

Aerodynamic Comparison of Tractor-Trailer Platooning and A-Train Configuration

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ABSTRACT

Modern aerodynamic Class 8 freight tractors can improve vehicle freight efficiency and fuel economy versus older traditional style tractors when pulling Canadian style A- or B-Train double trailer long combination vehicles (LCV's) at highway speeds. This paper compares the aerodynamic performance of a current generation aerodynamic tractor with several freight hauling configurations through computational fluid dynamics evaluations using the Lattice-Boltzmann methodology. The configurations investigated include the tractor hauling a standard 53' trailer, a platooning configuration with a 30' separation distance, and an A-Train configuration including two 48' trailers connected with a dolly converter. The study demonstrates CFD's capability of evaluating extremely long vehicle combinations that might be difficult to accomplish in traditional wind tunnels due to size limitations. The paper discusses the relevance of improvements in freight configurations to legislative discussions in the United States and other countries on rules modifications to achieve improved freight efficiency and associated reductions in greenhouse gas emissions.

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INTRODUCTION

This paper documents Lattice-Boltzmann aerodynamic drag analysis comparisons between a selection of long combination vehicles (LCV's), platooning vehicles and individual tractor/trailer scenarios, with a focus on the associated potential freight efficiency, technology development, legislative complexity and economic factors.

The history of transportation in North America shows a stepped change in trailer length occurs periodically producing a new defacto "standard" high volume use trailer configuration. Due to multiple economic, technology, infrastructure and legislative factors, the most common North American van trailer configuration has changed over time, from a single tractor pulling a 28 foot (8.53m) trailer, to 40 foot (12.19m) trailer, to 48 foot (14.65m) trailer and to 53 foot (16.2m) trailer. The lengths specified in feet are synonymous with their U.S. product descriptions, so this paper will employ the U.S. terminology [1].

Changes in today's standard North American configuration have been in discussion in State, Provincial, and National governments. Improving freight efficiency and associated environmental ramifications by considering alternatives to the single 53 foot trailer are the subject of industry and government research [2][3]. Similar investigations are occurring worldwide [4]. All efforts are attempting to move more freight, over a given distance, using more efficient methods.

One method, platooning, a concept in discussion since at least the early 1960's with Fenton's research for the Automated Highway System, is receiving renewed recent emphasis [5]. Platooning or drafting technology, allows two tractor/trailer vehicles to achieve freight efficiency gains by driving in tandem with some reduced separation distance. This can reduce aerodynamic drag forces on both vehicles [6][7][8].

The pursuit of platooning advanced technology when taken to its extreme shortest separation distances leads necessarily to performance comparison to the current technology A- or B-Train double trailer configuration pulled by a single tractor. The baseline for these discussions is the current high volume use single tractor, pulling the ubiquitous 53 foot van trailer.

BACKGROUND

Various Canadian provinces currently allow A- and B-Train double configurations that can have Gross Vehicle Weight Ratings (GVWR's) of greater than 140,000 lb (63,500kg). These configurations operate legally on the Canadian infrastructure and variations under special permits in many U.S. states.

Platooning has its roots in the advantages from the aerodynamics of two vehicles interacting to benefit both more than the sum of their individual performances.

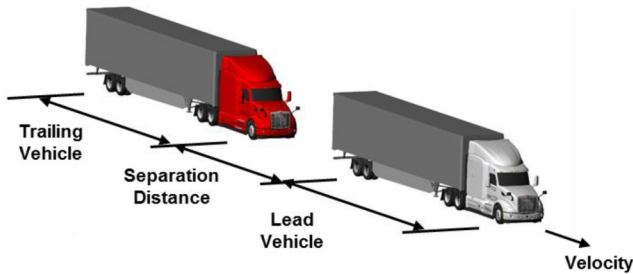


Figure 1. Two Vehicle Platooning

As the separation distance (X) reduces, aerodynamic drag for both vehicles improves [6][7][8]. The extreme limit is where X goes to near zero clearance between the lead trailer and the following tractor. The A-train LCV configuration is similar to this extreme limit, but removing the trailing vehicle tractor. Figure 2 shows the clearances between the two trailers of an A-train LCV are less than 6 feet (1.83 m).

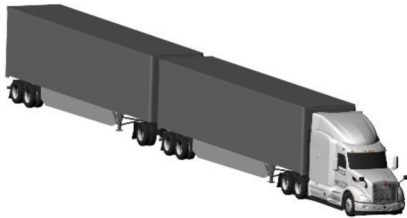


Figure 2. A-Train Double

The platooning configuration in Figure 1, and the A-Train Double in Figure 2 can be compared to a single tractor/trailer configuration as in Figure 3 or two single tractor/trailer configurations separated by sufficient distance to have no significant aerodynamic interaction shown in Figure 4.



Figure 3. Single Tractor with 53 foot Van Trailer

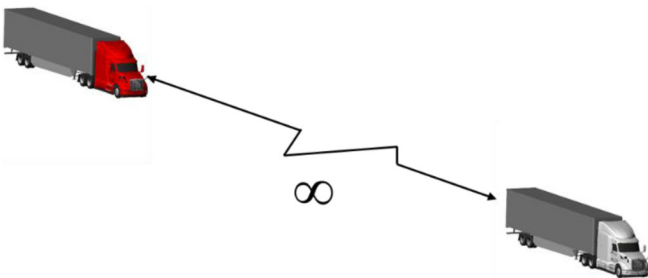


Figure 4. Two Single Tractor/Trailers with Large Separation

This study will focus on the aerodynamic drag comparisons of these scenarios. The comparison also includes an overview of the operating economics and legislative factors inherent in these configurations.

Economic Considerations

Freight hauling is the business of moving product between locations for financial gain. There are many factors relevant to economic evaluation of these four freight hauling scenarios, and this paper does not presume to evaluate them all. Significant factors in the business modeling of freight hauling are capital investment and operating costs as outlined in Figure 5 [9].

If we make a simplifying assumption that the same number of 53 foot trailers is required in all four scenarios to move a specified large amount of freight between the same two locations, then the capital investment evaluation reduces to comparing the double to permutations of the single. The double requires a single tractor to pull two trailers, while the platooning and two independent singles requires two tractors. The significant trade-off is between the full cost of a tractor versus the cost of the interconnecting dolly for the A-or B- Train.

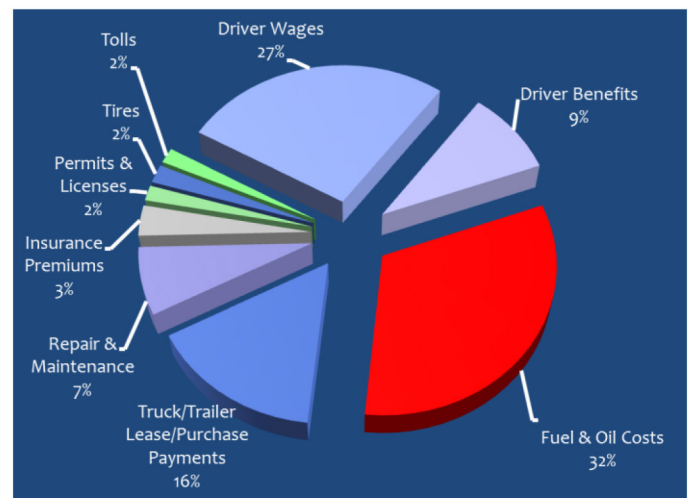


Figure 5. Typical Relative Operating Costs

Compared to a single making two trips, the A- or B-train focuses on operational cost factors that evolve to capital investment ones. One trip with two trailers versus two trips each with one trailer implies the single tractor making two trips will need capital replacement at an earlier date roughly half that of the A- or B-train tractor.

Operational costs to consider revolve around labor and maintenance cost differences. The A- or B-train double tractor sees fewer driver hours/year than a single making two trips for the same amount of freight. To accomplish deliveries over a similar period, this analysis might even require that the single have dual drivers versus the A- or B-train double. The B-train double tractor represents a significant labor cost reduction by roughly halving the paid driver man-hours versus any of the three scenarios involving the singles.

Similarly, tractor maintenance costs based on mileage/year would be roughly halved for the A- or B-train double versus any of the three scenarios.

Infrastructure maintenance might also see reduced pavement wear from A- or B-train doubles due to elimination of the second tractor or the second trip for the single.

Another key economic consideration is that the available pool of heavy truck drivers in North America has been decreasing to the extent that driver shortages are projected [10][11][12]. Double trailers require more experienced drivers with special qualifications, so replacing singles with doubles would not immediately reduce the driver shortage issue, but growth in use of doubles could provide incentives for improving driver training, driver pay and eventually have a positive impact on driver shortages.

Operating costs also include insurance and related factors. This comparison requires a detailed discussion of safety history, and projections for new technologies, both beyond the scope and purpose of this paper. Historic safety trend data with Canadian A- and B-train operations and U.S. experience with permitted load operations is a starting point for other investigations.

Weight Considerations

Comparing A- or B-Train Doubles to two single tractor trailers in traffic reveals that the two tractor unit carries less freight than the double when both configurations operate at the same net GVWR.

Compare axle loadings for two equivalent net GVWR's. A typical single U.S. tractor pulling a 53 foot trailer has a GVWR of 65,000 lb, which is the typical weight assumed for the Department of Energy SuperTruck program baseline, is in the range outlined by Oakridge National Laboratories based on Federal Highway Administration data collected from 15 states, and is slightly less than the Environmental Protection Agency value used for High Roof Sleepers in its Green House Gas Regulations, and is somewhat more than the American Trucking Association's estimate [13][14][15][16]. Two vehicles at this GVWR adds to 130,000 lb and is chosen as the comparison point for an A-train double as shown in Figure 6.

Determining the freight carried requires estimating tare weights. For the purposes of this evaluation, we assume a fueled tractor weight of 18,000 lb, 53 foot empty trailer equipped with SmartWay fairings is assumed 13,500 lb and we assume a single driver with all his possessions at 400 lb. The resulting freight carried per trailer is then 33,100 lb, for a net two-unit freight weight of 66,200 lb.

For the A-train double with a net GVWR of 130,000 lb similar to the two unit example above, the same weight values are used for the tractor, driver and his possessions. And while this aerodynamic analysis used 48 foot trailers for the A-train double, we'll assume here each trailer has the same tare weight as the 53 foot trailer, giving some advantage to the two tractor unit, but making the comparison less complicated and recognizing that A- and B- trains can pull 53 foot trailers. The single axle converter dolly connecting the two trailers is estimated at 3,050 lb [17]. The resulting freight weight per trailer is 40,775 lb for a net A-train freight weight of 81,550 lb.

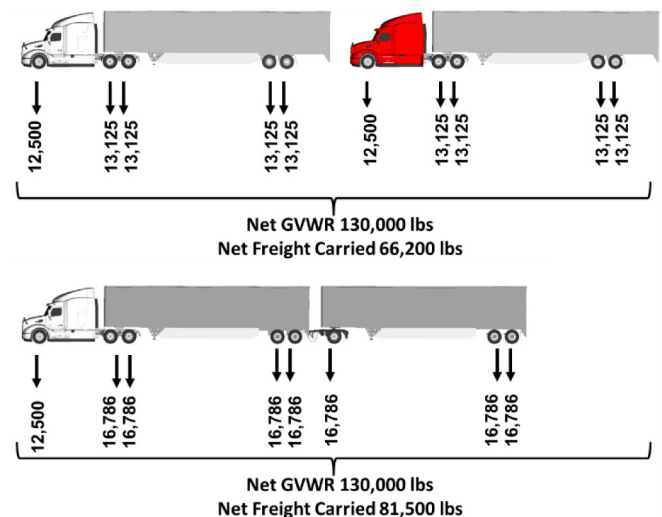


Figure 6. Axle Loading and Separation Comparison

The net freight transported by the double is greater than that of the two tractor unit by 15,350 lb. This is just one permutation provided as an example. Similar comparisons can be done at higher GVWR's, keeping axle loadings within allowable single truck values. This has led others to suggest that doubles are more efficient [2][3].

Comparing A- or B-Train Doubles to two single tractor trailers in traffic highlights that vehicle size and weight standards are particularly focused on individual vehicles, rather than combinations of disparate vehicles as exists in real world traffic. This may have been a legislative jurisdictional simplification that has propagated through time as enforcement of length rules on manufacturers and operators requires to some extent limiting the configurations to individual units.

Limiting size and weight rules to individual vehicles is highlighted by omission of dual vehicle definitions in the Federal, State and Provincial rules on vehicle size and weight standards. Even the Bridge Law focuses on individual vehicle axle loadings and separations [1]. Since real world traffic does see multiple vehicles separated by short distances, and the bridge and highway infrastructure is designed for those traffic conditions, it begs the question illustrated in Figure 5, of what is the technical difference between axle loading and spacing for two single tractor/trailer units following each other closely versus a A- or B-train double?

AERODYNAMIC EVALUATION

The aerodynamic evaluation of the four scenarios employed highly detailed geometric models of typical configurations. The computational fluid dynamics methodology used was the Lattice-Boltzmann Method as implemented in the commercially available PowerFLOW software [18]. Simulations were performed with full scale geometry and evaluated at 65 miles per hour. The Lattice-Boltzmann Method was chosen to maintain consistency with a previous study [6] performed by the authors as well as providing an efficient approach to simulate unsteady flow effects.