

Analyzing Fuel Savings of an Aerodynamic Drag Reduction Device with the Aid of a Robust Linear Least Squares Method

Jouke Van der Krieke and Gandert Van Raemdonck
WABCO

ABSTRACT

Improving the aerodynamic drag level of semi-trailers will contribute largely to reduce the fuel consumption and the emissions of harmful gases of heavy duty vehicles. The final step in product validation of aerodynamic drag reduction devices is often conducting fuel savings test during operational activities.

During an operational test, data is gathered for a period when the vehicle is not equipped with an aerodynamic device and consequently for a period with the device equipped. A simple fuel consumption comparison between the periods does not give the desired accurate result as the operating conditions are different for the control and test period. In an attempt to take these varying conditions into account, the average fuel consumption per ride is modeled as a linear function of several independent variables: the wind conditions, the outside temperature, the humidity, the payload, the road inclination and the presence of the drag reduction device. The coefficients in this linear relationship are determined using a robust linear least squares algorithm.

Applying this approach for a single vehicle test resulted in the finding of a fuel savings of 1.51 l/100 km. In contrast, a simple comparison of the fuel consumption during the control and test periods showed a fuel saving of 1.1 l/100 km when highway speeds are considered.

Residuals show little dependence on the independent variables, demonstrating the model fit is fairly good. Still the analysis could be improved if a more sophisticated model for fuel consumption is used, incorporating more relevant independent variables and more accurate (perhaps non-linear) relationships. Such a model could also contribute to more reliable results in one-day track tests.

CITATION: Van der Krieke, J. and Van Raemdonck, G., "Analyzing Fuel Savings of an Aerodynamic Drag Reduction Device with the Aid of a Robust Linear Least Squares Method," *SAE Int. J. Commer. Veh.* 7(2):2014, doi:10.4271/2014-01-2450.

BACKGROUND INFORMATION

The need for road transport, the present broad road network, increasing energy prices together with its economic and environmental impact, puts the heavy duty vehicle in a very interesting position; reduction in energy consumption can lead to a significant decrease in fuel costs, energy savings and emission reductions.

In the recent past several drag reduction devices were developed and tested with the aid of numerical simulations, wind tunnel experiments and track testing, by amongst others, Van Raemdonck [1], Ortega [2] and Wood [3]. An aerodynamically shaped skirt, called OptiFlow SideWing, was developed for a European tractor semi-trailer configuration. This solution successfully proved its efficiency during wind

tunnel experiments, dedicated track and operational testing on public roads [1]. Over the past years many track tests were conducted with an especially developed protocol which was based on the SAE Type II [4]: an average fuel saving of 1.5 l/100km at a vehicle speed of 85 km/h was obtained.

During the aerodynamic development of a drag reduction solution for semi-trailers full-scale road tests during operational activities is often the final step to convince the end-user of the solution's effectiveness. Due to test requirements and several operational and budget restrictions of the fleet, a small group of vehicles, often just one vehicle, is participating in such a long term test on public roads.

A simple fuel consumption comparison of the period without the drag reduction device (i.e. control period) with the period driven with the device mounted (i.e. test period), does not give the desired accurate result as the operating conditions can be very different for the control and test period. To take these varying conditions into account, the average fuel consumption per ride is modeled as a linear function of several variables: the wind conditions, the outside temperature, the humidity, the payload, the road inclination and the presence of the drag reduction device. The coefficients in this linear relationship are then determined using a robust linear least squares algorithm.

The set-up of this operational test will be discussed in the next section together with the used vehicle, its driven trajectory and the data acquisition system that is being installed to monitor the vehicle performance. Next, three analysis methods including the applied linear model that describes the fuel consumption are being presented. Finally, the results of the different analysis are discussed together with final conclusions and recommendations for future work.

TEST SET-UP

Together with a fleet operator a test was conducted during operational activities of more than a year to determine the fuel savings of a drag reduction device for a particular vehicle combination.

Vehicle Combination with Drag Reduction Device

In the Netherlands one is allowed to drive with a longer vehicle combination having a total length of 25 m, instead of the standard semi-trailer length of 16.5 m. This longer combination, called Long and Heavy Vehicle, has a 2×4 tractor, a 3-axled semi-trailer and a 2-axled drawbar trailer. The semi-trailer is equipped with the advanced shaped skirts, while the drawbar trailer has regular skirts, see Fig. 1. The final semi-trailer axle is a steering axle which explains the opening in the side panel. Dimensions of the skirts are not added because it is not relevant to the focus of this paper; more details of the skirt and vehicle system can be found at Van der Krieke [5]. A small, but fixed, group of 3 drivers were driving the vehicle almost 20 hours a day. The tractor was a SCANIA G400.



Figure 1. Illustration of the long and heavy vehicle combination: tractor semi-trailer, and a drawbar trailer.

Test Period and Trajectory

This fuel saving test was conducted with only one vehicle for a total period of fifteen months: from March 14th 2012 until June 19th 2013. The first five and a half months were driven without the aerodynamic drag reduction device, the remainder of the period with aerodynamic aid. An overview of the trajectory between can be observed in Fig. 2. The vehicle operated over fixed trajectories and with approximately known loading between several visiting locations to load or/and unload cargo.

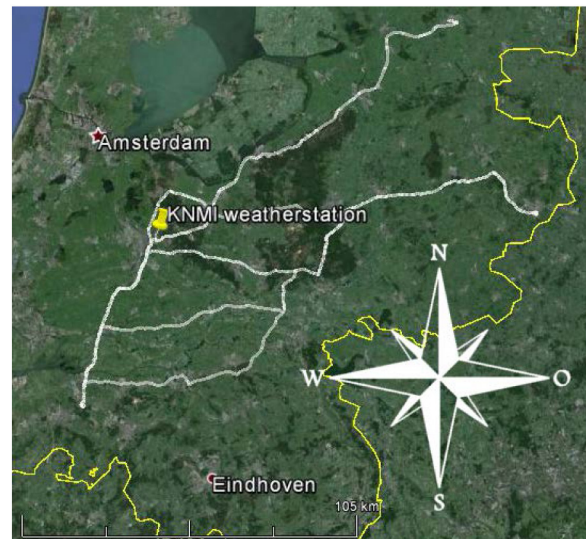


Figure 2. Overview of the vehicles trajectories indicated in white.

Data Acquisition System

A data acquisition system, that monitors several vehicle performance parameters together with its position through GPS, is connected to the CAN bus (Controller Area Network) of the truck through a CANcliQ connection, Squarell Technologies [6]. This complete system assembly is displayed in Fig. 3. Performance parameters such as fuel rate, distance, vehicle speed, revolutions per minute, torque, etc. are being registered every 1 second on the data logger with a total storage capacity of 512MB. Data is downloaded on a regular basis with the aid of a USB-cable and laptop.

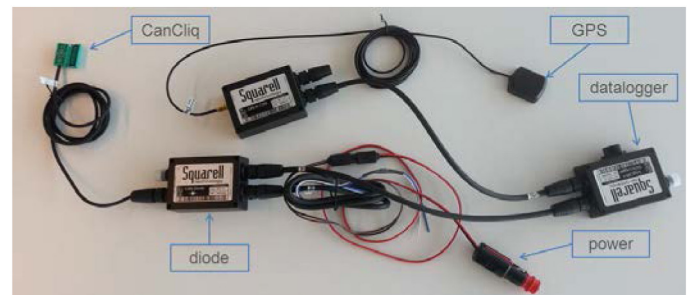


Figure 3. The data acquisition system comprising a data logger, a GPS antenna, a CanCliq connection to read the CANbus data of the truck via the diode and a power connection.

Weather Conditions

Weather information throughout the test period is collected by consulting online published hourly data from static weather station of the KNMI in De Bilt [7] which is located close to the test trajectory, see Fig. 2. The wind directions and speeds are displayed in a wind rose in Fig. 4. The vehicle experienced mainly a south west wind direction with a wind speed between 4 and 6 m/s. The overview of the humidity, temperature, barometric pressure can be observed in Fig. 5. A broad range of humidity percentages are measured, except during the winter months (higher percentages) and April 2013 (lower percentages). The air temperatures varied according to the seasons, indicating a clear freezing period in January and February 2013. No special remarks can be made for the barometric pressure.

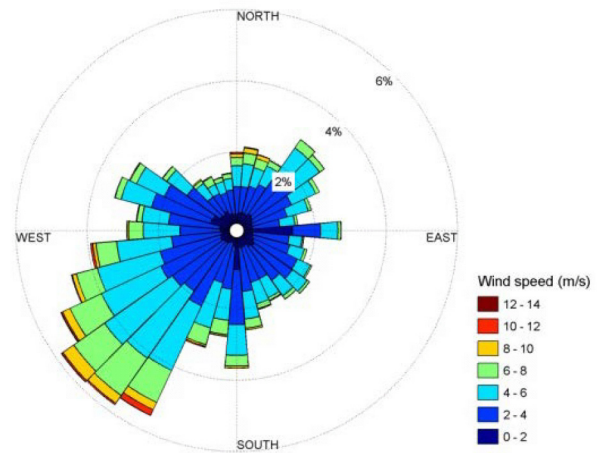


Figure 4. Overview of the wind direction measured by a local weather station for the complete test period of 15 months. The percentage resembles the occurrence of the corresponding measured point.

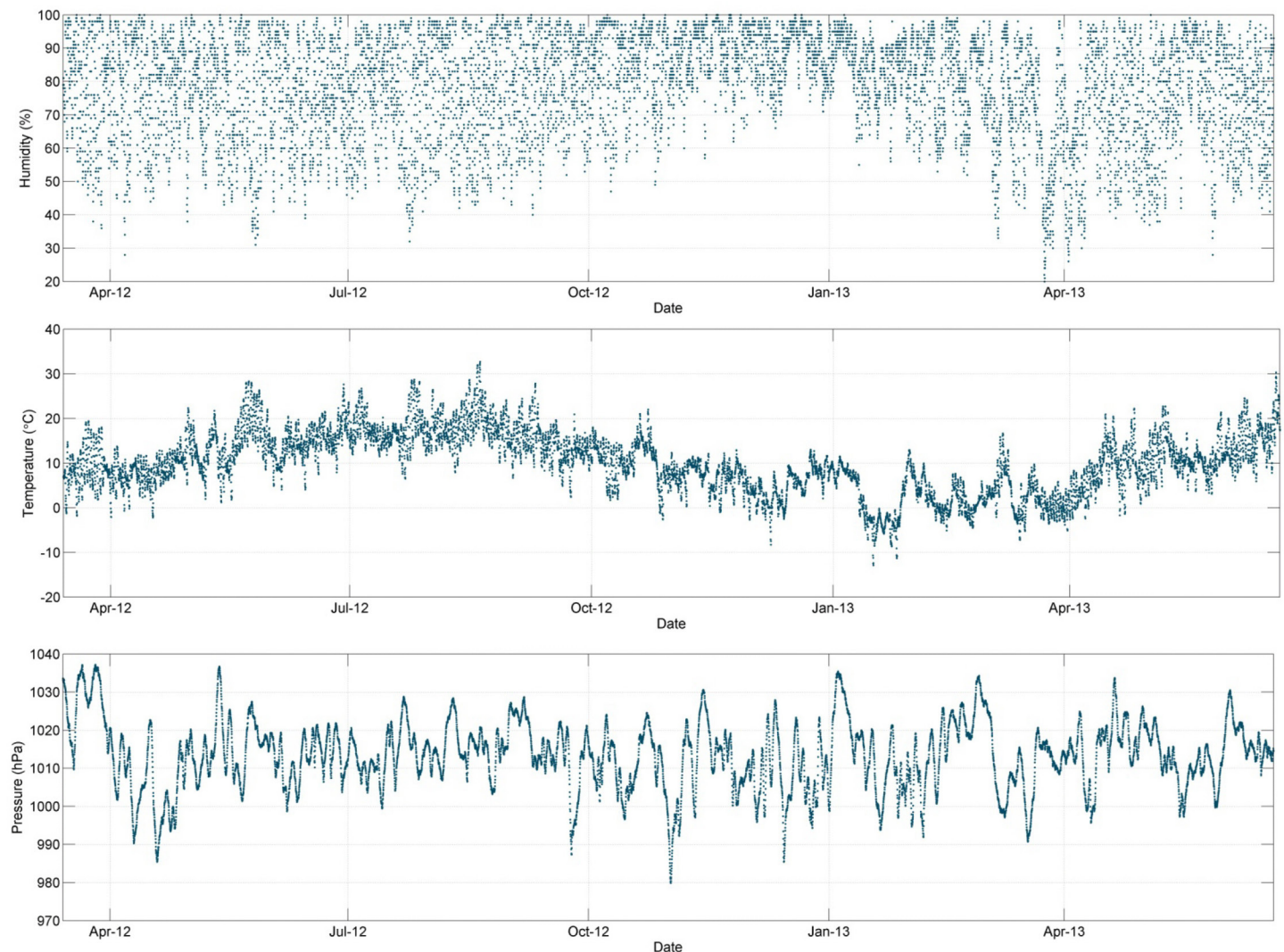


Figure 5. Overview of the humidity, air temperature and pressure measured by a local weather station for the complete test period.