

## TOWARD MORE AERODYNAMIC HEAVY COMMERCIAL VEHICLES IN EUROPE



**Bernard Jacob**

Deputy Scientific Director  
French Institute for Sciences and  
Technologies of Transport, Development and  
Networks (IFSTTAR), France  
[bernard.jacob@ifsttar.fr](mailto:bernard.jacob@ifsttar.fr)



**Jean-Paul Bouchet**

Engineer  
Scientific and Technical Center for Building  
(CSTB), France  
[jean-paul.bouchet@cstb.fr](mailto:jean-paul.bouchet@cstb.fr)

### Abstract

Aerodynamic improvements for HGVs, e.g. addition of flaps at the rear or reshaping the front of the truck, can significantly reduce fuel consumption and CO<sub>2</sub> emissions. COM (2013) 195 opened recently the way to allow the implementation of these solutions, without payload reduction, by adapting the European legislation on dimensions of HGVs. This important change in the transport regulation is a unique opportunity to reconsider the vehicle architecture in a larger view including comfort and safety issues, both for drivers and road users. After a brief review of existing aerodynamic devices and possible further improvements, this paper analyses opportunities and external constraints to take into account in the revision process. A summary of the on-going discussion and studies carried out by an expert group set-up by the European Commission (DG-MOVE) is reported, as well as the perspectives of the European Directive 96/53EC on heavy commercial vehicle weights and dimensions revision.

**Keywords:** Heavy vehicles, Aerodynamics, Fuel consumption, European regulation, Heavy vehicle dimensions.

## **1. Introduction and Context**

The European Commission White Paper on Transport (COM, 2011) urges actions to make road transport more resource-efficient, with the challenge of reducing Green House Gas (GHG) emissions by 20% by 2020. Aerodynamic improvement of Heavy Commercial Vehicles (HCV) may significantly contribute reducing fuel consumption and CO<sub>2</sub> emissions. Indeed, the reduction of aerodynamic drag of trucks is now recognized as a key factor in reducing fuel consumption. Aerodynamic drag is responsible for more than 40% of HCV fuel consumption at highway speed and 10% drag reduction is estimated to save about 5% on fuel consumption, and therefore on CO<sub>2</sub> emissions. Several studies (Platform for aerodynamic road transport 2011, S. Kopp 2012, Seifert and al. 2009, Welfers and al. 2011, Leuschen and Cooper 2006, Ortega et al. 2013) have proposed efficient solutions and some of these new aerodynamic devices are already in use, e.g. in the US. They are not yet developed in Europe because of legal limitations of truck dimensions and obvious priority given by the operators (manufacturers and hauliers) to maximize the loading capacities.

In COM (2013), the European Commission (DG-MOVE) announced a revision of the Directive 96/53 on heavy commercial vehicle weights and dimensions, to facilitate reduced energy consumption and emissions through new technologies, and assessed the impact of this revision. This should be seen as a unique opportunity for the redesign of some parts of the vehicle, and by the way improving the driver comfort and the road safety, above all of other (vulnerable) road users. A dialog was initiated between the DG-MOVE and the stakeholders (lorry manufacturers, hauliers, road operators, environment and users associations, and experts...) within an expert group to identify how adapting the European regulation and promoting relevant aerodynamic technologies without reducing road safety. The revision preparation process is described in COM (2013).

This paper aims at presenting a brief review of new aerodynamic add-ons and the external constraints and opportunities to take into account (road safety, infrastructure geometry, intermodality...) for an optimized adaptation of the European regulation to promote more aerodynamic HCVs. In this revision process, Performance Based Standard (PBS) approaches are introduced, while PBS criteria and certification procedures for type approval purpose are discussed.

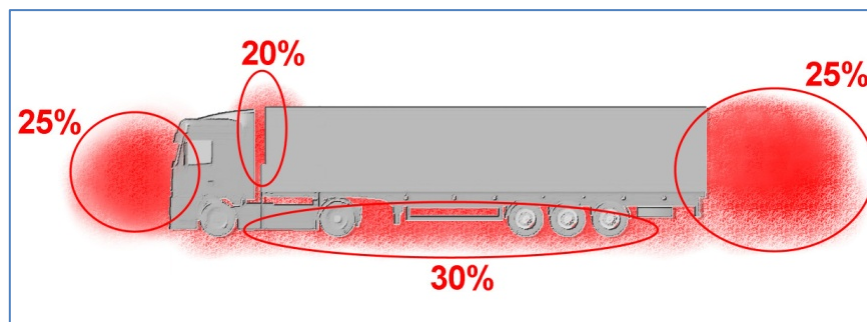
## **2. Brief Review of Aerodynamic Solutions and Rear Flaps Potential Effect**

During the last 20 years, many efforts have been expended (Patten et al. 2012) and partially implemented by tractor manufacturers to improve the aerodynamics of their vehicles. These improvements can be seen today on the HCV fleet regarding optimized cabin shapes, side mirrors, side edge turning vanes, etc... In the same time, numerous other aerodynamic add-ons for HCV have been designed and tested to lower fuel consumption. Those devices can be used for retrofitting or direct implementation on new vehicles. Due to the increasing part of the fuel in the total cost of road transportation, some of those add-ons are more and more implemented by the haulier companies like: cabin roof spoiler, tractor side fairing, tractor/trailer side skirts or trailer front fairings (Figure 1).

As illustrated in Figure 2, the main zones of the truck which are relevant for further aerodynamic improvements remain: the front of the truck cabin, the underbody of the truck and the rear part of the trailer (base drag).



**Figure 1 - Example of Fully Optimized HCV with Allowed Add-ons (source : IVECO)**







**Figure 2 - Main Zones of Aerodynamic Drag of HCV**

As the gap between the cabin and the semi-trailer, which can be protected by air deflectors or other “gap seal” devices, the underbody drag can be partially reduced in the frame of the current regulation by the use of flaps or skirts for example. This is not the case for the front of the cabin or the rear part of the trailer, where major improvements would require additional length to avoid reduction of the pay load volume to comply with the current Directive. Therefore, the new challenge is to adapt the European regulation on weight and dimension, in order to make possible the implementation of other aerodynamic improvements, without pay load reduction.

Today, it is clearly demonstrated that addition of flaps at the rear of the vehicles could significantly reduce the aerodynamic drag. The development and implementation of such devices on the European road network could be achieved in a very short term as most of the solutions already exist or are under development and could be implemented on the current vehicle fleet at little additional cost (2 to 3000 €).

Figure 3 gives the potential fuel savings for several rear devices of various lengths. The longer the flaps, the better the aerodynamic performance increases, at least up to a length of 2 m, much longer than the 0.5 m currently allowed by European regulation 1230/2012 (COM, 2012). Currently commercialized flaps in the US are typically around 1.2 m.

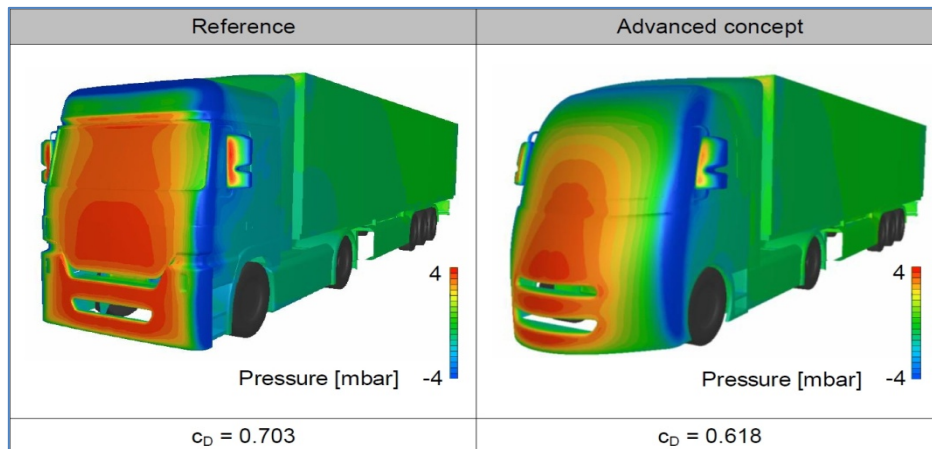
As depicted in Figure 3, several rear devices, often called as “boat tail”, have been studied and tested. Obviously, the aim of the revision process is not to promote one device against the others but to identify the relevant “extra length” to allow the best aerodynamic improvement. Regarding rear optimization, it is important to note that more and more studies are conducted also on active devices (blowing, pulsating jets...etc.), sometimes in combination with boat tails. That kind of advanced techniques should be taken into account in this revision process in order to define a new directive which remains relevant for long time.

picture	configuration	Length [cm]	Difference* [%]
	Rigid tail	150	5.7
		200	6.7
	Foldable tail	130	3.7
		130	5.5
	Inflatable tail	150	3.3
	top vane	50 (length) 15 (height)	2.6
* Based on: 1 liter diesel = 2.6 kg CO <sub>2</sub> ; averaged fuel consumption of 30l/100km			

**Figure 3 - Fuel Savings Performance Thank to Rear Devices (source: PART)**

### 3. Front Shape Profiling Potential Effect

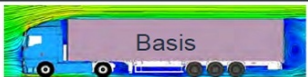

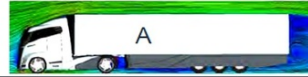
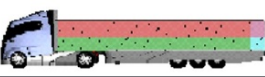
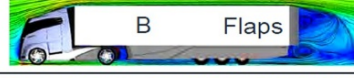




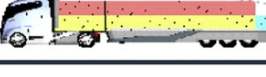
As illustrated in Figure 4, the truck cabin or tractor may also get significant aerodynamic improvements by profiling its front shape, which also means slightly extending the vehicle length. Indeed, by reducing the fore-body pressure, the drag coefficient ( $C_D$ ) could be significantly decreased.



**Figure 4 - Drag Reduction by Reshaping of the Cabin (source: T&E)**

Compared to current "flat front" cabins, this involves a great technological breakthrough with major industrial and financial issues, only feasible over a medium to long term period (5-10 years). Combining both improvements (rear and front) could lead to important fuel savings as illustrated in Figure 5.

The more the front shape will be optimized, the greater will be the impact of the rear shape in the overall drag. As it has been highlighted by several studies, the best improvement would be obtained by a combination including optimized cabin shape, tractor and trailer side skirts, gap seal and boat tail devices.

Variants	Length Change Front & Rear	Paletts [1m Height] Volume [98 m <sup>3</sup> ] const.	Fuel Reduction [Easy highway]
 Basis	Basis TGX	 68	0%
 A	Front : + 0,8 m Rear : 0	 68	- 5%
 B Flaps 10°	Front : + 0,8 m Rear : + 0,6 m	 68	- 8%
 D	Front : + 0,8 m Rear : + 1,2 m	 70	- 10%
 F Boat tail	Front : + 0,8 m Rear : + 2,7 m	 70	- 15%

**Figure 5 - Fuel Savings Performance vs Add-ons Combination (source: KOPP)**

The tractor is obviously a key zone for other improvements regarding CO<sub>2</sub> emissions like alternative power trains (batteries and alternative fuels), enhanced cooling system, waste heat recovery, etc. All these new technologies would benefit from an additional length of the tractor.

Moreover, regarding the comfort of the driver, cabin designs could be optimized in terms of ergonomics (for female or tall drivers for example), to enhance the acoustic insulation or to have more space for sleeping (bed width), cooking or working. Indeed, increasing the quality of seating, eliminate vibrations and optimize the space between workstation-seat-couchette could lead to significant comfort improvements on the drivers with obvious effects on road safety.

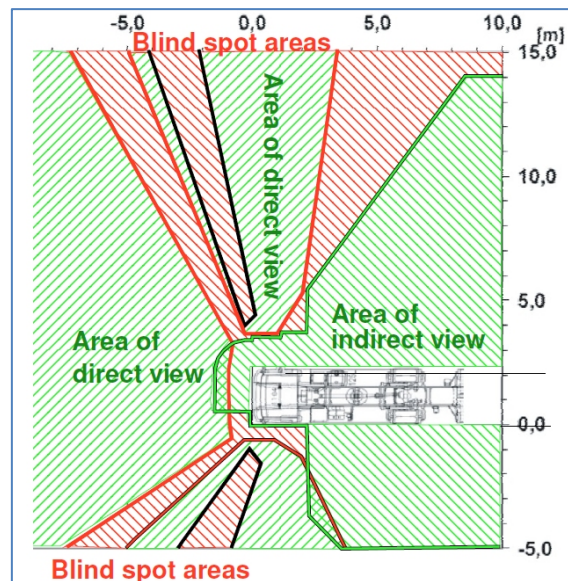
#### 4. Safety Opportunities

The safety aspect is an important issue in this revision process. More than an aspect to be taken into account, the redesign of the front of HCV must be seen as a unique opportunity to improve the road safety. Too many vulnerable road users (VRUs : pedestrians, bikers...) are victims of accidents in urban areas caused by maneuvering trucks. Front collisions against light cars also induce a rather high rate of fatalities. More than 4800 peoples died in road traffic accidents involving HCVs in 2010 (EU-24). Accident analysis shows the 3 main scenarios with involved HCVs and VRUs:

- right turning maneuver of the HCV with a conflict mostly of a bicyclist,
- overtaking maneuver of an HCV (passing a bicyclist),
- crossing of the pedestrian while the HCV is only moving along the road.

Recent studies suggest that a profiled front shape (a bulb) of the cabin could reduce the severity of most of the front collisions and save up to 500 lives per year in the European Union. This new shape seems to be fully compatible with aerodynamics optimization needs. On this topic, the FKA has proposed a HCV front shape for the prevention of “run over” mechanisms (VRU passing under the HCV without wheel contact) in both forward driving and right turning scenarios (Fassbender and Hamacher, 2008). The numerical simulations performed with this “rounded” shape demonstrate that more than 80% of run over situations can be prevented by the deflection of the human model to the side. Obviously, by adding a crumple zone or shock absorbers, severity of injuries can be drastically reduced.





**Figure 6 - Areas of Direct View, Indirect View and Blind Spot Areas around the Truck**  
(source: APROSYS project)

To reduce the causes of these accidents, another important issue is the direct/indirect fields of vision of the drivers (Loughborough University, 2011), which are illustrated in Figure 6. This figure highlights the mandatory indirect field of vision and several “blind spots”, i.e. the sight obstructions caused by A- and B-pillars and by the mirrors.

These “blind spot” areas are responsible of the most common incident when the HGV turns right without being able to see the cyclist. The cyclist is knocked off the bicycle and falls under the HCV as the HCV turns and the cyclists goes under the wheels. The reshaping of the cabin could lead to improvements of direct vision around the cabin by optimizing driver position versus windscreen location (lower edges) or by adding door panel apertures, which seem to be a relevant enhancement.

## 5. Towards a Revised Regulation

### 5.1 Guidelines and principles

If the elongated front cabin could lead to relevant improvements in comfort and safety of drivers and VRUs, and added rear flaps could reduce the drag forces and fuel consumption, jointly with the front cabin reshape, several constraints have to be taken into account in this revision process. These constraints address safety issues, maneuverability and compliance with the infrastructure, as well as intermodality ability. Some possible negative impacts of the proposed changes of HCV design at the rear or the front have been investigated to prevent any deterioration of the global safety or maneuverability (Patten et al., 2010).

The implementation of the revised regulation is expected through performance criteria, tests, and type approval procedures. A performance based approach is recommended. The expert group is analyzing the Performance Based Standards (PBS) developed outside Europe and how the PBS approaches can be relevant in this revision process. Lessons will be drawn from the Australian (NTC, 2006) and Canadian (NCHRP, 2010) experiences. Identification and discussion are on-going about the most relevant performance criteria.

No prescriptive recommendations regarding maximum extension are planned, but performance criteria are focused on aerodynamic improvement, safety, comfort, infrastructure compliance, and intermodality ability.

## **5.2 Proposals on Rear Devices**

Technical requirements for the flaps or other rear devices are recommended by the expert group in a revised regulation in order to avoid safety issues.

### *Material and resistance*

A minimum height for the lower parts and requirements regarding sharp edges or hardness of material should be defined to avoid the risk of injury by the flaps in case of a collision. A recent Canadian study demonstrates that in order to prevent at least 90% of the vehicles from initial boat tail strikes, long boat tails (4 ft) must be mounted higher than 1740 mm from the ground (Patten et al., 2010).

Resistance of materials and fixation to the trailer or truck shall avoid any risk of ripping or breaking due to severe climatic conditions (e.g. temperature from -30 to +50°C) and strong lateral wind (up to 80 km/h) or longitudinal wind (up to 160 km/h). Moreover when deployed, the rigidity of flaps shall be sufficient to avoid dangerous swaying or oscillating motion. The rear underrun protection shall remain effective when flaps are folded or deployed.

### *Foldability/retractability*

Due to various road network possibly crossed by HCV like urban areas, the foldability of rear devices should be studied and regulated. E.g. flaps longer than 0.5 m should be automatically foldable by the driver from the cabin and manually when the vehicle is stopped. The flaps shall not be opened by the wind action up to a wind velocity of 160 km/h.

### *Maximum dimensions*

The maximum vehicle width and height as specified in the Directive 96/53EC shall not be exceeded while the flaps are deployed. An allowance of 5 cm on each side is granted for the folded flaps fixed to a trailer or semi-trailer. The maximum added length to a vehicle by folded flaps for trailers to be transported on a railway wagon shall not exceed 0.2 m.

### *Compliance to the infrastructures and maneuverability*

The maneuverability of HCV or compliance with infrastructure leads to limitations regarding admissible maximum dimensions. Flaps longer than 0.5 m cannot be deployed in area where the maximum allowed speed is less or equal to 50 km/h (e.g. urban area), and must be folded when the vehicle is parked.

The driver is responsible of the flaps deployment and shall comply with the infrastructure clearance, with inducing any risk for the other road users.

### *Signaling and lighting*

Vehicle equipped with flaps shall comply to the UNECE regulation 48 on lighting, signaling and conspicuity of retro reflecting marks, either when flaps are deployed or folded. Flaps shall not reduce the visibility of registration plates. Flaps longer than 0.5 m shall have conspicuity marks to make visible the lower, upper and lateral limits of the deployed flaps.

### 5.3 Proposals on Front Cabin

#### *Aerodynamics*

The derogation in length will be based on demonstrable improvement in aerodynamics, assessed through the certification procedure (see section 5.4). The loading capacity shall not be increased.

#### *Maneuverability*

The maneuverability of HCV and compliance with infrastructure will lead to limitations regarding admissible maximum dimensions. In roundabouts, the maximum dimensions of the HCV are regulated by the compliance of the complete vehicle (towing a trailer or semi-trailer) with “turning radius” requirements (COM, 2012). The possible maximum extra-length for the tractor seems to be of about 1 m, taken into account other requirements e.g. regarding the front underrun protection.

#### *Safety*

The "rounded" shape resulting from the cabin length extension has the potential to improve the protection of vulnerable road users in initial (low speed) impact, and to deflect them or other (light) vehicles away from the vehicle. Manufacturers should optimize this deflection effect in their design.

The expert group recommended to include deformable structures in these rounded shapes, as well as a soft zone to reduce head impact.

A longer cab should improve the field of vision of the driver, avoiding blind spots, especially on the side of the cab, or right under the windscreen. The truck occupant protection shall also be improved.

#### *Driver comfort*

The space increase in the cab should be used to adapt the seats to the size of the driver, to allow him to get promptly into correct driving position, to include lumbar support, arm rest, to allow adjustability of the steering wheel, and to eliminate bulkheads around the seat. The additional space should also be used to allow the driver exit more easily from the cab in case of emergency.

The expert group recommends that new cab designs reduce vibrations by cab suspension in 4 points.

### 5.4. Definition of Certification Procedures for Homologation Purpose

The demonstration of aerodynamic improvement for rear devices or front cabin design, which is the condition currently considered by the authorities to grant the derogation in length, has been analyzed and will be the subject of further works. For rear devices, the demonstration is quite simple as the same tractor-trailer combination can be used (with or without the device) to assess the aerodynamic optimization by drag or fuel consumption measurements. Specific and normative methods like the *Joint TMC/SAE Fuel Consumption Test Procedure – Type II (SAE J1321)* or the *SAE Wind Tunnel Test Procedure for Trucks and Buses (SAE J1252 JUL2012)* can be used as reference.

For front cabin design, the achievement of this demonstration is much more complicate. First, a reference vehicle should be agreed to compare any new cabin design and to assess the



improvement. A common reference seems to be preferable to promote a fair competition. However, the newest tractor by each vehicle manufacturer could be the reference in order to take into consideration differences and various stages of development of each manufacturer. The assessment methods must be accurate enough to compare aerodynamic performances of different tractors equipped with different engines. Moreover, the methods must remain compatible with an early stage demonstration. To fulfill this last objective, the use of numerical simulations is considered. Nevertheless, without any existing standards or other experience of computational fluid dynamics simulation (CFD) usage for homologation purpose, the definition of this procedure will need time.

Constant speed testing (VECTO), computational fluid dynamics simulation (CFD) and wind tunnel testing are the proposed methods. For the last method, full scale and reduced scale models may be used.

## **6. Discussion and Conclusion**

The output of the studies carried out and the discussions within the experts and stakeholders group invited by the DG-MOVE are reported in this paper. The first decisions of the European Parliament and Council confirmed that the revised Directive 96/53EC will allow additional length to improve the aerodynamic behavior of HCVs, both by adding rear end add-ons as flaps, or by an additional length of the cabins to encourage a rounded front shape. This last provision would also help increasing the safety of VRUs, other road users, and the comfort of the HCV drivers.

The rear add-ons may be implemented immediately and at low cost, therefore this revision can be adopted quickly. For the front cabin shape, the industrial process and lifecycle of the tractors lead to announce the revision at least 5 years before its implementation to avoid a risk of competition disturbance between manufacturers.

At this stage, the additional lengths are not defined as prescriptive measures, but could be defined by performance criteria in a PBS approach. Test and certification procedures still need to be developed, and the main methods were already discussed: VECTO, CFD and wind tunnel tests.

A recent survey conducted in the US (TRB 2010 and 2014) showed that only 5% of the companies are currently using tractor-trailer gap devices and trailer base devices, while 4% are using trailer skirts. However, 2-7% of the companies are planning to use these devices in their operations and another 27-30% would consider using them within the next 12 months to increase their fleet fuel economy and reduce fuel costs. Most of the companies currently using drag reduction devices noted an increase in vehicle fuel economy comparable to that which was expected when the devices were purchased. Additional benefits that result from the installation of these devices are reported to be improved vehicle handling under windy conditions and a reduction in the amount of debris and water spray ejected by the vehicle.

## **7. References**

- COM (2011) 144, White Paper, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, March 28, 31 pages.

- Platform for Aerodynamic Road Transport (2011), Towards a Lower Fuel Consumption and CO2 Emissions by Means of Aerodynamic Add-ons for Trailer Rear-End.
- Kopp, S. (2012), CO2 Reduction by Truck Aerodynamics, Truck Aerodynamics; Transport & Environment.
- Seifert, A. Stalnov, O. Sperber, D. Arwatz, G. Palei, V. David, S. Dayan, I. and Fono I. (2009), Large Trucks Drag Reduction using Active Flow Control, The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains, Volume 41, Springer, Heidelberg, 115-133.
- Welfers, T. (2011), Design of a Tractor for optimized Safety and Fuel Consumption, Transport & Environment.
- COM (2013) 195, Impact Assessment, Proposal for a Directive (...) amending the Council Directive 96/53EC (...), Commission staff working document, European Commission, April 15, 72 pages.
- Patten, J, McAuliffe, B., Mayda, W. and Tanguay, B. (2012), Review of Aerodynamic Drag Reduction Devices for Heavy Trucks and Buses, Technical Report CSTT-HVC-TR-205, NRC-CNRC, May 11, 120 pages.
- COM (2012), Implementing Regulation (EC) No 661/2009 (...) with regard to type-approval requirements for masses and dimensions of motor vehicles and their trailers (...), Commission Regulation (EU) No 1230/2012, Dec. 12, 49 pages.
- Leuschen, J. and Cooper, K.R. (2006), Full-Scale Wind Tunnel Tests of Production and Prototype, Second-Generation Aerodynamic Drag-Reducing Devices for Tractor-Trailers, 06CV-222, SAE International, 2006.
- Ortega, J., Salari, K., Brown, A. and Schoon, R. (2013), Aerodynamic drag reduction of class 8 heavy vehicles: a full-scale wind tunnel study, LLNL-TR-628153.
- Fassbender, S. and Hamacher, M. (2008), Modification of a Truck Front for Improved Kinematics in Run Over Accidents, APROSYS Final Workshop.
- Loughborough University (2011), The Development of Improvements to Drivers' Direct and Indirect Vision from Vehicles – Phase 1, Phase 2.
- Patten, J., Poole, G. and Mayda, W. (2010), Trailer Boat Tail Aerodynamic and Collision Study, NRC-CSTT; CSTT-HVC-TR-169, March.
- NTC (2006), Performance Based Standards, SMART heavy vehicles, Information Guide, September, 22 pages.
- NCHRP (2010), Review of Canadian Experience with the Regulation of Large Commercial Motor Vehicles, Report 671, National Cooperative Highway Research Program, TRB
- TRB (2010), Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, Contract DTNH22-08-H-00222, The National Academies Press, 250 pages.
- TRB (2014), Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two, Final Report, Contract DTNH22-12-H-00389, The National Academies Press, 158 pages.