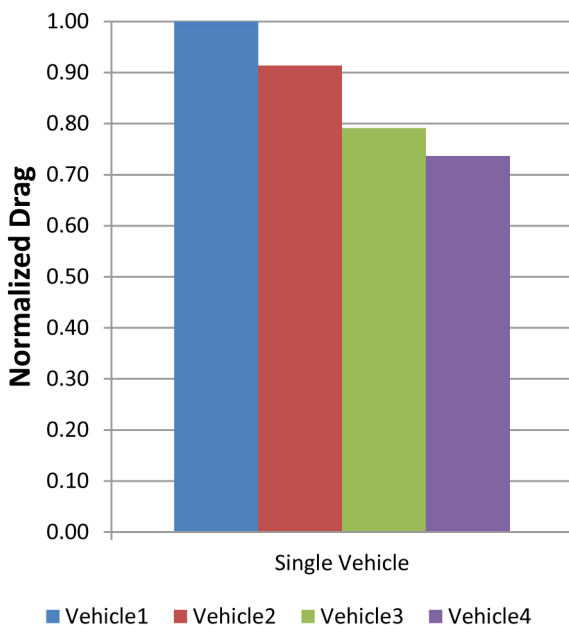


Figure 2. Single Vehicle Drag - Yaw-averaged.

In Figure 2, the drag coefficient is reported as a simple average of the 0 degree and 5 degree yaw result. This simple averaging will be defined as the yaw-averaged result for the results review and subsequent figures in this paper will reference yaw-averaged values.

Based on these results shown in Figure 2, the stand-alone vehicle simulations yield a saving of 9% going from Vehicle 1 to Vehicle 2, 21% from Vehicle 1 to Vehicle 3, and 26% from Vehicle 1 to Vehicle 4, these drag savings again attributed to increasing levels of aerodynamic performance packages.

The following chart shows the normalized drag for each one of the vehicles as well as the averaged drag of each 3-vehicle platoons:

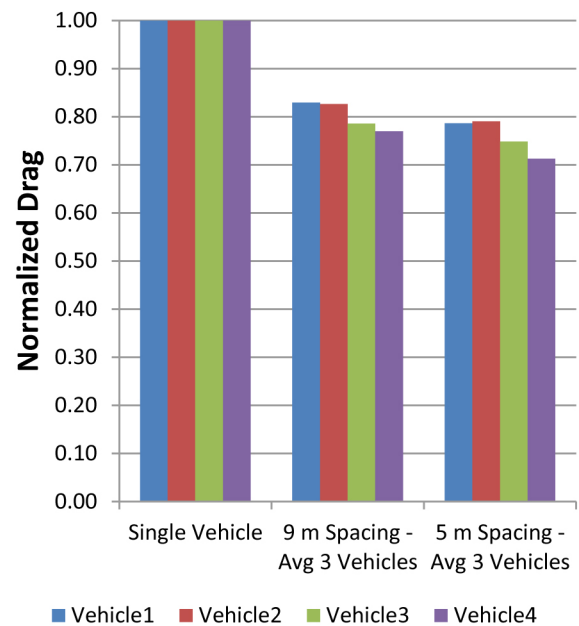


Figure 3. Platooning Drag - Normalized by Single Vehicle of each kind.

It is clear from Figure 3 that most of the drag reduction benefit is realized going from single vehicle to 9 meter separation platooning, and that going to 5 meter separation platooning only offers marginal additional gains. Another interesting aspect is that platooning is more beneficial for the more aerodynamic vehicles (Vehicles 3 and 4) as opposed to the less aerodynamic vehicles (Vehicles 1 and 2). The main reason for this is that more aerodynamic vehicles take better advantage of the protection offered by the vehicle upstream. In other words, the aerodynamic performance packaging works very well for a stand-alone vehicle but works even better when the vehicle is following another truck. On the other hand, the trailing vehicles see a large reduction in cooling flow going through the front grille, which also reduces the total drag. In order to separate the drag effects of the body versus the porous media, the following figure shows the platooning surface drag (excluding porous media). Note that the most aerodynamic vehicles 3 and 4 still achieve greater surface drag reductions than the less aerodynamic vehicles 1 and 2: