

Aerodynamic possibilities for heavy road vehicles – virtual boat tail

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Abstract

The focus of this paper is presenting concept survey made for lowering the aerodynamic coefficient of heavy road vehicles. Target vehicles were a long distance bus and a vehicle combination of 25.25 meters and 60 ton. The conception goal for the truck was to cut the aerodynamic coefficient into half. Because of such a target, it was agreed not to follow normal technical and economical characteristics of today's truck engineering.

The main objectives were to raise discussion about the potential of aerodynamics in the context of heavy road vehicles in Finland and particularly to test one technical solution to improve the aerodynamic performance of the rear end of the trailer. This solution is called virtual boat end. It is based on flow of pressurized air through the trailing edges of the trailer. Tests were done in wind tunnel using 1:10 scale models. This kind of virtual boat tail seemed to work at least in small scale. The aerodynamic coefficients of the modified models were, as expected, significantly lower than the reference.

Keywords: aerodynamic coefficient, bus, truck, trailer, wind, 60 ton, fuel consumption, wind tunnel, virtual boat tail

* Aalto University is formed at the beginning of the year 2010 from three separate universities in Helsinki area. One of them was Helsinki University of Technology TKK, what is the Alma Mater for the authors.

1. Introduction

The focus of this paper is presenting a concept survey made for lowering the aerodynamic coefficient of heavy road vehicles. There were two target vehicles, a long distance bus and a vehicle combination of 25.25 meters and 60 ton. This combination is allowed on road in Finland and some other countries like Sweden.

The main objectives were to raise discussion about the potential of aerodynamics in the case of heavy road vehicles in Finland and to test one technical solution to improve the aerodynamic performance of the rear end of the trailer. This solution is called virtual boat end and it is based on flow of pressurized air through the trailing edges of the trailer. There was agreed, at the beginning of the conception work, target to cut the aerodynamic coefficient into half. Because of such a target, it was agreed not to follow normal technical and economical characteristics of today's truck engineering.

In Finland there has been over last 18 years a coordinated research consortium dealing with traffic energy matters rising from various aspects. In the sub-projects of research programs, there has been regular discussion about the possibilities of aerodynamics in heavy vehicle engineering.

Better aerodynamics has benefits in various sectors like fuel consumption, driving performance and demanded engine torque, water spray, fouling and noise emission. These aspects and their magnitude are not discussed in this paper. The focus is in the aerodynamics from point of view of fuel consumption. In early days of motoring, the better aerodynamics was also a matter of achieving top speed and capability to maintain cruising speed under headwind. Figure 1 present one example of early days concepts. Also a greater outlook and impression of more modern outlook must have been important factors. During more recent times with powerful engines this aspect has shown lower importance. But it is worthwhile remembering that good aerodynamics could also play part in the discussion of down sizing of the engines.



Figure 1. Labatt Streamliner /McCallen/

Most of the solutions and principles to lower the aerodynamic coefficient of vehicles have been known for decades. However they have not found favor among industry and operators. There have been challenges to adapt them with every day operation, fear of compatibility between tractors and trailers as well as not sufficient pay back assumptions. Also the size and form of cargo causes limitations for the design.

Truck has character to consist of various parts like cabin, chassis and cargo space. When there is a trailer attached there more parameters. Trailer has its own chassis and cargo space participating to vehicle over all aerodynamic performance. It is important to remember that cargo space may be manufactured separately from the cabin-chassis and at least the trailer is manufactured separately. In some cases trailers are changed even several times per day. And finally a trailer may also live much longer than a tractor i.e. very many more years on the road than a tractor.

2. Research Method

At the beginning of the work, the literature survey were conducted both in the bus and truck side. Based on that, there were a lot of arguments for discussion inside the project. It was agreed, beforehand, not to follow the technical and economical limitations in design of the aerodynamic forms. Work was considered to be conceptual and the main target was to be an activator for discussion of possibilities of aerodynamics in heavy vehicles.

Tests were done in the wind tunnel of Aalto University (formerly known as Helsinki University of Technology TKK) using 1:10 scale models. There was a common heavy steel body for all models and modifications were made by mounting different components and body work on it. For simplification, the underbody of the vehicle and the engine compartment was not modeled. This situation was the same for all combinations. There was no moving road approach available. Buses and especially trucks are very long compared to their width. This brings along a need for special carefulness when focusing the tail part of the vehicle in wind tunnels. Trucks have however typically relatively high ground clearance, so the quality ground plane flow and demand for moving ground are somewhat less critical than with passenger car models.

In case of automobiles, aerodynamic coefficient is normally given only by a single value based on the air flow attacking from straight ahead. However, especially in case of long multibody vehicles like tractor-trailer combination, the angle of the wind orientation has a significant role for the aerodynamic coefficient. This is why the angle of wind orientation was tested up to the possibilities. In Figure 2 can be seen a literature taken example of the components participation to total drag. Left side is wind coming straight ahead and on the right the drag coefficient as a function of wind orientation is presented. It is worth while to notice, that the role of cabin seems to be constant, but the drag of the bodywork itself reacts noticeably. In case of tractor trailer the increase of drag as a function of wind orientation is dominated by the trailer. /Hucho/

Computational tools like CFD have proved their capability during the last decade in vehicle aerodynamics becoming a basic tool for this area of research. However, for this research a more practical approach, having drawback of laborious model construction, was chosen. There are challenges in computational approach what comes to modeling and verification of

models which cannot be accepted in these kind of partly student driven projects. It can also be estimated, that the reference construction of existing vehicles with sharp edges, driven by maximizing cargo volume and easy manufacturing cargo space, would have needed special approach for modeling the turbulence. One special benefit of computational approach is its capability to be able to repeat test setups which cannot be realistically done by other means. These kind of special situations are for example taking account overtaking and oncoming traffic's role.

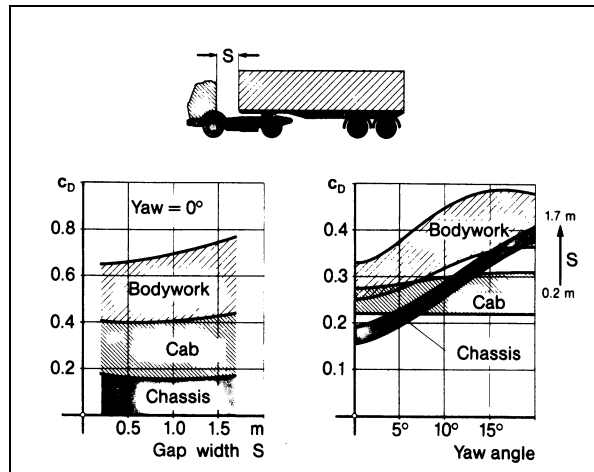


Figure 2. Tractor trailer parts of whole role. /Hucho/

2.1 Models for the bus

Back in the year 2006 there was a Master of Science project for long-distance bus aerodynamic performance. /Nyholm/ For the bus there was one central body with 4 different noses and 3 different tails surveyed in this project. In this case of the bus, there was a demand for realistically technical feasibility. Basic shapes are presented in Fig 1. /Nyholm/

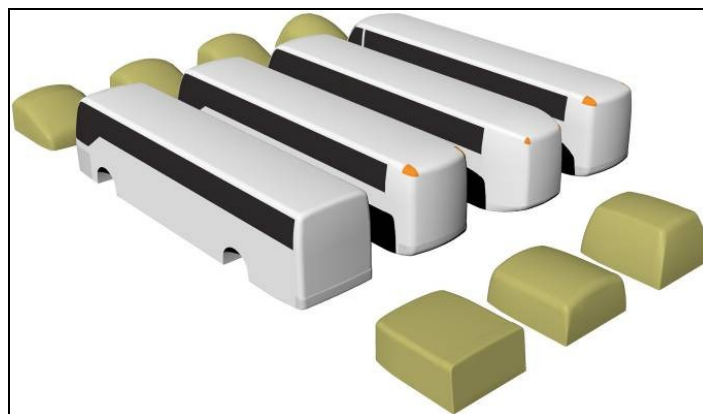


Figure 3: Models used in wind tunnel testing. Model was in scale 1:10 being 1.28 meters long. So the target bus length was 12.28 meters long.

In the bus case there was collected information about both the nose and tail design. The short conclusion was that tail is dominant when nose is reasonable. The potential of the nose is

achieved already with quite modest design when remembering the demands for driver positioning, need for sight, rear view mirrors, wind screen wipers, soiling etc.

The biggest improvement of aerodynamic coefficient was achieved with round nose and boat tail like rear end (see Figure 3). With the bus being short, there were side wind measurements made up to 25 degrees of yaw.

2.2 Models for the truck

The reference vehicle was following general scheme of the articulated vehicle in Finland being a big truck and a 5-axle trailer behind it. For the scale models, there has been neglected much of the normal details. The reference shape and four modified versions of the truck-trailer are presented in Figure 4. These models were tested with ± 15 degrees of angle of wind yaw. Both scale measurements and usage of marker color for visualizing purpose were used. /Killström/

For all the models there is a common steel frame, where components were mounted with bolt joints. Tires were made of plywood and were fixed to the steel frame. Tires had planar bottoms in order to emulate the deformation of a real tire under road contact. The other very important reason was not to keep the height of the vehicle right. Wheels were not allowed to touch ground level. Chassis of the vehicles is very much simplified, there was no air ducting for engine compartment and details like mirrors etc were ignored in the models.

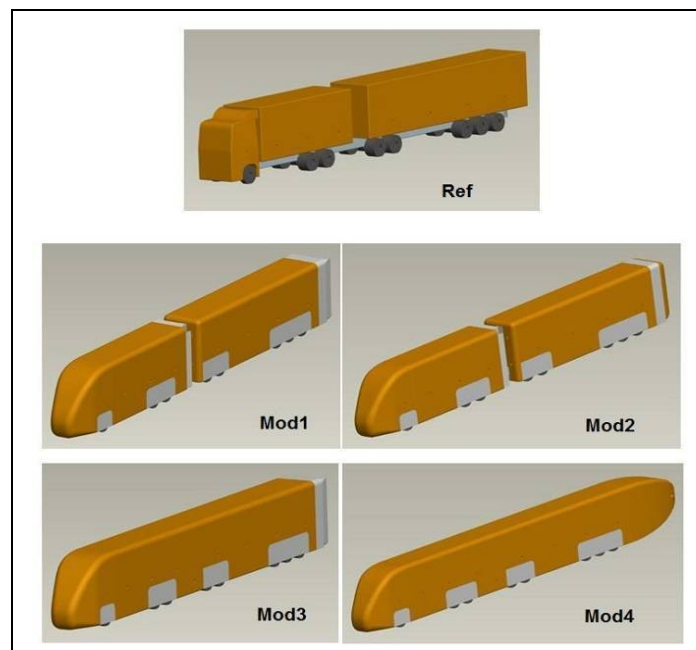


Figure 4: Models used in wind tunnel testing. Mod 1, Mod 2 and Mod 3 have the possibility to use trailing edge blowing, what is called here also as a virtual boat tail. The Mod 4 is a physical boat tail.

In this paper the focus is the role of the tail, while the front end having the same shape in all the models. During the bus case, there was a remark made that the front end has so many more operation based restrictions and it can be made relatively good already without dramatic out

appear. There is notice from the literature, that the beneficial form of a boat tail is greater in the case of trucks having aerodynamically good front end. This may be a result of flow changes at the boundary layer as well as down underneath of the chassis. /Cooper/ Also from the point of view of Finnish logistic companies and manufacturing industry the construction of cargo space and trailers was much more interesting.

From literature there can be detected several means to realize a boat tail and even projects with a full scale implementation. In Figure 5 there can be seen flaps in different directions, steps and curvatures.



Figure 5. Different boat tail construction in full scale. /Leuschen, TMA/

The front end for modified models was adopted from high speed trains with assumption of driver being seated centrally. The cabin was extended 1.5 meters in forward direction and the gap between cabin and cargo space was sealed. The rounding's of the corners are targeted to have a Reynolds number over 80 000 under highway cruising speeds.

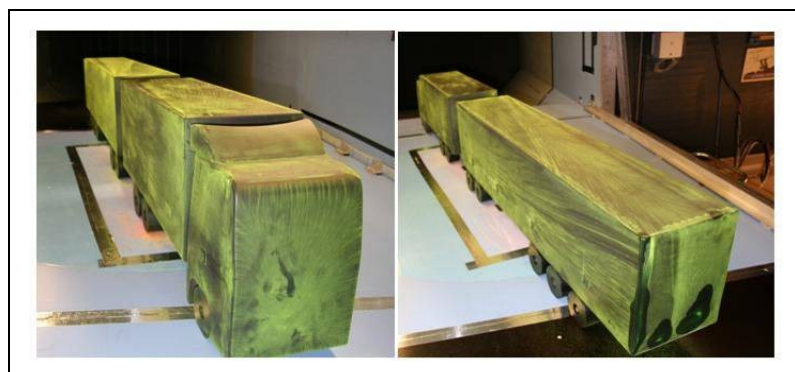


Figure 6. Example of color test for reference.

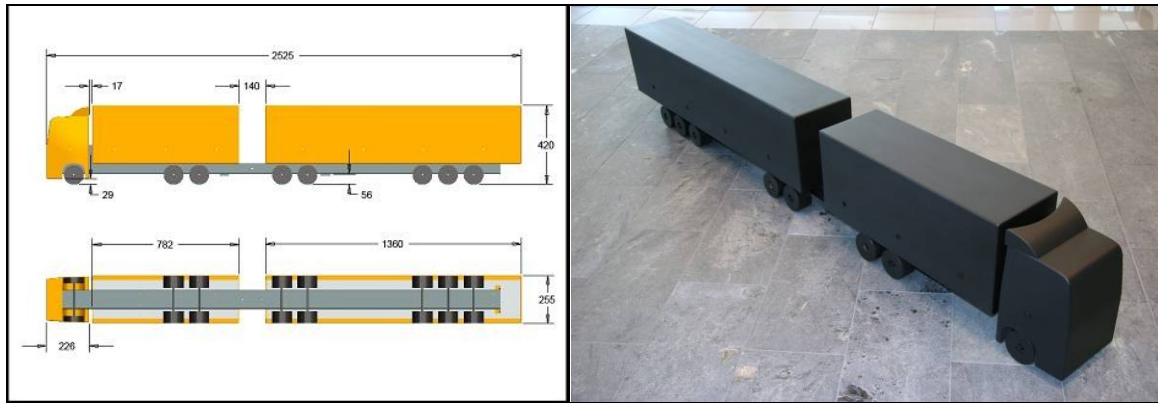


Figure 7. The reference model for the truck before modifications. The overall length of the vehicle is 25.25 meters allowing total weight of 60 tons. These kinds of combinations are commonly used in Finland.

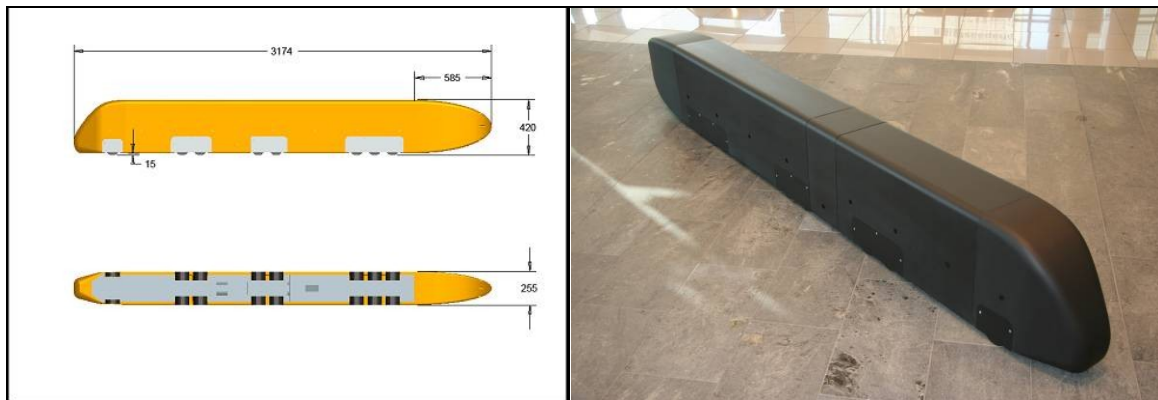


Figure 8. Mod 4, the real boat tail approach, the overall length of the vehicle would be 31.74 meters. This shape was chosen to be the extreme one based on recommendations from source /TorenBeek/

2.3 Boundary-layer blowing

Between truck and trailer there was used a trailing edge flanges and flow control fence. There was also possibility to cover the gap totally. For the rear end of the trailer there were engineered three different shapes: 10 degree trailing edge flanges, trailing edge arcs with radius of 100mm (in scale) and the real boat tail. The two first mentioned were also possible to be used with trailing edge blow, which is called here also as a virtual boat tail.

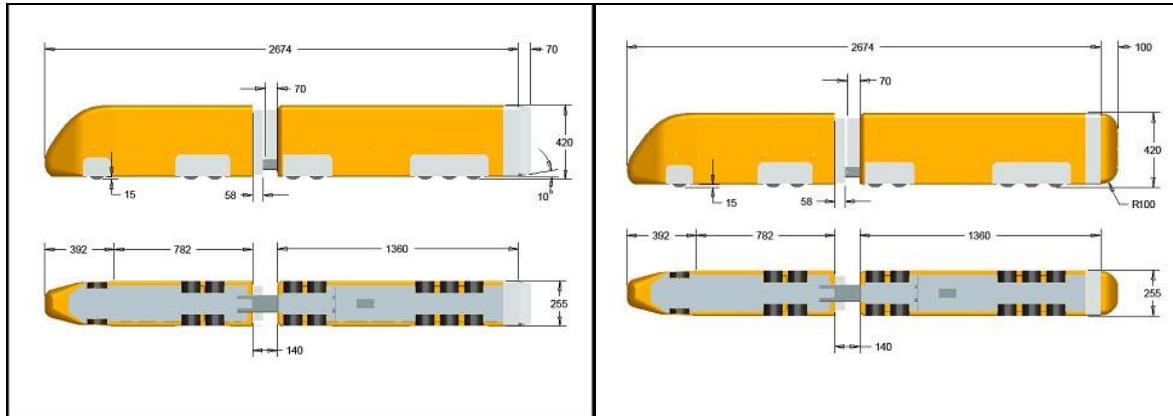


Figure 9. On the left the dimensioning of Mod 1 and on the right Mod 2. Both have an overall length of 2674 mm which would result in full scale to 26.74 meters. This would mean an overall length 1.49 meter longer than allowed today.

The boundary-layer blowing unit was milled from aluminum and plastic. The nozzle gap in the model was in both versions 0.4 mm and the overall area of the nozzle was 394 mm². In the construction there was first built an aluminum chamber where the pressurized air can diffuse and after that there were 2 different geometries for the flow. The length of the tail part was increased 70 mm (Mod 1 and Mod 3) or 100 mm (Mod 2) as compared to the reference. In Figure 9 can be seen the dimensioning of the virtual boat tails used for wind tunnel testing.



Figure 9. Detailed picture of the boundary-layer blowing units. The left is the one used in the Mod 1 and Mod 3 having 10 degrees angle and the right in Mod 2 having arc with radius of 100mm in the scale model.

3. Results

Measurements were made with tunnel velocities from 40 m/s up to 65m/s. It has to be underlined that the upscale speed in this survey was lower than targeted being some 16 km/h below limit, but the results seems to be interestingly consistent. Side wind measurements were made with angles of -15°, -10°, -5°, 0°, 5°, 10° and 15°. There were forces measured from the

six component wind tunnel scale on which the model was bolted on, as well as photos of marker color for visualizing purposes.

Essential results are presented in Figures 10, 11 and 12. In all of those the air flow velocity has been 45m/s. The velocity of the air used for trailing edge blow has been approximately 105 m/s. The aerodynamic coefficients of the modified models are, as expected, significantly lower than the reference. The best result was with Mod 4. It has its origin more like a high speed train unit than a real road using vehicle, so perhaps it has to be considered the extreme one. The resistance coefficient was 76% lower than the reference, when the angle of wind was 0 degree i.e. no side wind component was present.

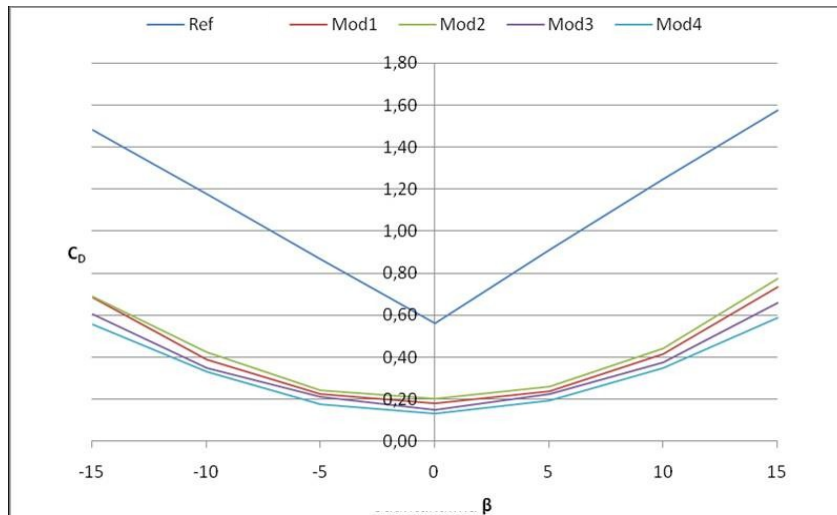


Figure 10: Aerodynamic coefficients with different wind yaw β .

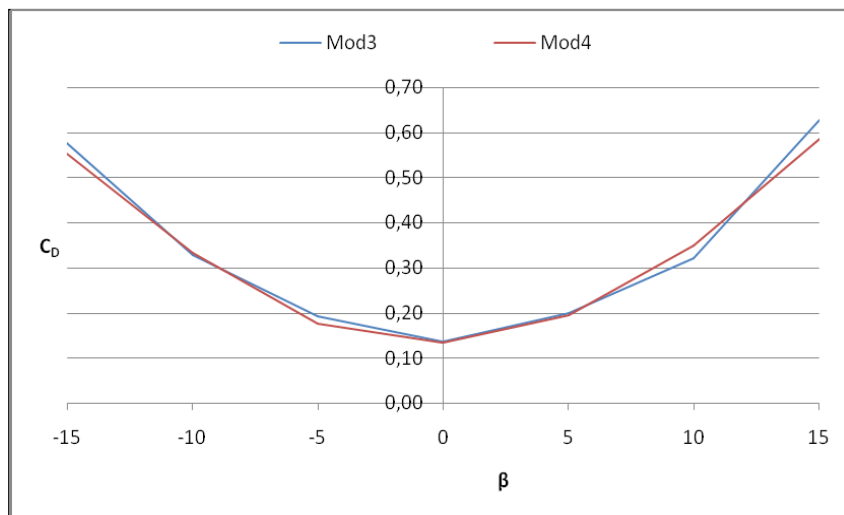


Figure 11: Comparison of aerodynamic coefficients with different wind yaw β between trailing edge blow (Mod 3, Figure 9) and a real boat tail (mod 4, Figure 8). Performance is identical but the advantage for virtual boat tail is to be much shorter.

The lowest effect was with Mod 2 having resistance coefficient about 64% below the reference. It was an interesting observation, that all the modified models achieved relatively

similar behavior in terms of wind angle. The reference model had a coefficient about 0,6 at 0 degree wind angle yaw and it was rising rapidly over 1.0 with the side wind component present.

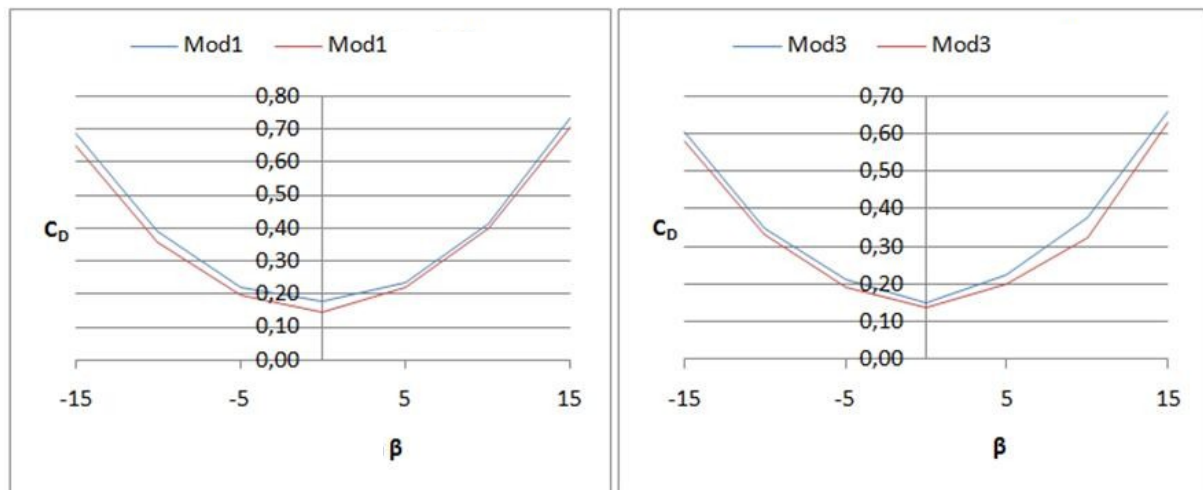


Figure 12: Comparison of aerodynamic coefficients of Mod 1 and Mod 3. Blue line is model itself and the red line is model with trailing edge blowing on.

4. Conclusions

The boat tail approach is known to be a good solution in terms of aerodynamics. The results have been widely presented in literature, and they are tested both in tunnels and in full scale. Our interest was to try to create a kind of virtual boat tail by blowing pressurized air into the trailing edge via very narrow gap. The classical boat tail may increase the length of the vehicle significantly, but using trailing edge blowing there might be possibilities to shorten the solution and still to have the full aerodynamically performance of the long boat tail. This seemed to work at least in small scale. Of course costs of the pressurized air production in the trailer are a matter of serious discussion, but the target of this paper was to discuss this possibility in theory.

This kind of solution would bring along the performance of a boat tail without increasing notably the length of the trailer or having negative influence to the loading or unloading the vehicle.

5. Acknowledgments

This paper is based on work done on a past project called RASTU www.rastu. Work was done in M.Sc projects of Juha Nyholm (the bus part) and Kimmo Killström (the truck and virtual boat tail part). Special acknowledgements to Kimmo for carrying out the truck part and suggesting by himself the virtual boat tail approach.

The work for improving the energy efficiency of road transport and also promoting better aerodynamics will be continued in TransEco-project. www.transec.fi

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