On the Aerodynamics of Tractor-Trailers

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Abstract

Wind tunnel experiments on the aerodynamics of tractor-trailer models show that the drag on the model is sensitive to the width of the tractor-trailer gap (G) and to the angle of yaw with respect to wind direction. At zero-yaw, relatively low drag is measured up to a critical gap width \( G/\sqrt{A} = 0.5 \), where \( A \) is the cross-sectional area. At the critical width the drag experiences a sharp and large increase; most of the drag contribution is attributed to the trailer alone. As the gap is widened further, tractor and trailer become increasingly decoupled from each other and the drag reaches a near-plateau, rising much more gradually.

DPIV measurements in horizontal planes in the gap show that the flow is steady and consists of a relatively stable, symmetric toroidal vortex when the width is below critical. The symmetry breaks down at the critical gap, as evidenced by intermittent ejections of flow from the cavity to either side of the model. These ejections are believed to be at the origin of the sharp increase in trailer drag. As the gap width is increased further, the nature of the flow transitions from cavity-like to wake-like.

These observations can be qualitatively extended to moderate yaw angles (up to ~4 degrees), but the size of the critical gap width diminishes with yaw angle. At higher angles, the drag rises much faster with gap width.

The second part of this paper discusses the drag savings that can be realized by arranging two truck-like models in a tandem. Four tandems were formed by combining two models; each of the models was either "rounded" (i.e. lower drag) or "blunt" (higher drag). The drag of any tandem is generally lower than the sum of the drags of the models in isolation. However, the drag savings also depends on the choice of models (rounded vs. blunt) and on which model is placed in front. A rounded model followed by a blunt model achieves the most relative drag savings, while reversing the order produces the tandem with the least savings.
Introduction

At typical cruising highway speeds, most of the fuel consumed by a large scale road vehicle is expended to simply overcome aerodynamic drag, even in the absence of unfavorable wind conditions. The remaining fuel expenditure is needed to overcome the rolling resistance on tires and internal losses. The fuel efficiency of tractor-trailers, which account for the greatest portion of heavy vehicle traffic by a large margin, is influenced by the shape and physical dimensions of these vehicles. Shape and scale are themselves severely constrained by economic considerations (the parallelepiped shape of trailers is meant to optimize volume loading) and by regulatory constraints (truck dimensions are fixed and drag-reduction devices cannot exceed specified limits).

A look at the evolution of tractor-trailer design over the last several decades reveals gradual aerodynamic improvements to the front of vehicles, namely from the front of the tractor to the front of the trailer, but very little has been done to improve the back of trailers. Tractors have benefited from tremendous improvements, such as the adoption of the aero-shield as an integrated part of the cab. The problem of the gap between tractor and trailer, which is an important source of drag, has been partly mitigated by the introduction of cab extenders that effectively reduce the size of the gap but do not eliminate it entirely.

In contrast, trailers have seen little modification, aside from the rounding of their vertical leading edges in the front. The fact that hard-shell trailers are designed to be loaded from the back makes the implementation of drag reduction devices in the back particularly challenging. Truck operators are extremely reluctant to deal with any type of physical device that may interfere with routine loading and unloading operations.

The main objective of this paper is to investigate the impact of tractor-trailer gap width on the drag forces experienced by a truck. The study relies on detailed measurements performed on truck models in a wind tunnel. These models are not replicas of actual trucks that can be seen on the roads, but rather truck-like shapes. While these shapes are simplified to the extent that they do not incorporate any of the secondary features of real vehicles (such as mirrors, handlebars, cab extenders, etc...), they do capture the first order effects that account for virtually all aerodynamic forces acting on a real truck. Also, it is worth noting that Reynolds number matching is not achievable in our flow facility because of limitations on model size and flow speeds. However, the experiments discussed here are not meant to simulate the flow around an actual tractor trailer. Instead, the goal is to unveil relevant flow physics that can be generalized, at least to a first order, to higher Reynolds numbers. The simplified shapes also have the advantage of lending themselves to numerical computations. The elimination of detailed features on the models allows numerical computations to be conducted without the costly burden of