Real-World Savings

Better aerodynamics for long-haul truck-trailers on EU roads

V.2021.02

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1 Executive Summary: Real-world performance of BETTERFLOW AeroPACKAGEs

There is a growing interest for reducing CO_2 in the road transport sector. Logistics and transport companies are facing an increasing need to run their fleets on less fuel because of 1) growing environmental standards of their clients, 2) increasing CO_2 emission prices, 3) coming EU road toll prices in connection with CO_2-emissions, and 4) increasing energy prices[1].

It is industry-wide known that aerodynamic improvements deliver an important contribution to reduce CO_2-emissions. Especially in the **long-haul** segment, where high driving speeds on long routes occur, **aerodynamic improvements even have the highest potential** for reducing fuel consumption and CO_2 – for two reasons: 1) The share of aerodynamic drag compared to other drag sources is highest and 2) the potential for optimizing the aerodynamic properties is large.

BETTERFLOW has realized the urgency and relevance of aerodynamics in the long-haul trucking segment and therefore offers an add-on **Aero-PACKAGE** for long-haul fleets which improves the aerodynamics of their vehicles.

Calculations, wind tunnel tests, simulations and certified "EU Constant Speed Tests" with **Demonstrator-AeroPACKAGEs incl. the rear flaps** have shown that the savings under standard conditions for such a package are in the order of **1.5-1.8 L/100km**. The savings for a package **without the rear flap is 0.8-1.0 L/100km**. These standard conditions are also used to determine the EU VECTO values, which are decisive for the toll calculation.

For a fleet owner, however, the only decisive factor is what savings can be expected under **"real-world" conditions**, so that the purchase of aerodynamic devices is justified and then results in an added value for the entire service-life of the trailer. Real-world conditions express the daily use with varying loads, in all weather conditions, with changing traffic, and on the routes of the individual transport business.

The problem of proof in practise: On the one hand, daily practice shows that the consumption of identical vehicles, even if averaged over many months or kilometers for the sake of comparability, varies in a greater range than the actual expected savings value. Given this range of consumption under real-world conditions, determining the savings achieved by AeroPACKAGE becomes a challenge. On the other hand, the carrier's expectation and goal is to receive a reliable forecast for the expected savings so that a serious investment decision can be made. This requires an accuracy of +/- 0.2 L/100 km for the promised savings.

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[1] Diesel and gas (today), hydrogen, bio-methane, etc. (in future)

BETTERFLOW has taken up this challenge and has therefore built 30 automatic AeroPACKAGEs as a pre-series, which have been tested in daily practice by selected customers all over EU roads so that eventually a robust savings value could be determined.

It turned out that conventional methods of statistics are not feasible for determining the savings. This is because the fluctuations in consumption due to the strong effect of real-world influencing variables are so large in relation to the required accuracy, that excessively high distances would have been necessary for an excessively large fleet of test- as well as reference-vehicles. The alternative of driving test- and reference-vehicles in pairs to achieve better comparability is also not feasible in practice.

Therefore, state of the art data science methods, i.e. intensive data-logging and **machine learning**, were used, which provided the desired accuracy for the results. In principle, the evaluation procedure consists of classifying 5 km long sections of the drives with and without AeroPACKAGE regarding the physical influencing variables, and then comparing them with each other. This provides a very large, reliable database.

The fleet-tests took place in **2019 and 2020**, were performed with 7 fleets all over the EU, with 30 test- and 30 reference-vehicles, and after more than **4 million kilometers in real duty** the results are as follows:

1. The BETTERFLOW AeroPACKAGE is robust, and the unique automatic function makes it fully practical in daily operations: **trailer operation as usual, docking and loading as usual, no damaging**.
2. The BETTERFLOW AeroPACKAGE in its pre-series configuration delivers a conservative average long-term savings effect in long-haul of 5.5% fuel savings, respectively 1.5 L/100km. Due to fine-tuning and improvements, the AeroPACKAGE in its series configuration delivers an average long-term savings effect in long-haul of **6.5% fuel savings, respectively 1.8 L/100km**. These results apply for the complete duty cycle and all-year weather- and road-conditions in the EU.

Both results enable a robust investment decision for an efficient fleet and establish aerodynamics as a crucial technology, now and in the future, for effectively reducing CO_2 and for effectively contributing towards zero emissions in transport.

2 Relevance and applicability of aerodynamic improvements

There is a growing need for improving the fuel- and CO_2-efficiency in the EU transport sector. Special focus lies on the improvement of trucks due to their important role in the European supply chain. The greatest portion of transported goods in the road sector is transported by European long-haul truck-trailer combinations.

The covered number of annual kilometers typically ranges from **80,000-200,000 km per year**, with an average peak at 120.000 km per year. Effective European travelling velocities of long-haul transport range between **75-90 km/h** with respect to individual velocity profiles. The typical aerodynamic drag property is located between **c_DA = 5.8-6.2**. These vehicle parameters (speed and aerodynamic property) produce the very high level of nominal aerodynamic drag which results in **36-60% of total fuel consumption** (depending on the vehicle duty).

The messages of BETTERFLOW:

1. **Reducing only the aerodynamic drag of the trailer in larger amounts (12-16%) is technically already possible today and results in an improved fuel- and CO_2-efficiency of 6-8% depending on the duty cycle.**

2. **In long-haul, reducing the aerodynamic drag of the trailer is practically the only solution at hand to achieve noticeable efficiency leaps at a reasonable cost. “A-level” tires on truck and trailer are already widely in use and noticeable engine improvements are approaching a technical, thermodynamic limit.**

In North America, the fuel efficiency improvement of trailer aerodynamics in real fleets has been long proven – early beginnings in 2010. The ICCT confirms the potential of trailer aerodynamics for European trucks, and that it is relevant for achieving necessary climate targets – also in combination with other effective actions. Industry players acknowledge the impact of aerodynamics. Compared to other innovative climate improvement measures in long-haul (e.g. LNG trucks), this improvement in efficiency is not only relevant, but also easily accessible since market entry obstacles have been consequently overcome:

- In 2019 the EU established type-approval and operational **legislation** for aerodynamic features such as rear-flaps for trailers.
- Quick applicability is given due to the possibility of **retrofitting** to existing fleets and also **ex works** integration by OEMs for new trailers.

- Compared to other efficiency measures in long-haul (e.g. LNG trucks), the costs for a complete aerodynamic optimization range much lower between € 8.000-9.000. The ratio of “CO_2-reduction per Euro” is attractive compared to other measures.
- **National subsidies (e.g. Germany since 2021) are enabling feasibility noticeably.**
- The EU is working on future **road toll measures** (starting 2023/24) which will reward CO_2-efficiency (and punish non-efficiency) of vehicles (especially due to aerodynamics) in terms of reduced (respectively increased) road toll fairs.

BETTERFLOW has designed **AeroPACKAGEs** for long-haul trailers according to essential criteria so that the above potential can be realized permanently: They are robust, do not damage in daily duty, and can be used without particular constraints or additional work or processes. They not only prove their fuel efficiency in theoretical or scientific tests, but also confirm the targeted fuel efficiency improvements in real-world conditions throughout live-fleet daily operation. This paper gives an insight into BETTERFLOW’s substantial, transparent, and rigorous testing operations and fuel efficiency results so that fleet owners, politicians, and associations can make substantiated and informed decisions.

The test fleets during the 2019/2020 fleet-test campaign

3 Influences on savings in real-world environment

There are many influences in the real-world operational environment, which affect fuel consumption and aerodynamic savings.

The savings results produced by the fleet-test comprise all these environmental and operational effects.

The following compilation intends to inform and clarify:

Possible Influence	**Explanation**
Weather	
Wind	Wind prevails in a statistical variety of speeds and directions relative to the heading and velocity of the vehicle. Generally, wind improves the savings value due to the square-effect of air speed vs. drag, respectively saved drag, and because of the AeroPACKAGE's feature of improving in side-wind conditions. When dealing with wind it is necessary to know: Due to the "boundary layer" adjacent to the ground, the wind velocity slows down in ground proximity. Assessing it in an **aerodynamically relevant speed range above 60 km/h** an average resulting angle of attack of air flow of **β = 2.8° at 2 m** height was discovered[2]. The real effect of wind was measured in the fleet-tests, where vehicle and weather data were synchronically logged.
Temperature	Temperature has a noticeable thermodynamic effect on air density which impacts the aerodynamic drag, as well as tire- and engine-performance. Regarding aerodynamics: Generally, colder air is denser and thus produces more drag and savings than warmer air. A year-long temperature profile throughout the EU was recorded during the fleet-tests with a symmetric distribution of temperatures between -10°C and +45°C and a weighted average of +20°C.

[2] 2 m being the aerodynamic center of 0 m (ground) and 4 m (truck height).

	For determining a long-term total savings effect, +20°C is a feasible and representative baseline value.
Humidity	Relative humidity alters air density and generally reaches levels above 75%. Here, however, no noticeable influence on aerodynamics occur.
Rain	Rainfall appears in different varieties and strengths. Generally, rain has no noticeable effect on the aerodynamic performance of trucks. In aircraft engineering rain even has a positive effect on the flow. Background: Very small and sprayed droplets follow the flow path (see the wake of a truck in rainy weather) of the streamlines (more precise “smoke lines”) and thus are so small that the energy needed to carry the particles in the flow can be neglected. Heavier rainfall inserts advantageous energy into the flow due to an increased level of turbulence, which generally has a positive effect. However, rain does have a heavy effect on rolling resistance and the measurement noise when recording fuel data. A level of **0.3 mm** of wetness due to rain on the pavement can cause an increase of rolling resistance of 40% under highway speeds[3]. Therefore, an extensive amount of driving data in different rain conditions is necessary to obtain credential results.
Snow	The findings on rain can be likewise transferred to events with snow. According to annual temperature distribution recordings in the EU during the fleet-test campaign, the annual temperature ranged between -10°C and +45°C. In any case, BETTERFLOW systems are designed for this complete range and also for freezing below -10°C. In addition, BETTERFLOW RearFLOW 500 features a temperature shut-down at freezing temperatures.
Vehicle	
Speeds	Due to the quadratic relation between experienced air speed of the vehicle and its aerodynamic drag, respectively saving, total air speed (the vector-sum of wind- and driving-speed) with its main contributor, the driving-speed, has a large impact on savings. Therefore, trucks with urban or regional velocity duty cycles experience less aerodynamic savings, and so the **true area of application for aerodynamic improvements is the long-haul trucking segment**. Here, a high and continuous

[3] Ejsmont, J. et al: „Influence of Road Wetness on Tire-Pavement Rolling Resistance”, Journal of Civil Engineering and Architecture 9 (2015), 1302-1310, doi: 10.17265/1934-7359/2015.11.004

	driving speed is typical, and the savings are further only influenced by total vehicle mass, respectively loading, and topography. But due to active cruise control and mostly sufficiently powered engines in the long-haul market, inefficient uphill slowdowns under maximum load occur seldom. Thus, cruising speed and constant aerodynamic performance are maintained.
Loads	As explained above, heavy loads only have a detrimental influence on the velocity profile and savings in the case of underpowered engines. In general, payload affects rolling resistance and also shifts the engine operating point inside the engine map, followed by altered values for specific fuel consumption.
Other external Influences	
Traffic	Traffic has a noticeable influence on savings, which is why it was enclosed in the scope of BETTERFLOW's test campaign at a very early stage. In short: driving in dense traffic (English: "slip stream", German: "Windschatten") is equivalent to driving at reduced speed. This affects the savings value. Platooning, a concept of interconnected vehicles driving close to each other, intends to maximize and harvest this effect for enhanced fuel efficiency. **But even without platooning, the general traffic-effect is always present**[4], and during the fleet-test campaign – a test in real traffic – it was automatically considered when establishing the savings. Reported BETTERFLOW savings are a real-world savings effect **with traffic**. In detail: To determine the real influence of different traffic density situations, early track-test and highway-test campaigns were conducted in 2015/2016. Using a calibrated wind-anemometer at the front of the truck (calibration means mapping of measured data with respect to a secondary anemometer) and synchronizing with local weather data, vehicle FMS data, and vehicle distance data, it was possible to extract the portion of the air speed which was related to the traffic situation. For dense traffic situations on western Germany highways (dense traffic compared to the rest of EU) with respect to different day- and night-times, a range of traffic distances could be established with a weighted

[4] Off-topic: The evaluation of platooning also needs to take into account the presence of real daily traffic effects.

	average distance of 85 m and an associated reduction in air speed of 1.5 m/s (5.4 km/h). Measurements executed during the 2019/2020 fleet-test campaign confirm this value for the complete EU with an average weighted following distance of 87 m for the complete test campaign. A more detailed view into the data even reveals the effect of the event of Covid19 pandemic in the EU during the 2019/2020 fleet-test: A comparison of vehicle distances before and after the begin of Covid19 in Europe in March 2020 (traffic density being an indicator for economic vividness) reveals an average increase in vehicle distance (respectively drop in commercial truck activity) from 86 m to 94 m. Biases of fuel savings due to reduced traffic density during the testing period can therefore be taken into account. As a result, traffic density can equivalently amount up to 5.4 km/h reduced driving speed, which needs to be considered when transferring aerodynamic savings potentials into the real-world environment.

4 Real-world fleet-test campaign

The test configuration 2019/2020 of the BETTERFLOW Demonstration-AeroPACKAGE (compare AP 203) consists of the following parts in their pre-series state:

BETTERFLOW RearFLOW

BETTERFLOW LowFLOW

BETTERFLOW HighFLOW Connect

The AeroPACKAGEs were made available to the fleet participants by BETTERFLOW, who also arranged the equipment of the vehicles.

Test Methodology

These are the characteristics of the fleet-test methodology:

- For the tests, the regular vehicles of the fleets were used. Reference-vehicle and test-vehicle configuration was always equal; age and wear of tires and exterior were as equal as possible.
- The vehicles travelled regularly on their daily loaded missions.
- Drivers were given no special training or treatment to avoid biases.
- Twin-principal: For every test-truck there was a reference-truck in the fleet.
- Data FMS loggers with additional sensors for GPS, heading and acceleration were installed in reference- and test-trucks. They collected FMS-data and sensor data on 10 Hz frequency which were transmitted via mobile network for data evaluation.
- GPS-coordinated weather- and height-data (for road-grade) was additionally aggregated to the data sets.
- Meta-data, for evaluating the condition of the vehicles and systems, were collected daily in close cooperation with fleets and drivers.

Key facts

The following table gives a brief overview of the 2019/2020 fleet-test campaign:

Fleet participants	**7 fleets, 2 technical partners**
Usual annual ranges of fleets	**120,000-200,000 km/a**
Area covered during fleet-test	**EU and UK**
Number of trucks involved	**30 aerodynamic trucks** **30 reference trucks**
Kilometers covered by test fleet	**4.3 million**
Data points for the complete test campaign	**1.8 billion**

During data recording and collection every driving operation was monitored with **46 parameters**. The following list comprises the key performance parameters.

Vehicle Data	Weather Data	Mission Data
• Type of vehicle (aero or reference) • Fleet name • ID of truck and trailer • Truck and trailer model • Components • Age, kilometers and wear	• Precipitation probability, intensity and type (rain, sleet, snow) • Air temperature	• GPS and height data • Speed • Distance • Fuel rate • Air speed and β-angle at 2 m height. Beta β is the angle, with which the air speed confronts the vehicle. It is a result of driving speed, heading of the vehicle, wind speed, and wind direction. • Total weight • Throttle setting, engine rotations, and temperature of engine coolant. • Cruise control and brake activity • Distance to front vehicle, type of front vehicle, speed limit and lateral position on lane (measured optical technology for some vehicles)

5 Results

5.1 Fundamental remarks on the measurement of savings

The basic message of aerodynamics in trucking is: No matter the duty of the truck, the weather, the road condition, or the skill of the driver: Aerodynamic drag is **always present** in long-haul transport due to the resulting air speed and the drag characteristics of the vehicle. Consequently, a truck-trailer equipped with an AeroPACKAGE experiences less drag and less consumption:

In purely physical terms, improved aerodynamics automatically results in lower consumption.

The following diagram gives a brief example for the magnitude of an aerodynamic savings effect in typical EU cross-border long-haul:

Regular Load (19,3 t)							
Normal Consumption	**28**	**L/100km**					
Aerodynamic Share	**45%**		**→**	**13**	**L/100km**		
Aerodynamic Improvement Potential				**12%**		**→**	**1,5 L/100km**

The fundamental existence of aerodynamic drag improvement is commonly known and has been extensively tested and proven in the past. Also, BETTERFLOW has executed various windtunnel campaigns, CFD[5] simulations, and 1:1 Constant Speed Tests according to EU certification standards and VECTO[6]. The scientific proof of standardized savings is essential for certification and a general standardization of technology. But:

Beyond certification and standard values, it is essential for fleet owners to know the real net savings in the real-world and in their specific operational environment.

Despite this, detecting savings by driving in the real-world operational environment is a highly complex matter and comes with many difficulties because the consumption of the vehicle is affected heavily by multiple parameters. These are:

Loading, topography, weather, driving style, tire quality and condition, road condition, etc.

[5] CFD: Computational Fluid Dynamics: State of the art simulation technique for complex 3D flows.

[6] CST: Constant Speed Test: The EU demands a CO_2-rating for trucks and trailers, which is done by this certified track-testing and subsequent analysis with the EU VECTO tool.

The difficulty concerning these parameters comes from their many unfortunate characteristics:

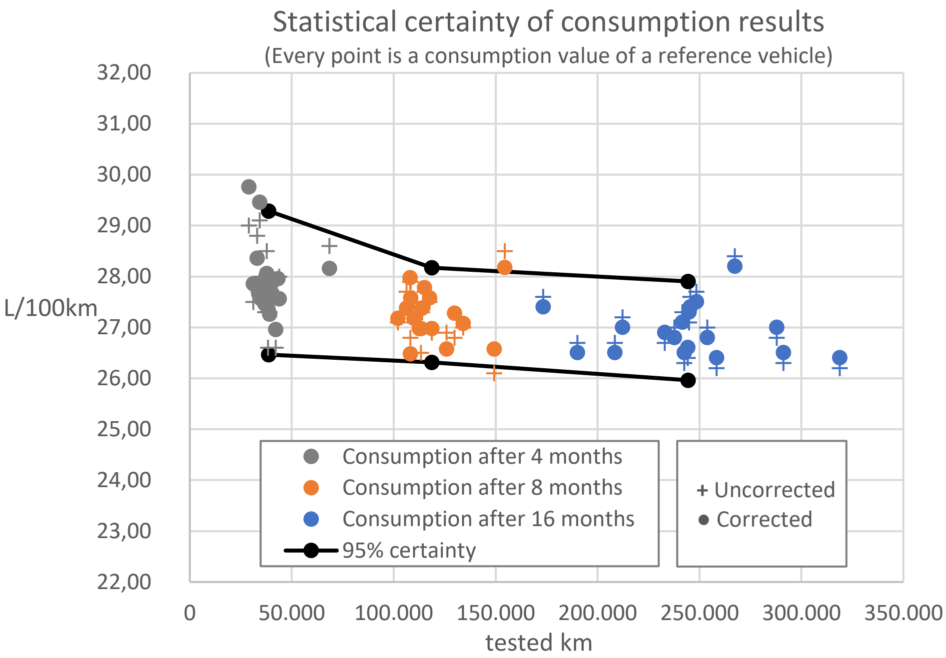
- They have a strong impact on consumption (e.g. per 1 extra ton approx. +0,4 L/100km)
- They strongly interact (e.g. loading and topography)
- They change over time (e.g. seasonal transport missions, seasonal weather, winter diesel)

Intuitively, it would be expected that by maintaining equal conditions as best as possible and by driving very long distances, the fluctuations caused by these influences even out until a statistical certainty appears. This is not necessarily the case:

The below graphic displays absolute consumption values for a group of 18 equal vehicles on arbitrary missions throughout the EU over several months. The consumption values are shown uncorrected (**+**), which is the data a normal fleet manager would see, and corrected (●) for possible weight differences[7]. **Despite this correction, the consumptions still vary between 26,4 and 28,2 L/100km after 16 months of monitoring and approx. 250.000 km**. The black curves depict the corridor of 95% certainty for the average consumption value. Intuitively understandable, the certainty improves at the beginning with increasing distance. However, after 100.000 km it does not improve further, but stagnates. **Even after an average of 250.000 km the consumption can only be ascertained by a fleet manager with a certainty of +/- 1 L/100km (> 7% of total consumption).** It is therefore possible that a comparison of vehicles with and without a technological treatment either leads to a massive over- or underestimation of the technological effect (here aerodynamics). This uncertainty is on the same scale as possible savings and therefore too high.

Therefore, the uncertainty about the effect of aerodynamic measures in practice is only too understandable.

[7] +0,4 L/100km per extra ton weight difference with respect to an average weight.



There are two messages from these findings:

1. **Real-world influences on the consumption are in such a way severe, that a long-haul fleet owner, when operating a fleet, cannot necessarily expect an accurate savings result from simple statistical checks (according to the motto "wait a long time – and then look").**
2. **Fuel efficiency proof in practice can still succeed, but only under strict equality of effects for both reference- and test-vehicles. This can only be done in extensive parallel pair-wise test runs, which are, however, not realizable for fleet owners over a longer time in daily duty.**

However:

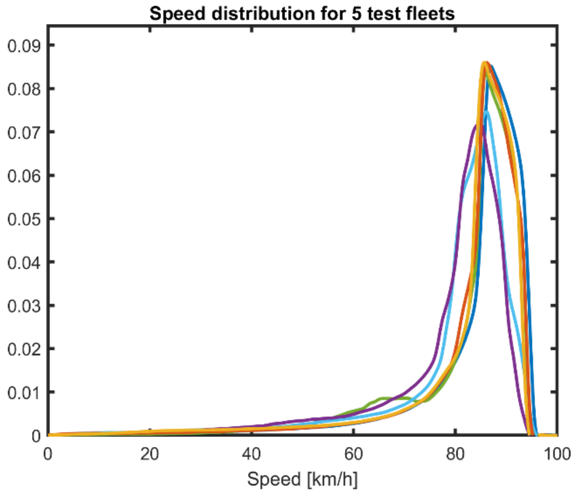
Due to the complex nature of the data, modern scientific approaches such as machine learning (see section 5.3) offer solutions for solving the dilemma of multiple, interacting, and varying external influence parameters.

5.2 Typical long-haul characteristics represented in the fleet-test

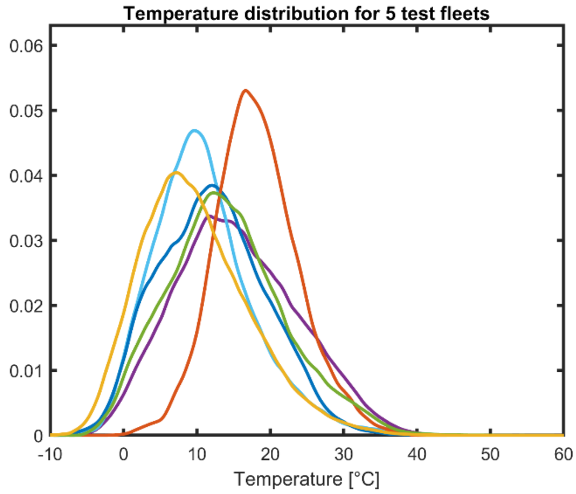
The data gathered during the fleet-test contains all the complex and diverse influences on fuel consumption such as weather, windspeed, height elevation, speed, etc. The below figures show the occurrence distribution of very meaningful real-world parameters. They represent typical EU long-haul driving characteristics of the fleet-test partners[8].

[8] Note that from 7 test-fleets 5 were used for this more in-depth data analysis.
Each distribution represents the occurrence frequency regarding travelled distance.
For the purpose of anonymization, colors are randomized between different figures.

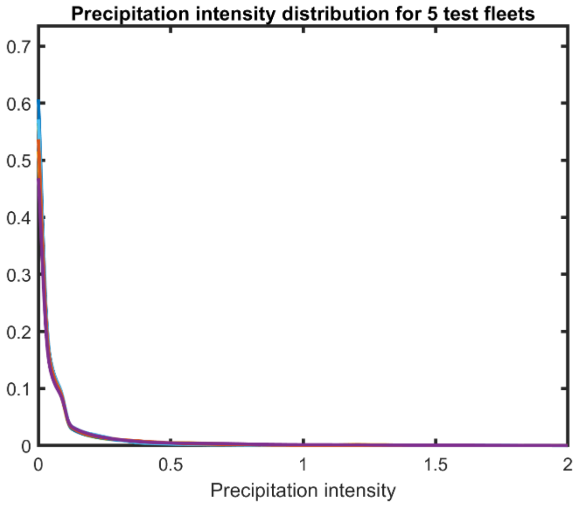
Speed



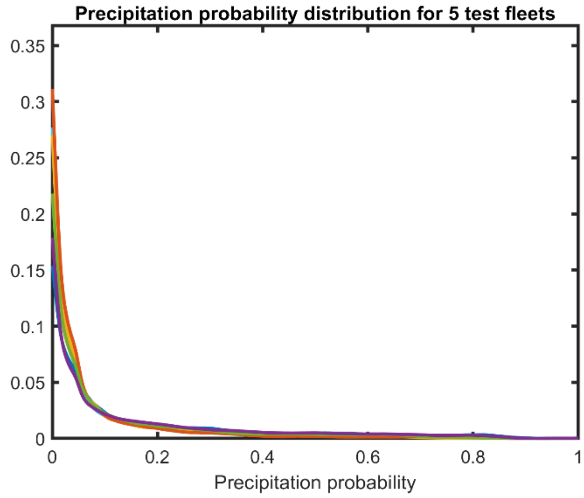
Air Temperature



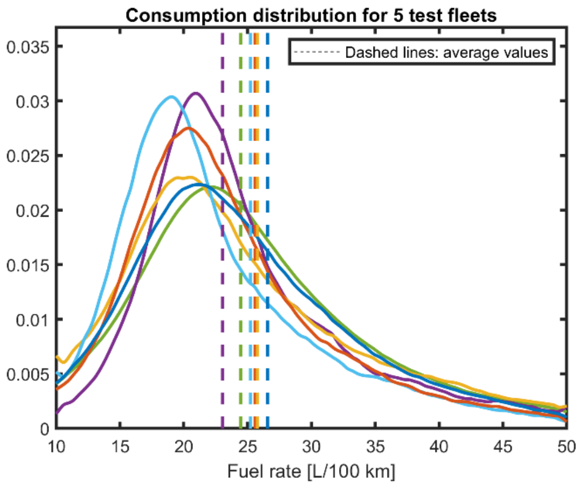
Precipitation Intensity



Precipitation Probability



Fuel Consumption



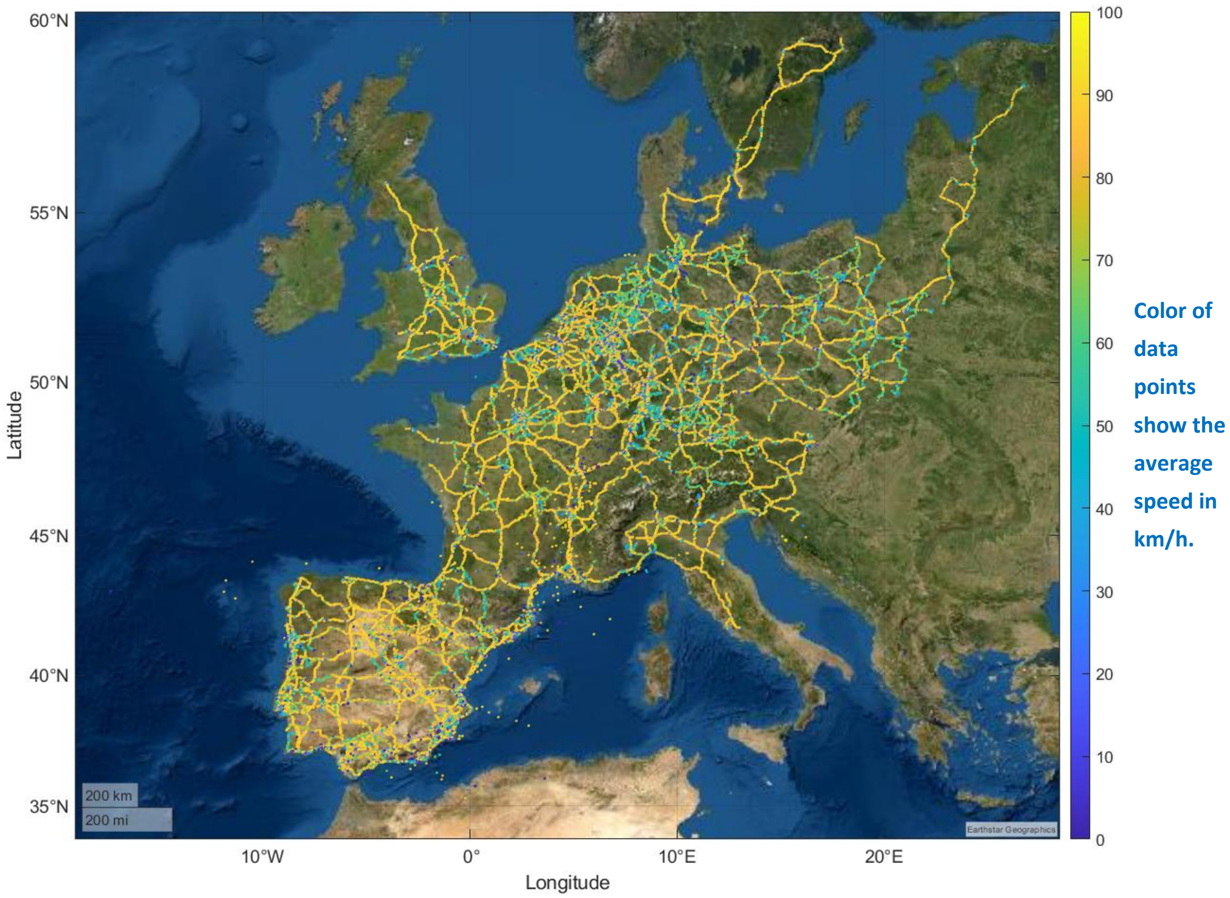
The speed-distribution is the most meaningful characteristic. It shows an extremely high occurrence for high-speed driving situations at high-way speeds:

More than 94% of driving distance takes place at speeds > 60 km/h.

More than 80% of driving distance takes place at speeds > 80 km/h.

This clearly justifies aerodynamic improvements in long-haul.

In addition, the following map displays very vividly where on EU-routes which average speed-level can be accomplished.



Speed-map of the fleet-test in EU. Coloured routes show the measured average speeds in km/h.

For the purpose of adding weather-data to the drive-data, local weather-data was acquired and mapped to the current location of the vehicle: The air temperature distributions demonstrate that the fleet-test represents a year-long temperature cycle, typical for EU ranging from -10°C to +45°C. The precipitation distributions show the intensity and likelihood for precipitation (mostly rain) along the path of the individual vehicles during the testing period.

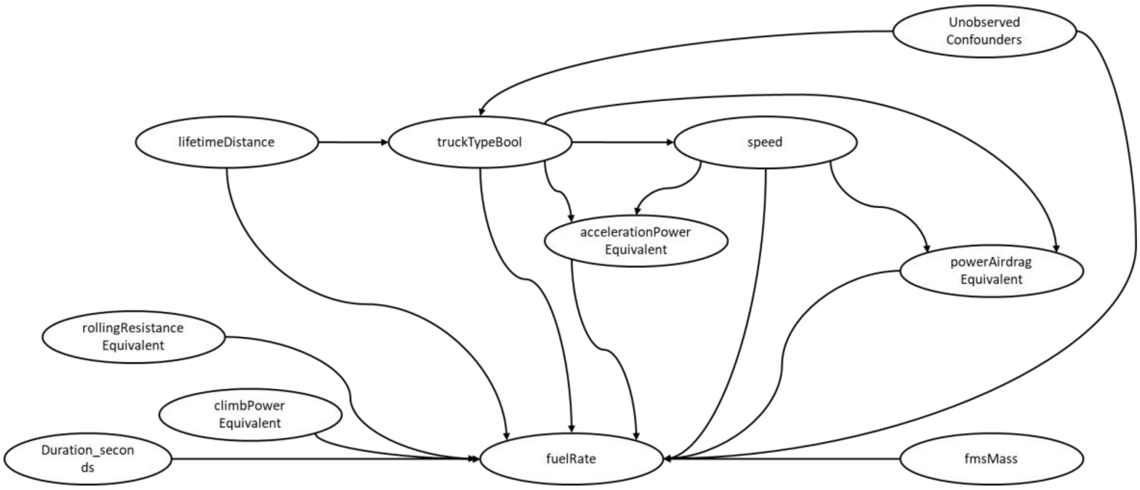
The fleet-tests were done under the influence of year-long weather distributions in the EU.

The distribution of fuel consumption shows a weighted average between 23-27 L/100km, depending on the aforementioned real-world parameters and the individual fleet missions.

5.3 Evaluation methodology: Machine Learning

Creating a reliable savings result based on real-world operational driving data, which is irregularly influenced by a multitude of complex external effects, is only possible using advanced data analysis techniques such as machine learning.

Machine learning means to build a mathematical model using an algorithm. In this case, a causal model of the effects of various parameters on fuel rate needs to be built. Ultimately, the causal effect of the “treatment” AeroPACKAGE vs. no AeroPACKAGE (expressed by *truckTypeBool, “1” vs. “0”*) is of interest. As a foundation, the causal connections of important parameters are captured in a graph as it is shown in the figure below. In mathematical science a “graph” represents the relation of objects. The graph is built by human experts, and the result is then controlled statistically by algorithms and confirmed by neural networks.



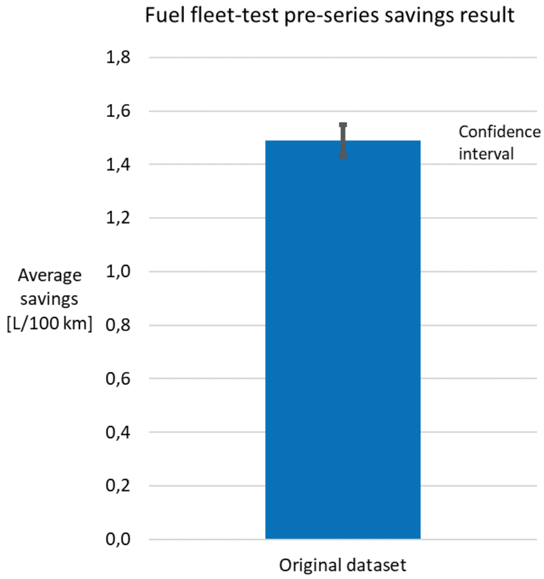
Graph showing the causal connections of the generated statistical model.

This graph serves as input for a method called *Causal Inference*, which creates a statistical model for every causal relationship using the data from the fleet-tests, including various checks to make sure that the result is not affected by any methodological error.

The original data is recorded with a resolution of 10 Hz (10 times per second). Therefore, the physical dynamics of the truck – such as the delay between an acceleration and an increase in fuel rate – are included. To obtain a dataset suitable for the current tasks, the datapoints are combined into ***snippets* defined by a driven distance of 5 km**.

For achieving the best results from machine learning, some basic modelling has been done to connect singular parameters into power equivalents. As an example, the *powerAirdragEquivalent* is a combination of dynamic pressure and driving speed of the vehicle: dynamic pressure is calculated from air temperature, driving speed, heading, wind speed, wind direction and a constant vehicle area, forming the air drag. By multiplication with driving speed, it becomes a power equivalent.

Besides the original dataset described above, two subsets were investigated: One with removed outliers and one with a perfect match of all parameters for the aerodynamics-group and control group. The resulting savings result is displayed below, which is finally based on the “Original”-dataset. The results based on both other processed datasets are dismissed (although they would lead to higher savings) because: Removed outliers in the trimmed dataset might condition the data; and matching might bias the evaluation towards higher speeds, since here more matching pairs can be found in the data, and overestimate the effect.



As a final result of the fleet-test campaign BETTERFLOW determines 1.5 L/100km savings using the conservative “Original“ dataset. This result is based on the <u>pre-series</u> AeroPACKAGE design (compare AP 203).

The specific algorithm used here is *DoWhy* from Microsoft Research. The data was gathered by BETTERFLOW and the evaluation was done by external experts from aiXbrain GmbH in Aachen[9].

Concluding remarks:

- **It is essential to have a precise scientific foundation for assessing the benefits of CO_2 reducing technology in the real-world.**
- **The results prove the relevance of aerodynamic components for long-haul trucking.**
- **The results prove the fuel savings effect of BETTERFLOW components in the real-world environment.**

[9] The report is available at BETTERFLOW.

6 Prediction for individual fleets

The fleet-test delivers a representative savings value for typical long-haul fleets in the EU. Additionally, and based on the findings, an individual robust prediction of savings for individual fleets can be performed.

For this purpose, BETTERFLOW has created the CONSEMS[10] simulation environment. With this the vehicle- and mission-physics are modeled, and the fuel consumption is then simulated. The underlying methodology is similar to the VECTO simulation tool. The tool computes the required energy of the vehicle for performing a fleet-specific real trucking mission on EU roads[11], and by using powertrain data the fuel consumption is determined. The following gives an overview of the CONSEMS top-level settings for a representative long-haul case, and shows the simulated results for the 2019/2020 fleet-test.

CONSEMS parameters

Vehicle Parameters

Mass	Empty Masses	Loading	Fuel mass over time	Ad-Blue masses over time	Mass of aero-equipment	Drivers
Tire Rolling Resistance	c_R (Tire Label)	Tire Pressure	Temperature	Speed	Load	Rain
Aerodynamic resistance	c_D (Drag coefficient)	Frontal area	Wind direction	Wind speed		
Drive train	No. of gears	η gear	Gear ratios	Axle transmission ratio	η axle transmission	Wheel diameter
Engine Mechanics	specific consumption	η engine	Max Power	EUR Norm		

Mission Parameters

Traffic	Effic.-density-correlation	
Topography on route	Height profile	Lat.-long. wind profile

Environmental Parameters

Wind	Direction	Speed	
Air data	Temperature	Humidity	Pressure

Top-level settings for a representative simulation of the fleet-tests

Mission	Long-haul, medium traffic, 20 t load, 85 km/h EU top speed
Vehicle	Reefer-trailer, efficiency tires, modern powertrain, $c_D A_{reference} = 6.0$
Weather	Seasonal average conditions

[10] CONSEMS: Consumption and Emissions Simulation tool by BETTERFLOW. Simulation environment similar to the VECTO tool, in which individual fleet duty cycles can be validated in order to predict consumption and savings values.

[11] VECTO and ACEA long-haul missions can also be run.

Simulated results of the fleet-test

Reference configuration	27.7 L/100km
BETTERFLOW fleet-test 2019/2020 configuration	26.3 L/100km
Saving	**1.4 L/100km**

The results show that with the CONSEMS simulation an accurate and conservative prediction of individual savings-values is possible.

For an individual prediction of a fleet’s saving the following input data of the fleet is necessary:

1. **Vehicle Configuration**

   (Palette boxes, storage boxes, service boxes, existing aerodynamic components, spare tire arrangement, rear underrun configuration)

2. **Speed Limit**
3. **Typical Mass**
4. **Engine Power**

These parameters are simple to determine for fleet owners and serve as input data for the performance- and savings-analysis. In cases where the operational setting is more closely defined, these data may be added:

1. **Special weather**
2. **Special routes**

7 Aerodynamics of AeroPACKAGE 204 in 2021

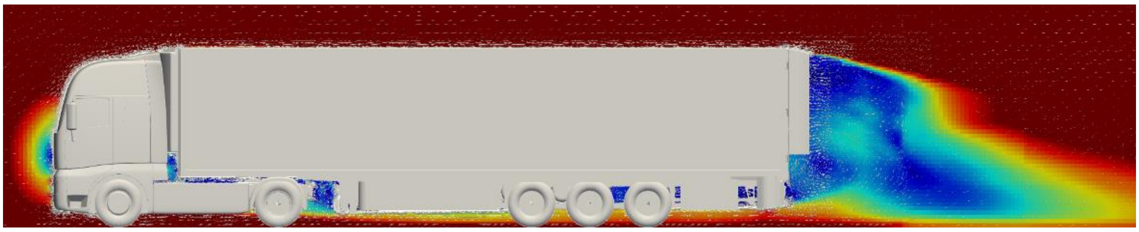
Based on the findings of pre-series and fleet-test the performance of the BETTERFLOW Aero-PACKAGE was improved and is now ready for serial production.

Compared to the reference case (here shown with the help of CFD flow images, the colors denote air speed) the flow is noticeably better:

- ✓ In the area of HighFLOW and the tractor-trailer-gap: Note that low energy separation regions have been eliminated.
- ✓ In the area of LowFLOW beneath the trailer: Note that the flow sustains its energy during its movement below the vehicle, undisturbed by the underbody shape.
- ✓ In the area of LowFLOW and RearFLOW behind the trailer: In combination with each other the energy-consuming wake is stabilized, more symmetric and smaller.
- ✓ The introduction of LowFLOW Shape, guiding elements in the area of the underride protection, improves the outflow near the ground.

Example for reference configuration

Example for BETTERFLOW 2021 configuration



Improved results for series 2021

Improved savings of the "BETTERFLOW AeroPACKAGE 204" due to improvements of LowFLOW across different trailer configurations.	**1.8 L/100km**

8 Practicality for daily duty

Aerodynamic devices can only allow for long-term benefits if they are practical in daily duty and very robust in design. Many fleet owners have doubts to invest in aerodynamic components due to past disappointing experiences with other products.

The 2019/2020 fleet-test campaign specifically focussed on fuel efficiency and on these practical aspects. The results are gathered here:

Doubts	**Results**	**Status**
Disturb-ances in daily duty	BETTERFLOW RearFLOW 500 is **automatic** and operates by it-self – **no driver interaction** is necessary. This is appreciated very much by the drivers. Just in case, the RearFLOW system can be **closed manually** as well. LowFLOW and HighFLOW **do not interfere** in any way during daily operations. Repair of cooling machine or of the axles is undisturbed.	**OK**
Damages in daily duty	RearFLOW 500 is **automatic** and operates by itself. That way it is already closed when maneuvering begins. **No damages** oc-curred during the complete testing period. LowFLOW and HighFLOW are not in the way of the wheels and **no damages**, for instance at the ramp, can occur. No damages occurred during the complete testing period.	**OK**
Docking at the ramps	BETTERFLOW RearFLOW 500 was given an extremely robust and strong kinematic system, which was designed to be as flat as possible. Naturally, door opening is not as wide as before, and some drivers reported for some ramps that at first they needed more care when approaching the docking bay. How-ever, **no complaints and no damages** were reported. When the doors are open, RearFLOW 500 is safely stored between door and side-wall.	**OK**
Dirt in daily duty	During the fleet-tests the vehicles were used in the usual way. Indeed, street-dirt, salt, and rain accumulate on the surfaces, but **not in an adverse way**. RearFLOW 500 was tested extensively in industrial life-time tests with regular appliance of dirt and salt. Due to the	**OK**

	improved flow at the back of the truck much less dirt is carried in the flow and so the rear doors of the truck are much cleaner. LowFLOW features an improved version of the “A-shape” ridge: dirt will slide off so that it does not begin to stick in the area around the wheels.	
Cleaning in daily duty	The systems are robust and specially made for regular cleaning in the **truck-wash or with the high-pressure washer**.	**OK**
Snow and ice	RearFLOW was tested in ice-chambers down to -5°C and below. Temperature ranges during the fleet-test were gathered in 2 winters 2018/19 and 2019/20 all over Europe and no noticeable driving occurred below -5°C. Tests in heavy winter conditions show noticeably less snow/ice accumulation on the rear-doors than on trailers without aerodynamic systems because of the improved flow. LowFLOW features the special “A-shape” ridge: Tests in heavy winter conditions show that snow and ice slide off so that in the area around the wheels it does not begin to stick. No problems with snow or ice were reported. Further winter tests in 2021 under extreme conditions also showed no adverse effects.	**OK**

9 BETTERFLOW fleet-test partners

We are very thankful for an impressive line-up of innovative and dedicated companies which have been supporting BETTERFLOW and took part in the testing campaign:

Bussmann Spedition Logistik – Germany

CCT Logistik – Germany

Kawczynski Logistics – Poland

March Transporte – Germany

Papstar – Germany

Primafrio – Spain

Sackmann Transport – Germany

Refritrans 2000 – Spain

Truck Center Vreden – Germany

Dr.-Ing. Rainer Buffo

Rainer Buffo

Dipl.-Ing. Ingo Martin

Dirk Sieprath

Dirk Sieprath