CONFIDENCE REPORT: TRAILER AERODYNAMIC DEVICES

ABSTRACT This report documents the confidence that North American Class 8 trucking should have in Trailer Aerodynamic Devices for improved fuel efficiency. The study team engaged with the entire industry in generating the findings that are presented here. Thanks to all of those who contributed to this important work.

Trucking Efficiency Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.

Acknowledgements:

Study Team:

Rick Mihelic, NACFE Program Manager, Mihelic Vehicle Consulting LLC

Dave Schaller, NACFE Engagement Manager

Mike Roeth, NACFE Executive Director

Study Editor:

Tessa Lee, Carbon War Room

NACFE Technical Advisory Committee:

Tim Dzojko, Air Products	Steve Duley, Schneider National
Dan Deppeler, Paper Transport	Bruce Stockton, KAG
Ezel Baltali, Ryder System Inc	Dale Spencer, UPS
Ken Marko, Frito Lay	Randy Cornell, XPO Logistics
Dan Deppeler, Paper Transport	Mike Roeth, NACFE Executive Director

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EXECUTIVE SUMMARY

TRUCKING EFFICIENCY CONFIDENCE REPORT: Trailer Aerodynamics Executive Summary

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. In 2014 diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable.

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. Unfortunately, multiple barriers have stymied industry adoption of such technologies, including a lack of data about the true performance gains these technologies offer, and a lack of confidence in the performance testing data that does publicly exist today. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, the North American Council for Freight Efficiency (NACFE) partnered with Carbon War Room (CWR) to form Trucking Efficiency. The work of Trucking Efficiency has begun by producing a series of Confidence Reports, of which this report on technologies to improve the aerodynamics of trailers is the eleventh.

The goals of this Confidence Report are: (a) to give the industry a foundational understanding of trailer aerodynamic devices, (b) to provide an unbiased review of available trailer aerodynamic technologies on the market today, and (c) to increase investment into cost-saving trailer aerodynamic technologies.

> "FLEETS HAVE MOVED FROM ASKING WHY THEY NEED AERODYNAMIC DEVICES ON THEIR TRAILERS TO DETERMINING WHEN AND HOW THEY WILL ADD THEM."
> **Mike Roeth, Operation Lead, Trucking Efficiency**

Methodology

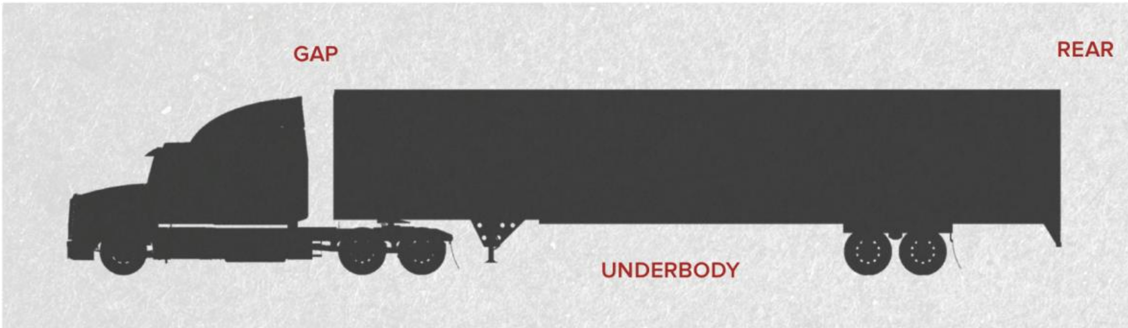
This report's conclusions were generated through desk research, conversations at a variety of trucking industry events around the country, and a series of structured interviews with fleets, truck and trailer OEMs, and many of the trailer aerodynamic manufacturers active in the North American market today.

FUEL SAVINGS AND OTHER BENEFITS OF TRAILER AERODYNAMICS

Trailer aerodynamic devices help to increase fuel efficiency by lowering air resistance so that it takes less fuel to move down the road as speed increases. The per-vehicle fuel economy benefit of trailer aerodynamic devices can be high, ranging from 1% to over 10%, depending on the devices chosen. Given these potential savings, trailer aerodynamic devices are excellent technologies for significantly increasing fuel efficiency. However, it is quite a large technology set, and they can be complicated to adopt.

Trailer aerodynamic devices can also improve stability and rollover, splash and spray, and driver fatigue.

AREAS OF OPPORTUNITY



CHALLENGES OF TRAILER AERODYNAMICS

The challenges of integrating trailer aerodynamic technologies into fleet operations include:

- Added weight
- Complicated and difficult-to-compare methods for testing device performance
- Confusion between precision and accuracy, and the difficulty of obtaining accuracy in aerodynamics testing
- Variance among aerodynamic device manufacturer information
- The need to optimize tractor/trailer ratios
- Questions of device reliability and/or durability

While the devices currently available on the market do add some weight to the vehicle, weight's impact on fuel economy is just 0.5–0.6% per 1,000 lbs. of added weight. Even the most aggressive aerodynamic fairings for trailers add less than 2,000 lbs. today, so the maximum mile-per-gallon reduction due to the weight of aerodynamic fairings would be less than 1.2%—much less so than the 9%+ mpg gain offered by advanced trailer aerodynamic systems in on-highway hauls for typical van trailers.

The main challenge preventing widespread adoption is the perceived complication of improving trailer aerodynamics. The physics involved in testing trailer aerodynamic device performance can be complex, and there are multiple ways of measuring and evaluating performance (described in the Determining Efficiency Confidence Report available at www.TruckingEfficiency.org). Additionally, fleets will see the greatest benefit from adopting multiple aerodynamic devices, but as the net benefits from the package of devices do not simply equal the sum of each individual device, it's difficult for fleets to prioritize investment decisions and feel confident in their paybacks.

TRAILER AERODYNAMIC TECHNOLOGIES

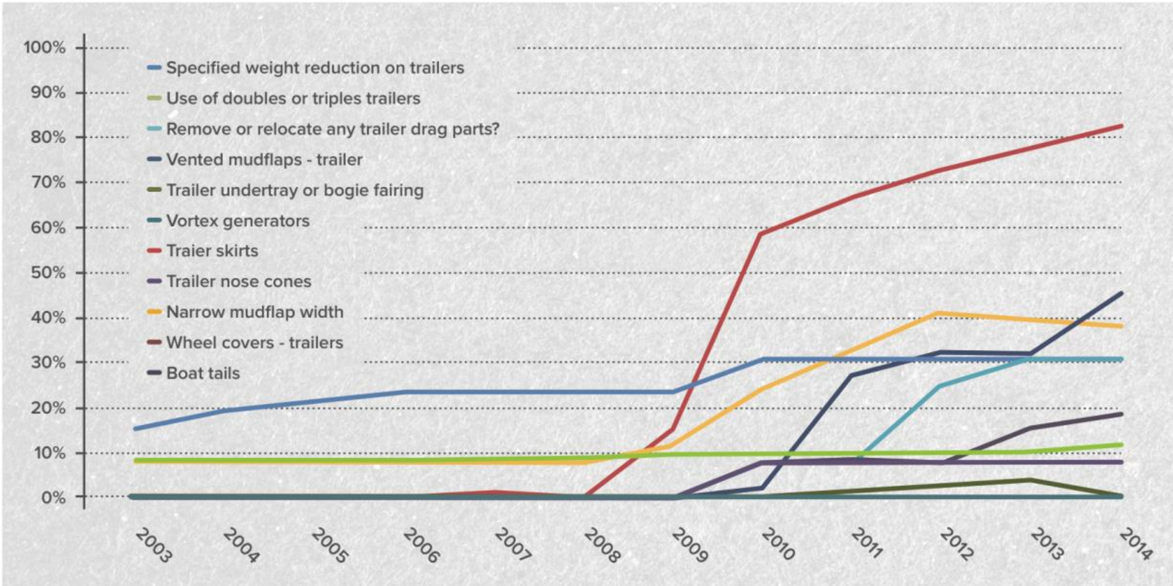
Obviously all vehicles are concerned with fuel economy and freight efficiency, but to date the focus of aerodynamic trailer technology development (and of rulemaking) has almost exclusively been on van trailers. Van trailers are the most common trailer type, travel the most miles, are "large boxes" with wheels, and are most easily adapted to aerodynamic improvement. Reducing the aerodynamic drag of a basic van trailer comes down to adding one or more devices onto three key areas of the trailer: the underbody, the rear, and the gap.

This Confidence Report details devices for improving the aerodynamics of these three key areas, as well as more novel options, such as vortex generators, wheel covers, and mud flaps.

Underbody: For the underbody, trailer skirts are the most popular devices for addressing drag. All trailer underbody skirts serve to extend the trailer side walls much closer to the ground, preventing wind from ducking in under the trailer and running into the non-aerodynamic trailer bogie. Trailer skirts offer 1% to more than 5% fuel savings versus non-skirted trailers.

Rear: Devices to mount at the rear of trailers are generally called boat tails or trailer wake devices. They modify the air flow as it leaves the trailing edge of the side and top surfaces of the trailer. The goal in all rear trailer devices is to reduce the wake field following the trailer, which can affect air some distance from the back of the trailer. Trailer tails are the most common device in use to improve aerodynamics at the rear of the vehicle, but have deploy and retract challenges.

FIGURE ES1: TECH ADOPTION - TRAILER AERODYNAMICS



Gap: Tractor-to-trailer gap management devices are relevant for a subset of the industry, in large part due to the evolution of the current aerodynamics of many tractors. Highly aerodynamic tractors have largely reduced the importance of trailer aerodynamic gap devices. However, many older tractors and daycabs, which require a higher tractor-to-trailer gap for maneuverability, would still benefit from trailer devices that address drag in the gap.

There is a clear prioritization in the industry of which areas to address with aerodynamic devices: the underbody, with nearly 30% of trailers equipped with skirts today, followed by the rear, with about 5% of trailers equipped with tail devices, followed by the gap and the other smaller novel ideas.

Overall, roughly one-quarter of all trailers on the road in the U.S. have at least one aerodynamic technology installed, and by 2015, in excess of 30% of new trailers were being equipped with trailer aerodynamic devices. Feedback from trailer and component manufacturers gives evidence of a robust market for aerodynamic technologies for both new and used trailers. In addition, the cost of trailer aerodynamic technologies—particularly side skirts—has decreased significantly in recent years, due to far more market entrants driving cost competition and much higher deployment volumes, reducing cost per unit and availability of devices directly from the trailer manufacturers.

CURRENT INDUSTRY TRENDS

Tractor and trailer aerodynamic design concepts have been around for a very long time. A series of trends over the last 20 years have moved the industry from asking, “Why should my fleet use trailer aero devices?” to “When and how will my fleet implement trailer aero devices?”

The most recent NACFE Annual-Fleet-Fuel-Study found that since 2008 or 2009, fleets began ramping up their investment into trailer aerodynamics, most notably trailer skirts, as shown in Figure ES1.

Extensive insights into fleet decision making on trailer technologies were recently assembled through a fleet survey by Ben Sharpe of ICCT and Mike Roeth of NACFE in the February 2014 ICCT/NACFE white paper *Costs and Adoption Rates of Fuel-Saving Technologies for Trailers in the North American On-Road Freight Sector.* That report provided a summary of cost and adoption rates shown in Table ES1.

While the desire to save fuel in an era of volatile and often high fuel prices does motivate the adoption of trailer aerodynamic devices by fleets, regulations also play a major role in this technology space.

TABLE ES1: SUMMARY OF INTERVIEW RESPONSES ON TRAILER TECHNOLOGY COST AND LEVEL OF ADOPTION

TECHNOLOGY	FUEL SAVINGS	COST TO END USER		TYPICAL PAYBACK TIME	ADOPTION IN NEW TRAILER SALES
		HIGH	LOW		
Side skirts - average	3%	$1,100	$700	1–2 years	40%
Side skirts - best	7%			< 1 year	
Boat tails - average	3%	$1,600	$1,000	2–3 years	3%
Boat tails - best	5%			1–2 years	
Gap reducers	1–2%	$1,000	$700	2–5 years	Minimal
Underbody devices	2–5%	$2,200	$1,500	2–5 years	3%
Low rolling resistance dual-sized tires	1–3%	Data on costs and payback time inconclusive			50%
Wide base single tires	2–4%	Data on costs and payback time inconclusive			10%
Tire pressure monitoring systems	1%	$1,000	$750	1–2 years	10%
Automatic tire inflation systems	1%	$1,000	$700	1–2 years	30%

In the last half of the 1990s, regulatory focus dramatically increased on truck engine emission standards, including the Environmental Protection Agency's (EPA) Clean Air Act emissions regulations and EPA's Phase 1 Greenhouse Gas (GHG) rules. These rules initially focused on engines and components, but evolved into vehicle-level standards. In parallel with ever-more-demanding emissions rules came federally-legislated reductions in the sulfur content of fuels, as well as the introduction of "no idle" rules in many locations. Nearly all of these requirements have resulted in increased tare weight or other changes that worsened fuel economy.

With respect to tractor aerodynamics, OEMs have continually introduced new and improved models over the last 20 years, such that the tractor side of the industry has achieved, in general, net improvements in fuel economy over that period. Yet both government and industry have recently realized that tractor efficiency improvements alone could only go so far toward saving fuel. The EPA very recently proposed requiring trailer aerodynamics as part of its Phase 2 GHG rulemaking, to come into effect in 2018. Other regulations, such as the rules enacted in 2008 by the California EPA Air Resources Board, which mandated the use of SmartWay-certified tractors and trailers in California, are likewise driving investment in trailer aerodynamics. The industry should expect the next few years to see a continuation of this regulatory trend. Improving the aerodynamic performance of trailers is an excellent option for the industry looking to meet regulations and offset other fuel economy losses.

PERSPECTIVES FOR FUTURE SYSTEMS

Trailer aerodynamic technologies and strategies are constantly and rapidly evolving. The options detailed in the report are all currently available on the market today, and most are mature with a good track record of functionality, though they may be more or less economical depending on the specifics of a fleet's operations. In the near-term, new technologies and/or regulatory changes that open the door for platooning, long combination vehicles, and longer trailers, could significantly improve aerodynamics and increase fuel economy. Other technologies that are under development but have not yet reached market-readiness include:

- Active Flow Control Systems
- On-Board Aerodynamic Sensing
- Aero Adaptive Cruise Control and Routing Systems
- Automation Systems
- Trailer Geometry Morphing
- Trailer/Tractor Ratio Reduction
- Dedicated Truck Highways and Lanes
- Hybrid Electric Vehicles
- Combining Technologies

CONCLUSIONS

This report focuses primarily on sleeper tractors pulling van trailers on-highway in North America. It describes both individual and combinations of technologies and practices available to fleets in pursuit of fuel economy improvement, operating cost reduction, and greenhouse gas emissions decrease through the use of trailer aerodynamic devices. The study team found the following conclusions with respect to fleets, truck and trailer OEMs, manufacturers, and others concerning the adoption of trailer aerodynamic devices:

- Trailer aerodynamic devices save fuel.
  - Devices have matured and will continue to improve.
    - There are unique challenges such as trailer-to-tractor ratios, a split incentive in that trailer owners do not always buy the fuel for tractors, and deployment of devices.
- Performance for each fleet is difficult to determine.

TABLE ES2: SUGGESTED ACTIONS ON TRAILER AERODYNAMICS

IF YOU ARE CURRENTLY RUNNING THIS TRAILER CONFIGURATION:	THIS MIGHT BE YOUR NEXT BEST STEP FOR BETTER TRAILER AERODYNAMICS:
Aero tractor with typical dry van trailer	Add trailer skirts
Trailer with side skirts	Add trailer rear boat tail device
Trailer with side skirts and manually deploying rear boat tail	Convert to automatically deploying trailer rear boat tail device to increase time in use
Trailer with side skirts and rear boat tail	Add trailer front nose fairing
Trailer with side skirts, rear boat tail, and nose fairing	Start investigating other minor areas such as wheel covers, license plate position, and vented mud flaps.
Day cab tractor without air fairings or cab extenders	Add trailer nose dome to the upper front portion of the trailer

“EVERY TRAILER WILL BENEFIT FROM IMPROVEMENTS IN AERODYNAMICS BUT THERE ARE NO ONE-SIZE-FITS-ALL SOLUTIONS. THIS REPORT REDUCES THE CONFUSION AND EXPLAINS THE COMBINATIONS THAT MAKE SENSE FOR FLEETS.”
Rick Mihelic, Program Manager
NACFE

RECOMMENDATIONS

The study team has the following recommendations for those engaged in adopting or providing aerodynamic devices:

- Both aerodynamic device suppliers and fleet end users need to have better communication on performance.
- Manufacturers and trailer integrators should increase development efforts to improve the total cost of ownership/payback of the devices.
- Research into advanced aerodynamic techonologies should continue.
- Organizations such as SAE, TMC, EPA, and CARB need to push for improved aerodynamic assessment and correlation to real world conditions.

Table ES2 suggests actions that should be considered by fleets to prioritize their adoption of aerodynamic devices.

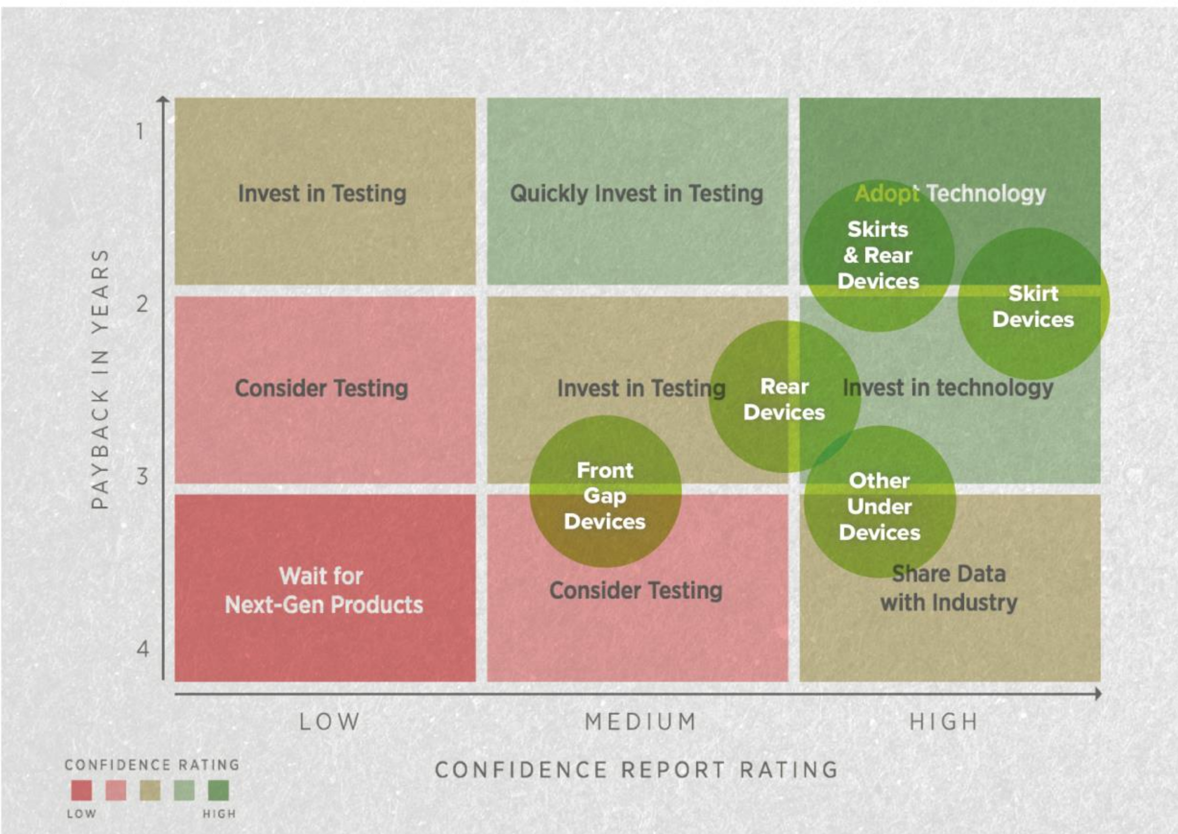
CONFIDENCE RATING

For each of the Confidence Reports completed by Trucking Efficiency, the various assessed technologies are plotted on a matrix in terms of the expected payback in years compared to the confidence that the study team has in the available data on that technology—that is, not only how quickly fleets should enjoy payback on their investment but also how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost, and moreover Trucking Efficiency has high confidence in those short payback times, usually because the technology is more mature and/or has a more substantial track record of results.

Trucking Efficiency is highly confident that all fleets should be considering the aerodynamics of their trailers and the adoption of devices that will improve those aerodynamics as a major opportunity to save fuel. The best device or package of devices to adopt will depend on a fleet's unique duty cycle. But overall, available savings are likely quite high, up to 10%, for the majority of fleets running 53' dry box trailers. Moreover, many regulations are likely to mandate the adoption of trailer aerodynamic devices in coming years, so fleets which have not even begun to consider this opportunity will be wise to do so in anticipation of mandates.

Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share your own experiences with trailer aerodynamic technologies.

FIGURE ES2: CONFIDENCE MATRIX FOR TRAILER AERODYNAMICS



TRUCKING EFFICIENCY

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement by eliminating barriers associated with information, demand, and supply.

Worldwide, heavy-duty freight trucks emit 1.6 gigatons of CO_2 emissions annually—5.5% of society's total greenhouse gas emissions—due to the trucking sector's dependence on petroleum-based fuels. With fuel prices still commanding nearly 40% of the cost of trucking, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost savings to the sector while reducing emissions. These technologies are relatively cheap to implement and widely available on the market today.

Trucking Efficiency provides detailed information on cost-effective efficiency technologies, including data from across a variety of fleets and best practices for adoption. This Confidence Report series from Trucking Efficiency aims to serve as a credible and independent source of information on fuel efficiency technologies and their applications.

In order to generate confidence on the performance claims of efficiency technologies, Trucking Efficiency, via these reports, gathers and centralizes the multitude of existing sources of data about the performance results of different technology options when employed in a variety of vehicle models and duty cycles, and makes all of that data openly accessible and more easily comparable. Furthermore, we assess the credibility of the available data, and provide an industry-standardized ranking of confidence in performance results, including ROI and efficiency gains.

www.truckingefficiency.org

Trucking Efficiency welcomes outside views and new partners in our efforts to help accelerate the uptake of profitable, emission-reducing trucking technologies.

CARBON WAR ROOM

Carbon War Room (CWR) was founded in 2009 as a global nonprofit by Sir Richard Branson and a group of likeminded entrepreneurs. It intervenes in markets to accelerate the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. CWR merged with Rocky Mountain Institute (RMI) in 2014 and now operates as an RMI business unit. The combined organization engages businesses, communities, institutions, and entrepreneurs to transform global energy use to create a clean, prosperous, and secure low-carbon future. The combined organization has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.carbonwarroom.com

NACFE

The North American Council for Freight Efficiency works to drive the development and adoption of efficiency-enhancing, environmentally-beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders, and other government and non-governmental organizations coming together to improve North American goods movement.

www.nacfe.org

Introduction

This Confidence Report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and Carbon War Room (CWR) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 70 available technologies can be found at www.truckingefficiency.org .

The fuel costs faced by the tractor-trailer industry have been extremely volatile over the past decade as shown in Figure 1. By 2015, through an unexpected combination of world political and economic forces, fuel prices actually dropped to 50% of their 2008 levels. These significant swings in fuel cost are expected to continue in the future, and make fuel costs the least predictable aspect of freight operations.

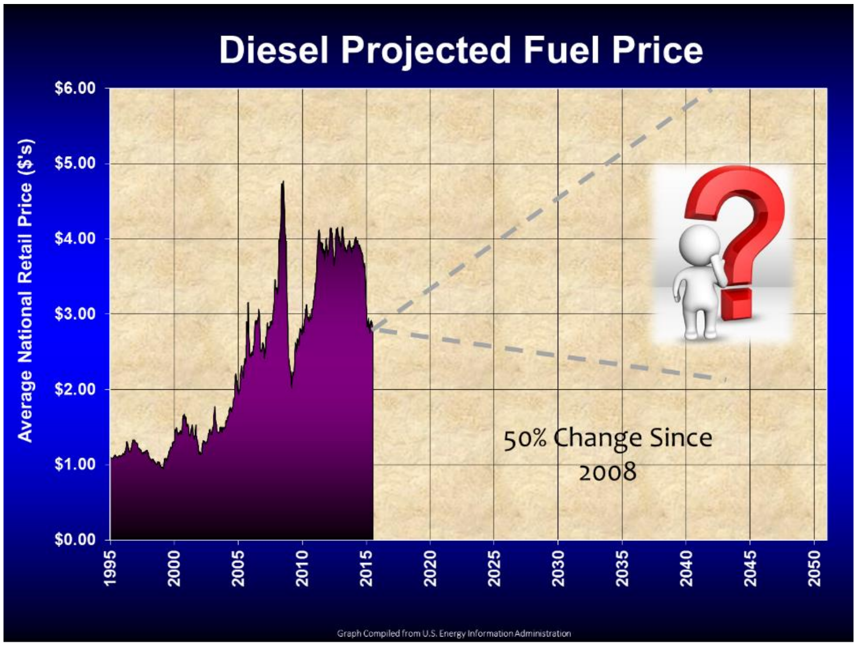


Figure 1 U.S. Diesel Fuel Prices

Truck operating costs have seen steady inflationary increases for labor, but Figure 2 shows, fuel costs in 2014 began decreasing to $0.58 per mile, on par with the costs for the driver (wages plus benefits). The 2015 data likely will show further fuel cost decreases but is expected to again rise as the oil producing countries return to more price conscious business models versus the market share capture approach seen in late 2014 and 2015.

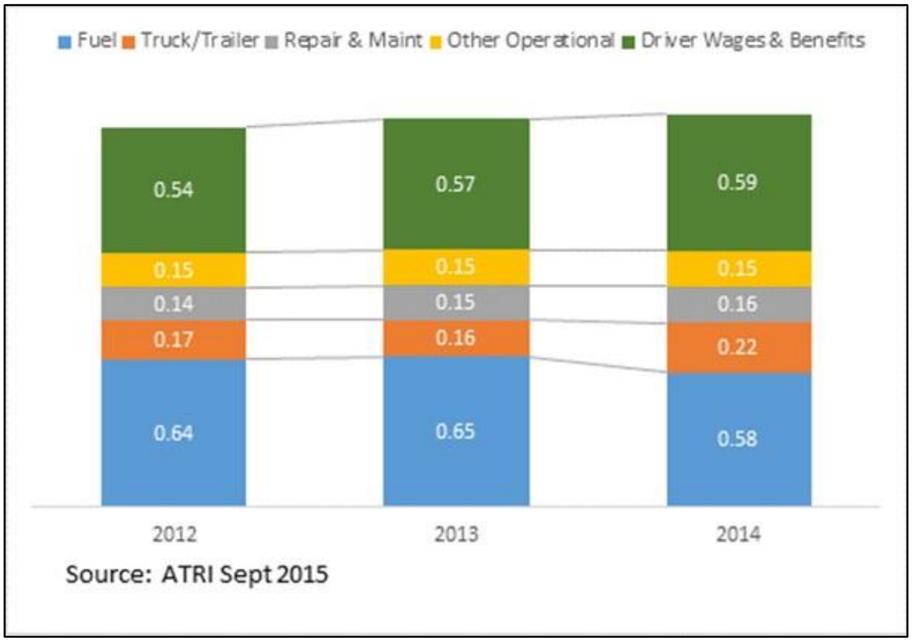


Figure 2 Trucking Operational Costs per Mile

Investment into proven technologies and practices that allow a truck or fleet to increase their fuel efficiency – meaning that they can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend.

To understand, and thereby better facilitate, the uptake of such technologies, NACFE conducts an annual review, the "Fleet Fuel Study," of the industry---wide adoption rates of nearly 70 fuel efficiency technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "the most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

Figure 3 Fleet Study Participants

The overriding take-away from the most recent Fleet Fuel Study, completed in 2015, is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting combinations of the various technologies surveyed — savings of about $9,000 per tractor per year compared to a fleet that has not invested in any efficiency technologies. It found that these fleets have fleet---wide fuel economy of just under 7.0 mpg, while the USA average, for the approximately 1.5 million tractors in over---the---road goods movement, is 5.9 mpg. This finding was drawn from research into the use of fuel efficiency products and practices by 14 of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long---haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 53,000 tractors and 160,000 trailers. The 2015 study reviewed twelve years of adoption decisions by these ten fleets, and describes their specific experience with the nearly 70 technologies. Each fleet shared the percentage of their new purchases of tractors and trailers that included any of the technologies. They also shared twelve years' worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated every year, NACFE is able to generate insights into the following aspects of the industry:

- Adoption curves for each of the technologies, indicating which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early---majority, late---majority, and even laggards, in new technology adoption.
- Comparison of technology adoption rates to overall fuel efficiency.
- Identification of three key insights: that the adoption of automated manual transmission has reached high levels, that aerodynamics are now available for natural gas tractors, and that the optimization of engine parameters is being pursued more widely as a fuel---saving strategy by large, medium, and small fleets.

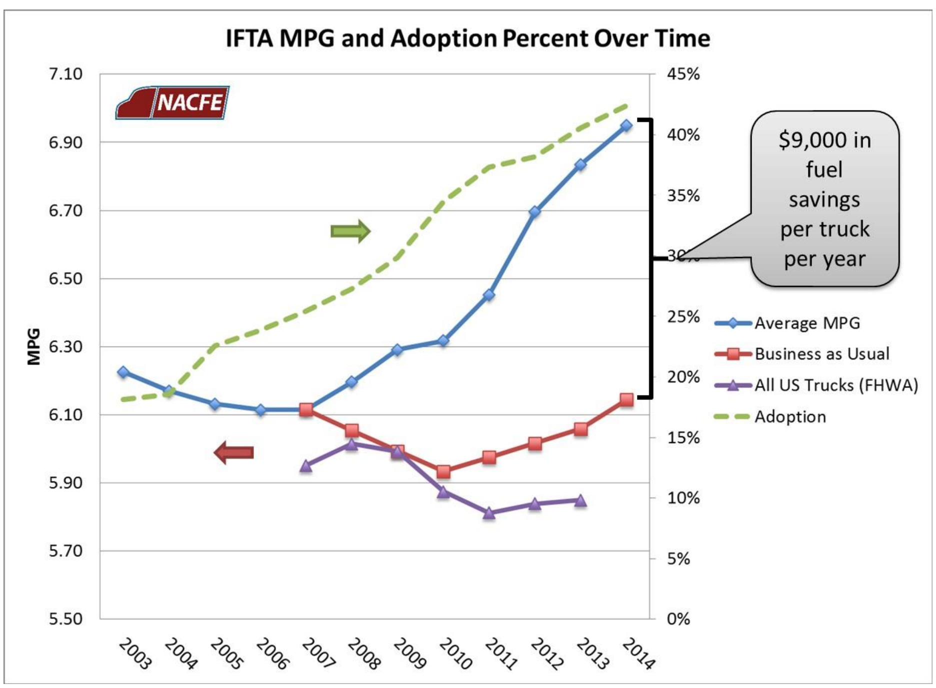


Figure 4: Fuel Savings per Truck

1.1. Trucking Efficiency's Confidence Reports

NACFE's Fleet Fuel Studies provide useful insights into adoption trends in the industry, as well as into the specific practices of different major fleets. NACFE hopes that this information could alone spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely---adopted technologies. However, in the course of conducting the studies, it became clear that some technologies are still only being adopted by the most progressive or innovative of fleets in spite of their showing strong potential for achieving cost-effective gains in fuel efficiency. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and CWR formed Trucking Efficiency and began this series of reports, called "Confidence Reports," which will take an in-depth look at those most-promising but least-adopted technologies one-by-one.

Confidence Reports provide a concise introduction to a promising category of fuel efficiency technologies, covering key details of their applications, benefits, and variables. The reports are produced via a data mining process that both combs public information and collects otherwise-private information (which is shared with Trucking Efficiency for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

Trailer Aerodynamic Device options represent one such technology set. The most recent Fleet Fuel Study found that, since 2008 or 2009, fleets began ramping up their investment into trailer aerodynamics, most notably trailer skirts. However, adoption rates, even among these efficiency-conscious fleets, are still fairly low (Figure 5).

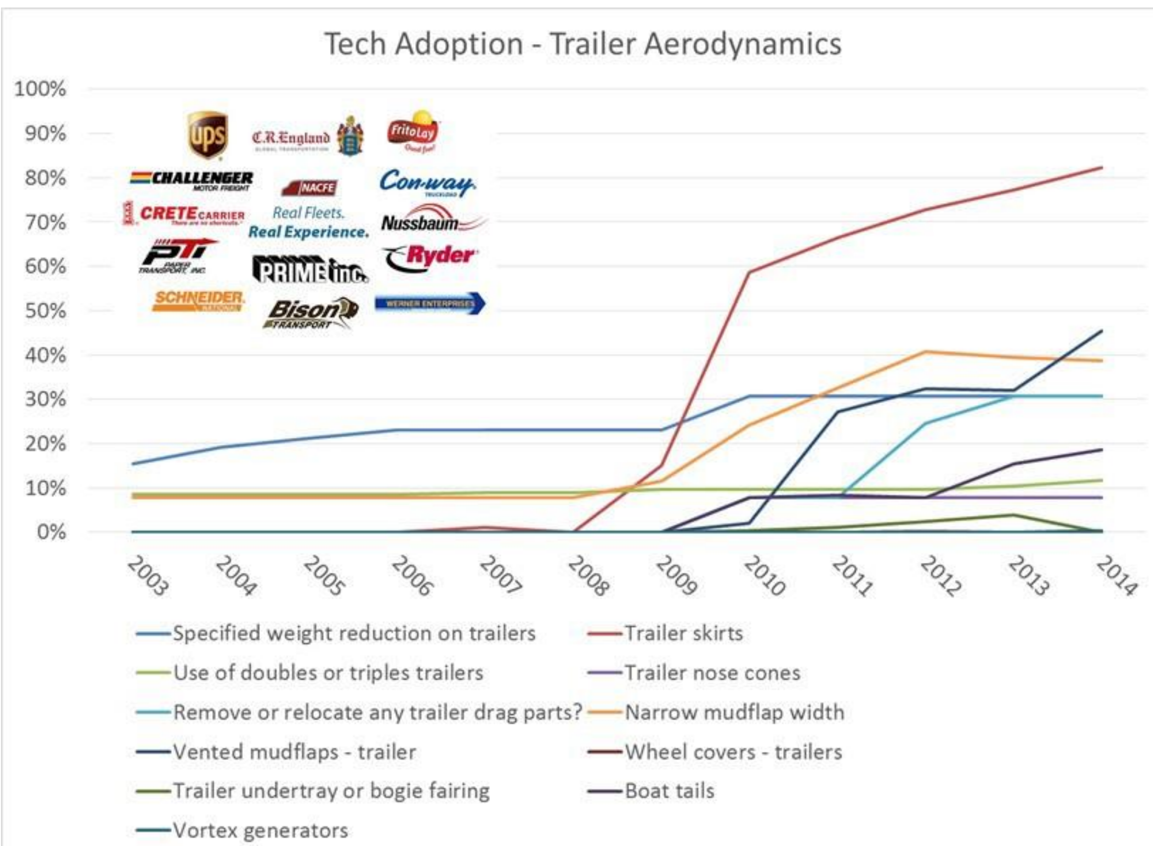


Figure 5 Trailer Technology Adoption (NACFE)

Trailer aerodynamic devices help to increase fuel efficiency, in two ways:

- They lower air resistance, so that it takes less fuel to move down the road as speed increases;
- They allow carriers to downsize other weight sensitive specifications such as fuel tank size and engine horsepower rating, thereby reducing overall vehicle weight and offsetting the added weight of the aerodynamic devices themselves;

The per-vehicle fuel economy benefit of trailer aerodynamic devices can be high, ranging from 1% to over 10%, depending on the devices chosen. While the devices currently available on the market do add some weight to the vehicle, weight's impact on fuel economy is just 0.5% - 0.6% per 1,000 pounds of weight. Even the most aggressive aerodynamic fairings for trailers adds less than 2,000 lbs. today, so the maximum mile-per-gallon reduction due to the weight of aerodynamic fairings would be less than 1.2% -- much less so than the 9%+ mpg gain offered by SmartWay Elite trailer aerodynamic systems in on-highway hauls for typical van trailers.

Given these potential savings, trailer aerodynamics is an excellent technology set for significantly increasing fuel efficiency. However, it is also quite a large technology set, and can seem like a complicated option to adopt.

The goals of this Confidence Report, therefore, are: (a) to give the industry a foundational understanding of trailer aerodynamic devices; (b) to provide an unbiased review of available trailer aerodynamic technologies on the market today; and (c) to increase investment into cost-saving trailer aerodynamic technologies.

This NACFE Trailer Aerodynamic Device Confidence Report is one in a series of NACFE focused reports on configuring vehicles and operations to improve their fuel efficiency. Visit www.truckingefficiency.org to view this and other completed reports on tire pressure systems, 6x2 axles, idle reduction, electronically controlled transmissions, electronic engine parameters, low rolling resistance tires, lightweighting, downspeeding, preventative maintenance and determining efficiency testing methods.

2. History of Trailer Aerodynamics

Tractor and trailer aerodynamic design concepts have been around for a very long time. A series of trends over the last twenty years have moved the industry from asking "why should my fleet use trailer aero devices" to "when and how will my fleet implement trailer aero devices?"

Early trailer designs in the 1930's and 1940's, as shown in Figure 6, featured rounded front ends and the U.S. patent office documents a significant number of supposed aerodynamic-performance-enhancing inventor's concepts over the subsequent decades.

Figure 6 Early Aerodynamic Trailers

For example, the 1930s and 1940s trailers had rounded front ends as seen in Figure 7. While not practical for loading and unloading pallet based freight, they do serve perhaps as inspiration for integrating aerodynamics into future trailer structures.

Figure 7 Rounded Front Trailers in '30's & 40's

But few if any of these ideas ever made it into production before the year 2000, and those that did rarely saw commercial success. One exception is the tractor roof fairing which was first developed through extensive work in 1953 by the University of Maryland with Trailmobile, and by Rudkin-Wiley in 1965-67, and which came into significant use in the 1970s as a result of reactions to the 1973 Oil Embargo. The cab roof fairing was a single add-on device with significant and obvious drag reduction benefits that could be easily visualized and easily measured in terms of reduced-fuel-costs over time. Figure 8 shows how the roof fairing aerodynamic function was easy-to-explain to fleets as improving on the trailer's basic box front shape.

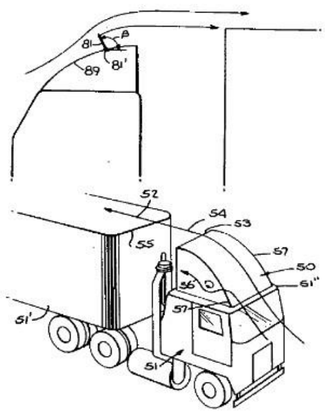


Figure 8 COE Aerodynamics Easily Visualized (TrailMobile)

Still, adoption was slow. By 1975, government estimates found that only 11% of tractors had roof fairings, and the stabilization of fuel prices meant that the market penetration for roof fairings stayed small. The 1974 enactment of the 55 mph National Maximum Speed Limit (NMSL) also limited uptake of aerodynamics, as it capped highway speeds at 55 mph. Such road speed limitations reduce the potential fuel savings offered by aerodynamic devices, as aerodynamic drag, while a factor at every speed, increasingly determined fuel burn above 50 mph. This is illustrated in a typical horsepower versus speed graph that apportions required engine power between mechanical drag (rolling friction and accessories) and aerodynamic drag. (Figure 10, as, published in 2000 in the "Technology Roadmap for the 21st Century Truck Program.")

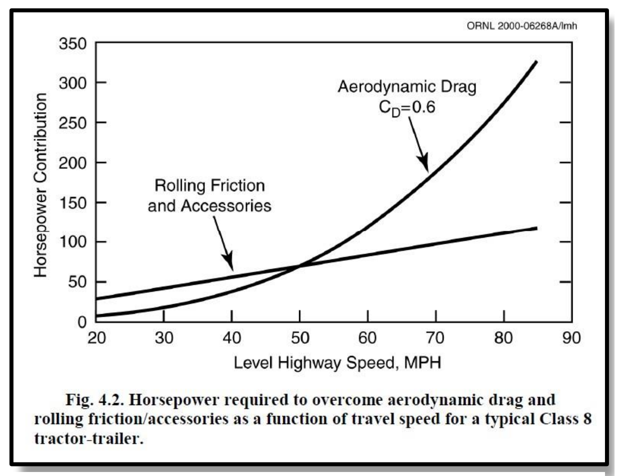


Figure 9 Horsepower Required to Overcome Opposing Forces

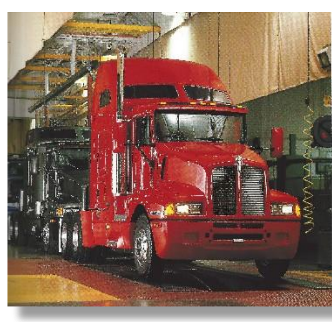


Figure 10 1985 Kenworth T600 (PACCAR)

Fleet use of aerodynamic tractors began as early as the 1980's, some say with the launch of the Kenworth T600 (Figure 10). It took the introduction of the Surface Transportation Assistance Act STAA of 1982, which opened the door for the replacement of the cab-over tractor design with the hooded conventional design, and the lengthening of van trailers to increase usage of 53 footers. The STAA act really kick-started the long evolutionary path of aerodynamic performance from cab-overs to today's very aerodynamic conventional tractors (Figure 11).

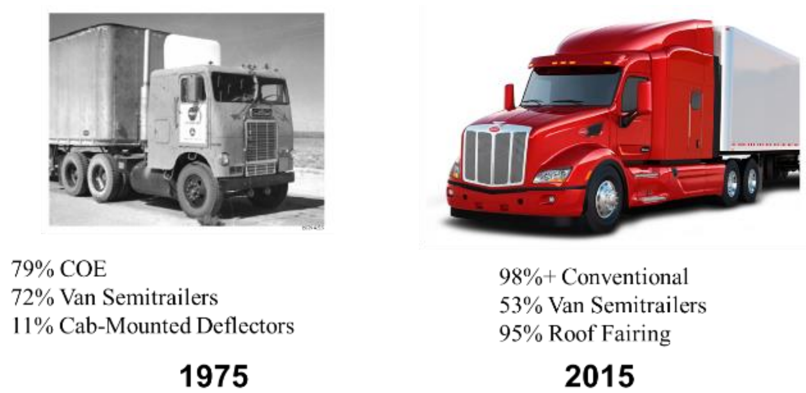


Figure 11 Significant Evolution in Tractor Shape Started by STAA Legislation

Then, in 1995, Congress repealed the National Maximum Speed Limit and returned full authority to set speed limits back to individual states. Thirty-three states quickly upped their speed limits, paving the way for market forces to demand better aerodynamic performance from tractor industry OEMs.

Moreover, this increase in speed limits coincided with the start of increasingly dynamic fluctuations in fuel prices, as shown in Figure 12.

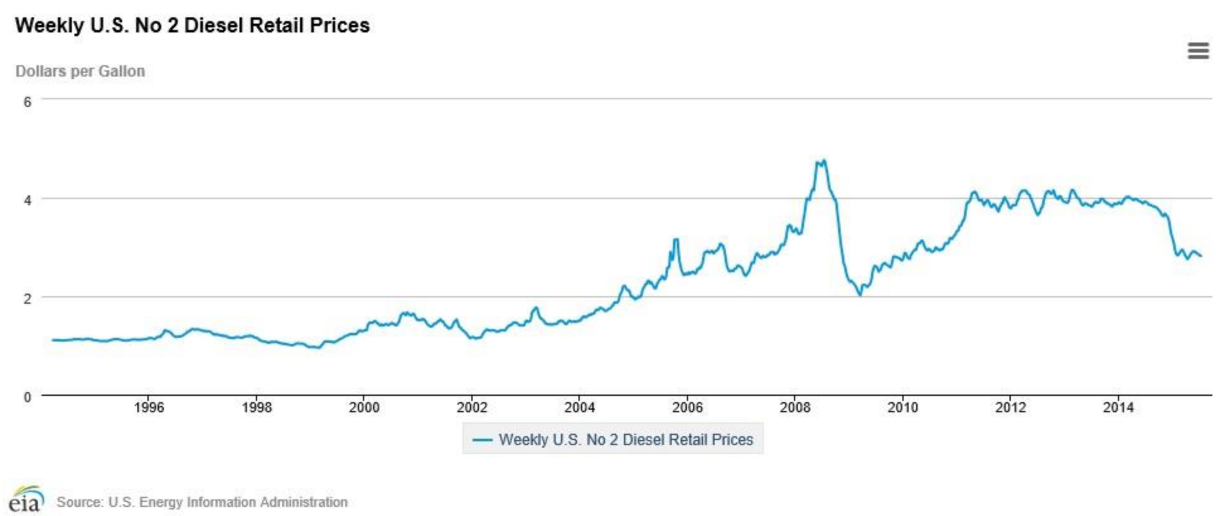


Figure 12 U.S. Diesel Fuel Price History

Higher speeds and high fuel prices combined to cause the industry to push tractor OEMs to release an unprecedented number of new, more aerodynamic models (Figure 13),including the Freightliner Century (1995), the Ford HN80 Aeromax (1996), the Kenworth T2000 (1996), the Volvo VN (1996), and Peterbilt 387 (1999). The aerodynamics of trailers, however, were left largely unchanged during this period, as both customers and OEMs focused aerodynamic improvement exclusively on tractors.

Figure 13 Late 1990's Aerodynamic Tractor Launches - (Ford HN80, Kenworth T2000, Freightliner Century, Volvo VN, Peterbilt 387)

The 1990s's saw significant changes in engine technology with the implementation of electronically controlled engines. Truck fuel economy performance became more predictable because of pre-defined software algorithms in the engine controllers. This enabled emissions regulation.

2.1. Impact of Recent Regulations

In the last half of the 1990s, regulatory focus dramatically increased on truck engine emission standards. In 1995 the Environmental Protection Agency (EPA), the California Air Resources Board (CARB), and the leading manufacturers of heavy-duty engines reached agreement on engine emissions reductions. They established a goal to have new standards that would halve NOx emissions of new trucks and buses. In parallel with this, the 21st Century Truck Partnership was initiated by the Department of Energy (DOE) as an on-going research effort to improve vehicle performance and investigate potential policy and technical improvements.

What followed were increasingly stringent EPA Clean Air Act emissions regulations beginning with the release of rules in 1997. These forced tractor and engine design changes roughly every two to four years, through 2017 when EPA's Phase I Green House Gas (GHG) rules w be fully implemented. These rules initially focused on engines and components, but evolved into vehicle-level standards. Still, trailers were excluded from these emissions management efforts through 2017. The EPA very recently proposed requiring trailer aerodynamics as part of their GHG Phase 2 rule making.

In parallel with these ever-more demanding emissions rules came federally-legislated reductions in the sulfur content of fuels, which changed in 1993 from 5,000 parts per million (ppm) sulfur to 500 ppm Low-Sulfur Diesel and then in 2006 to 15 ppm Ultra-Low-Sulfur Diesel (ULSD) with 15 ppm sulfur. These changes to fuel required additional design and performance changes to the engines and vehicles.

Finally, federal, state and regional authorities in various locations began introducing "no idle" rules over the last decade. These often require the use of automatic engine shut down devices, and promoted investment in idle-reduction technologies. (See Trucking Efficiency's Confidence Report on Idle Reduction).

Nearly all of these requirements have resulted in increased tare weight and/or devices which occupied critical space on the tractor chassis, in many cases thereby worsening fuel economy. Improving tractor/trailer aerodynamic performance

With respect to tractor aerodynamics, OEMs have continually introduced new and improved models over the last 20 years as each of these emissions mandates took effect. Introductions included the Peterbilt 386 (2005), Navistar ProStar (2006), Mack Pinnacle (2006), Kenworth T660 (2007), Freightliner Cascadia (2007), Navistar LoneStar (2009), Peterbilt 587 (2010), Kenworth T680 (2012), Peterbilt 579 (2012), Western Star 5700XE (2014), Volvo Optimized VNL (2013), Freightliner Cascadia Evolution

(2014), Kenworth T680 Advantage (2014), Navistar ProStar ES (2014) and Peterbilt 579 EPIQ (2015) as shown in Figure 14.

Figure 14 OEM Product Aerodynamic Progression - Peterbilt 386 (2005), Navistar ProStar (2006), Mack Pinnacle (2006), Kenworth T660 (2007), Freightliner Cascadia (2007), Navistar LoneStar (2009), Peterbilt 587 (2010), Kenworth T680 (2012), Peterbilt 579 (2012), Western Star 5700XE (2014), Volvo Optimized VNL (2013), Freightliner Cascadia Evolution (2014), Kenworth T680 Advantage (2014), Navistar ProStar ES (2014) and Peterbilt 579 EPIQ (2015)

In general, the tractor side of the industry has achieved net improvements in fuel economy over the last 20 years, even as regulations increased. Figure 15 maps FHWA data to show that by 2005 the tractor-only net freight efficiency improvements, taken in concert with all the other vehicle factors, was beginning to level out. Trailer aero devices had made minimal market penetration in this time period.

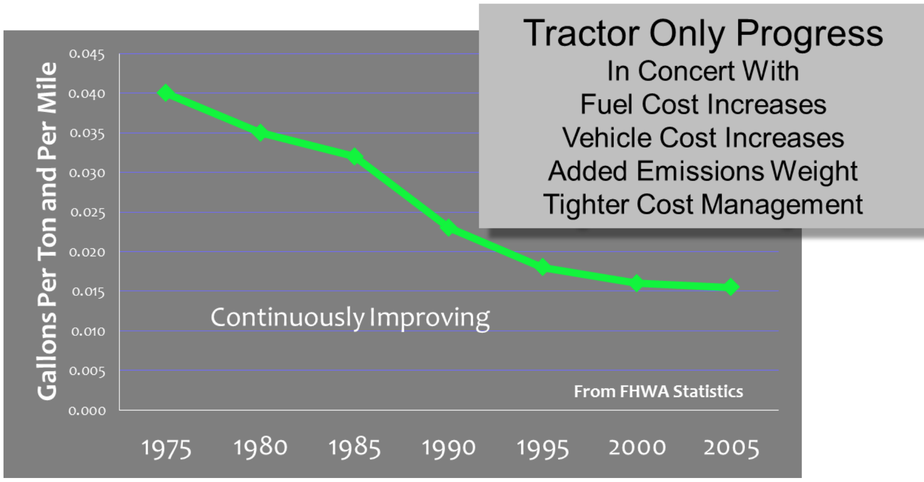


Figure 15 FHWA Freight Efficiency Improvement to 2005

Yet both government and industry realized that tractor efficiency improvements alone could only go so far toward saving fuel In 2004 the EPA introduced the SmartWay program a voluntary freight initiative with the goal of providing industry guidance on vehicle option selection with a focus on fuel economy improvement, including aerodynamic devices. SmartWay in turn deployed a Technology Verification program in 2005, which identified the key attributes of a highly fuel-efficient heavy-duty truck and included recommendations for 53 foot van trailer technologies. The EPA SmartWay's program and its thinking on trailer aerodynamics is dicussed in detail in Chapter 8 of this paper.

Though voluntary SmartWay recommendations attracted some early adopters to trailer aerodynamic devices, in 2006, trailer aerodynamic device market penetration was still nearly zero. Some fleets were experimenting with them, such as in the Great Dane/Walmart collaboration shown in Figure 16.

Figure 16 2006 Great Dane/Walmart Prototype Aero Trailer (DOE)

Significant market penetration really only began with the rules enacted in 2008 by the California EPA Air Resources Board, which mandated the use of SmartWay-certified tractors and trailers in California. The rules initially applied to new 53-foot van trailers, beginning with Model Year 2011, but phased in full compliance requirements for older trailers by 2017. Additionally, CARB pursued a mostly parallel path with the EPA on vehicle emission regulations and are lockstep now with EPA GHG Phase I rules and planning to adopt the proposed GHG Phase II rules. Similar efforts are in process in Oregon where complete fleet trailer aerodynamic compliance has been in discussion since 2009.

Overall, the recent regulatory environment at the state and national levels are tending to force technology choices regarding aerodynamic factors. Some of these rules directly apply to end users by requiring particular tractor configuration, such as the CARB and EPA rules just discussed. Other rules are being imposed on the OEM tractor manufactures, requiring them to tailor their production to favor more aerodynamic configurations, as per the EPA Phase I GHG rules and proposed Phase II GHG rules.

By 2015, in excess of 30% of new trailers were being equipped with trailer aerodynamic devices. Various state legislations and other voluntary incentive programs are likewise driving existing trailers to be retrofit with aerodynamic devices. Finally, competitive forces are driving adoption, as the benefits of investing in trailer aerodynamic technologies show up in the bottom line of company balance sheets.

In coming years, regulation is likely to continue to drive adoption of trailer aerodynamic devices. As mentioned, the EPA and NHTSA have released draft rules, commonly termed as GHG Phase II rules, which will require the use of aerodynamic devices for new van and refrigerated trailers longer than 50’ in 2021, with voluntary compliance beginning in 2018.

The proposed GHG Phase II rulemaking partitions the types of trailers into ten categories, and aerodynamic improvement requirements will apply to all but the last four, Short Box dry and refrigerated, Non Aero Box and Non-Box trailers. The draft rules additional note that “the partial-aero box trailers would have similar stringencies as their corresponding full-aero trailers in the early phase-in years, but would have separate, reduced standards as the program becomes fully implemented.”

- Long box (longer than 50 feet) dry vans
- Long box (longer than 50 feet) refrigerated vans
- Partial-aero long box dry vans
- Partial-aero long box refrigerated vans
- Partial-aero short box dry vans
- Partial-aero short box refrigerated vans
- Short box (50 feet and shorter) dry vans
- Short box (50 feet and shorter) refrigerated vans
- Non-aero box vans (all lengths of dry and refrigerated vans)
- Non-box highway (tanker, platform, container chassis, and all other types of highway trailers that are not box trailers).

Additionally, EPA & NHTSA propose to consider box trailers that have work-performing devices in two locations such that they inhibit the use of all practical aerodynamic devices to be “non-aero” box trailers that would not be expected to adopt aerodynamic technologies at any point in the program. This includes box trailers with more than three axles, since they are designed to be used in heavy-haul applications. The agencies are proposing to recognize box trailers that are restricted from using aerodynamic devices in one location on the trailer as “partial-aero” box trailers, where aerodynamic devices are not generally practical.”

3. What are Trailer Aerodynamics?

Trailer aerodynamics describes how air flows around the trailer, and provides mechanisms to quantify and then rank performance of both individual devices and combinations of devices. The physics involved in testing trailer aerodynamic device performance can be complex, and there are multiple ways of measuring and evaluating performance; these are described in the "Determining Efficiency" Confidence Report available at www.TruckingEfficiency.org. Fundamentally though, reducing the drag of a basic van trailer comes down to adding one or more devices onto three key areas of the trailer: the gap, the underbody, and the rear.

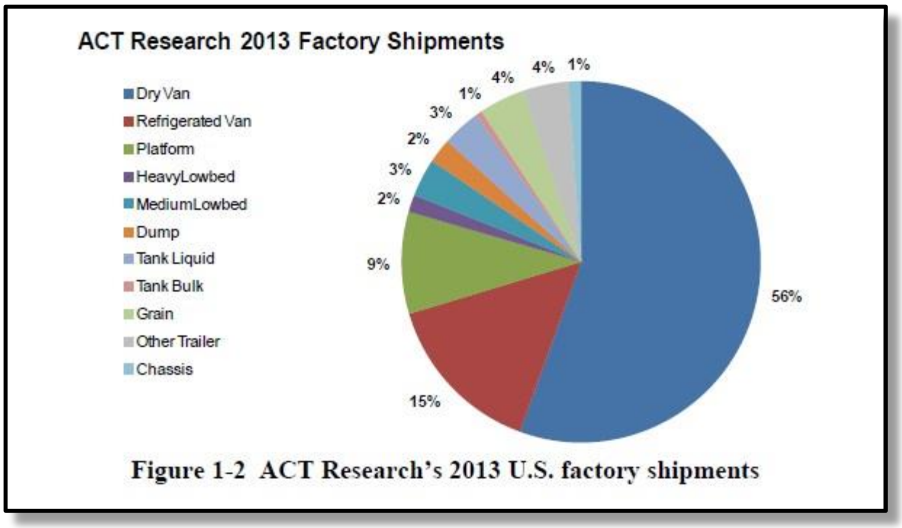


Figure 17 2013 Factory Shipments

There are a wide variety of trailer types and uses in North America. The U.S. Census Bureau had a program to track the transportation sector through the periodic Vehicle Inventory and Use Survey, or VIUS. The last report from 2003 showed trailer types and uses segmented into a wide range of configurations, as summarized in Figures 17 and 18, with the largest segment of roughly 52% described as van trailers and refrigerated van trailers. Today's segmentation is similar in complexity as shown in 2013 ACT data reported by the EPA, which found that van & refrigerated units claim a 70% share of the market.

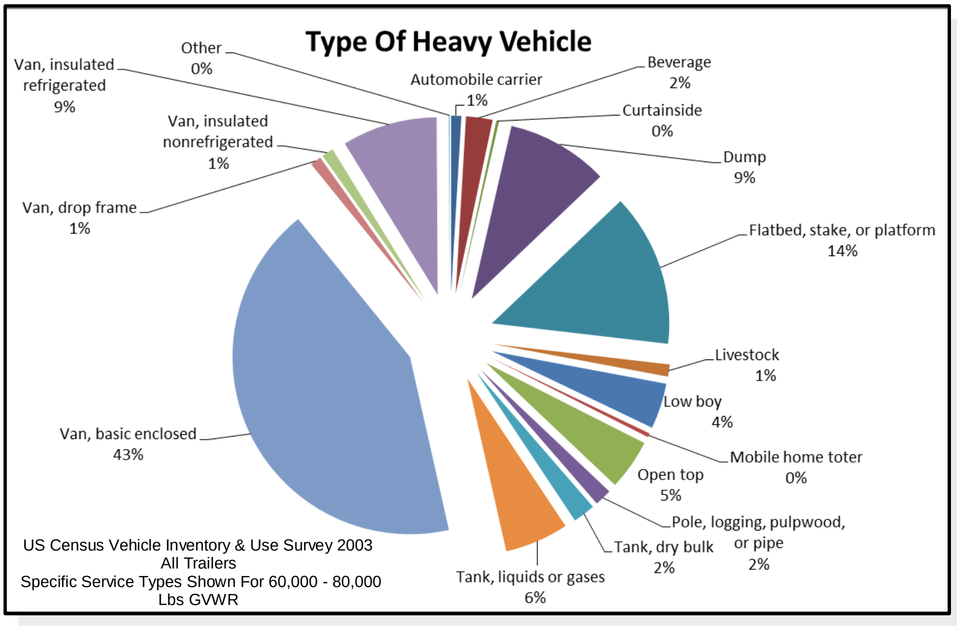


Figure 18 Trailer Type Distribution 2001

Obviously all vehicles are concerned with fuel economy and freight efficiency, but to date the focus of aerodynamic technology development (and of rule-making) has almost exclusively been on van trailers; since the van trailer is simply a large box with wheels, it lends itself most easily to aerodynamic improvement.

Figure 19 Typical 53' Van Trailer Is Box Shaped On Purpose

The reason most trailers are just boxes, rather than some more aerodynamic shape, stems from the fact that packaging is largely a rectilinear world. Products are moved in boxes and on the ubiquitous 40”x48” pallet (setting interior trailer width), which must be loaded by forklift (setting the interior trailer height) from warehouse docks (setting the trailer floor height). Meanwhile exterior width is set by the maximum permissible by highway lanes, and exterior height is set by highway underpasses and bridges. Length is managed by various rules and regulations for safe roads.

The lane width and bridge heights are effectively “go/no go” gauges, and trailer exteriors are pushed out to these maximums to provide the maximum rectangular floor space for pallet loads. The overall length of the trailer is the only variable that has potential for increasing freight space, but it is constrained by a myriad of state and federal highway rules tied to pavement life, bridge loading design and traffic safety, such that the two axle 53’ van trailer dominates trucking today in the United States. It is important to note that longer units and combination trailers are safely operated in various states and Canada under permits, and that there is a growing industry effort to reevaluate size and weight restrictions that may change the status of 53’ van trailers, which themselves evolved from 28’, 40’ and 48’s units in the past.

The basic box shape of the trailer shown in Figure 19 is thus fairly well-constrained at present to be what it is, a 53-foot-long, approximately 102-inch-wide, 13.5-foot-tall unit with floor/dock height between 46 and 52 inches. It is estimated that there are 8 million such van trailers in service today. EPA testing shows that “there is very little difference in performance between trailer manufacturers for their basic trailer models.” That said, there are trailer features that reflect better attention to aerodynamics. Most trailers do have some integrated aerodynamic structural treatments, like rounding the front vertical corner posts. Other options include:

1. Radiused front side and top edges, as increasing the size of the radius reduces drag.
2. Smooth sides and top surfaces, as structural seams and stiffeners can present gaps or steps to the air flow.
3. Flush rivets.
4. Hinges at the rear doors that are recessed or present minimal protrusions off the side surface.
5. Recessed structures found on roll-up doors, as these are more aerodynamic than flush base doors.
6. Eliminated or minimized rain gutters.
7. Rear edges that are chamfered inward.
8. Roofs that are level or that slope down toward the rear.
9. Sides that are parallel to the direction of travel.
10. Minimized tractor/trailer gaps.

The basic box shape also lends itself easily to adding on aerodynamic devices. The length itself is a key factor for better aerodynamics. Longer trailers tend to make more uniform flow along the sides and roof, although for non-skirted trailers the extra length can allow more air to hit the trailer bogie than on shorter ones or straight trucks.

On the other hand, other optional trailer devices can significantly worsen aerodynamics, or otherwise complicate the installation of aerodynamic technologies. Figure 20 highlights key examples of this potential complication.

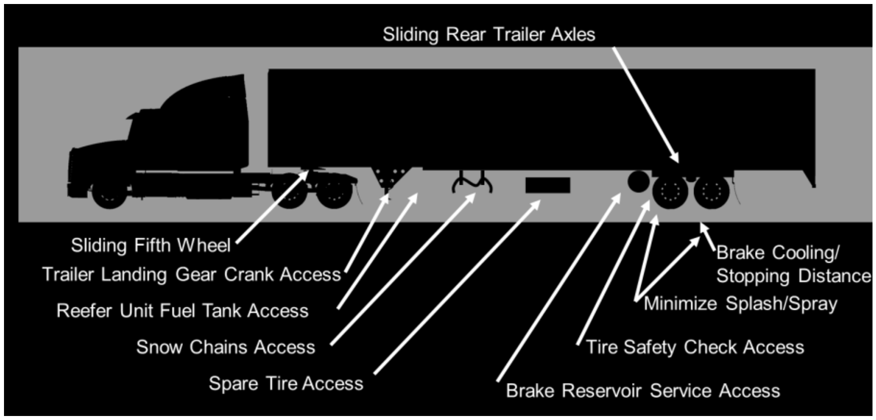


Figure 20 Optional Equipment Complicates Aero Configuration

Finally, note that a key aerodynamic element of the trailer is actually the tractor. The shape of the tractor, as illustrated in Figure 21, manages how the air is delivered to the trailer. In general, modern tractors are quite aerodynamic, as they have been extensively refined to provide smooth air flow around the trailer, dividing it into air over the roof, the sides, and the underbody. Much of the improvements in modern tractor aerodynamics have been to reduce air flow under the vehicle through the use of bumper air dams, tractor side skirts that extend nearly to the ground, and more recently, work on tractor bogie fairings. A complete review of tractor aerodynamic devices can be found in Trucking Efficiency's Confidence Report on Tractor Aerodynamic Devices.

Figure 21 Aerodynamics of the Cab Affect the Trailer (Exa/Peterbilt)

4. Benefits of Trailer Aerodynamic Technology Adoption

4.1. Saves Fuel

Improving fuel economy is the primary motivation for using aerodynamic devices. The National Research Center of Canada estimated fuel economy savings for representative trailer devices in their 2015 study, Improving the Aerodynamic Efficiency of Heavy Duty Vehicles: Wind Tunnel Test Results of Trailer-Based Drag-Reduction Technologies. They based the estimate on an 80% at highway speed duty cycle and typical Canadian average miles per year and operational factors. Their estimates were that fuel savings for adding various trailer skirts should range between 766 gallons to 870 gallons per year. At $2.50 per gallon, that translates approximately to $1900 to $2200 in annual savings. Fleets are investing in these devices because they have adequate ROI's and payback periods.

4.2. Stability & Rollover

Trailer aerodynamic devices add surface area to the trailers and modify the trailer air flows. These can both slightly improve and slightly worsen rollover physics in severe cross wind conditions. Skirts which are mounted below the center of gravity of the trailers can partially counter rollover forces in severe cross winds. On the other hand, the skirts may also route additional airflow over the top of the trailer creating slight lift forces as the roof edge can act a bit like an airplane's wing. The net result are likely offsetting. Boattails add surface area at the rear of the trailers, and in severe crosswinds this may slightly increase side forces resulting in an additional tendency for trailer off-tracking. In headwinds or tailwinds, the underbody and rear devices may help the tractor/trailer maintain its lane better than a non-aero equipped trailer. Conversely, in severe crosswinds, the trailer aerodynamic devices may make the vehicle more sensitive to gusts. Anectodal driver feedback is that aerodynamically equipped trailers are generally more stable requiring less lane correcting.

4.3. Splash & Spray Reduction

Aerodynamic device equipped trailers reduce drag by improving airflow around the vehicle, which also helps to reduce splash and spray. Passenger vehicles passing trailers in rain have perhaps the best first-hand perspective on whether trailer aero devices reduce splash and spray, but there are no clear measurement systems. A 1994 SAE J2245 Recommended Practice for Splash and Spray Evaluation. In 2011, SAE "stabilized" this document stating that SAE "will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements." Quantitative evaluations are challenging and SAE states "newer technology may exist." A peer reviewed 2003 study prepared for the AAA Foundation for Traffic Safety concluded: "an improvement in the aerodynamics of a tractor-trailer configuration can significantly reduce the amount of spray generated by large trucks in wet weather." A September 2015 article in Heavy Duty Trucking discusses that likewise TMC's Recommended Practice (RP) 759, Splash and Spray Suppression Guidelines, stated that: "for regular box vans and refrigerated trailers, the main generators of spray are the landing gear, rear axle, suspension, tires and mudflaps, the RP notes." All of these are areas of high aerodynamic drag, so both drag and spray will be mitigated by adding aerodynamic devices. The RP concluded that: "taking steps to improve the aerodynamics of any trailer can significantly cut the volume of road spray generated by a Class 8 tractor-trailer."

4.4. Driver Fatigue Reduction

Anecdotal feedback from drivers suggests that aerodynamic-equipped trailers are generally less taxing, and maintain their lane with less frequent steering correction by the driver. Several drivers contacted by NACFE confirmed that aerodynamic-equipped trailers were more stable in most situations, and one fleet volunteered "some of their drivers prefer the stability of the trailers with aero devices."

Another contributor to driver fatigue is ambient noise level; anecdotal feedback is that the more aerodynamic tractors tend to have lower interior noise levels. Driver fatigue with respect to aerodynamics is a future opportunity for more definitive study by TMC, SAE and other industry affiliated research groups.

5. Challenges of Trailer Aerodynamic Technology Adoption

The challenges of integrating trailer aerodynamic technologies into a fleets operations include:

- Added weight
- Complicated methods for testing device performance and difficulty in comparing between them
- Confusion between precision and accuracy, and the impossibility of obtaining accuracy in aerodynamics testing
- Variance among aerodynamic device manufacturer information
- The need to optimize tractor/trailer ratios
- Questions of device reliability and/or durability
- Other minor concerns

5.1. Added Weight

Aerodynamic improvement for today's dry van and refrigerated trailers involves adding on fairings, which means adding tare weight.

In a recent Confidence Report on lightweight technologies, Trucking Efficiency found that over the next 5–10 years, denser freight will be requested by shippers in each load (Figure 22), and the all segments of the industry should expect to gross out (reach their max weight) more frequently.

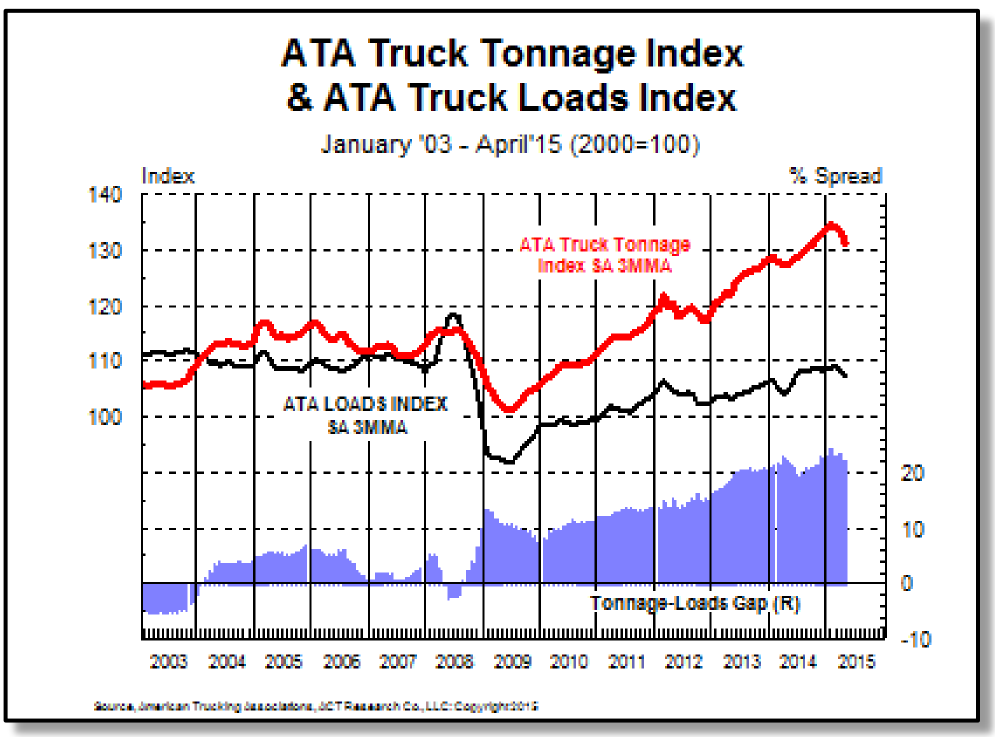


Figure 22 Tonnage per Load (ATA and ACT Research)

As trailer aerodynamic devices also add weight the critical trade-off between aerodynamic performance improvement and increasing tare weight will depend on the weight-sensitivity of the fleet in question.

It is important to keep in mind that weight's impact on fuel economy is just 0.5% - 0.6% per 1,000 pounds of weight, and even the most aggressive/comprehensive suite of aerodynamic fairings for trailers today adds less than 2,000 lbs while offering up to 9% fuel savings (but only sacrifice about 1% from the added weight). Even fleets that are highly weight sensitive may see overall fuel savings from a combination of trailer aerodynamic and lightweight technologies.

Another reason for this is that aerodynamic improvement devices can result in performance gains that allow for downsizing other systems on the vehicle. The Peterbilt/Cummins SuperTruck, for example, was able to "right-size" its tractor fuel tanks due to the improvements from aerodynamics, allowing a reduction in on-board fuel weight and tank size to cover the same distances and freight loads. That program also showed that switching to a higher aluminum content production trailer, and switching to aluminum singles from steel duals, could provide weight reductions to offset the addition of the aerodynamic devices. While there are generally additional costs associated with these options, and payback may vary with fuel costs, this goes to show that it would be a mistake to assume that aerodynamics will necessarily result in tare weight increases.

Additionally, aerodynamic improvement in some areas of a tractor/trailer can be accomplished by combining the aerodynamic functions with other functions, reducing the weight impact of the aerodynamics alone. An example is the integral sleeper roof which effectively replaced the separate add-on aerodynamic roof fairing as illustrated in Figure 23. This combined the benefits of greater head room in the sleeper with better aerodynamics. Similar integrations have occurred with the shaping of hoods, bumpers and mirrors so that secondary add-ons, and the weight they entail, are no longer required. Integration of aerodynamic functions with other functions on trailers is a future trailer design

Figure 23Aero Design Integration from Discrete Fairing and Sleeper to Integral Aero Sleeper

opportunity area as aerodynamic devices become standard.

The follow two case studies help to put the potential trade-offs between aerodynamics and weight in perspective.

5.1.1. Hypothetical Case Study: Beverage Hauler

The hypothetical example illustrated in Figure 24 is of a beverage hauler operating at the maximum 80,000 GVWR, who therefore would need to reduce their load of beverages to add 500 pounds of trailer skirt fairings. This case assumes the fleet's average fuel economy (before adding skirts) is 7 mpg, and average fuel price is $2.50/gallon. Those trailer skirt fairings are estimated to save 6% on fuel economy when driving at highway speeds the whole route. If the fleet travels as route from Denver to Dallas, approximately 800 miles, and assuming it can stay at highway speeds the entire route, then the new trailer skirts would save $16.17 in fuel on one run. However, the paying freight load was reduced by 500 lbs., say, from 45,000 lbs. to 44,500 lbs. At a freight rate of $1.75/mi the fleet would lose $15.73 in paid freight per run.

Figure 24 Beverage Hauler Aero vs. Weight Evaluation

Extrapolated over a year of operations, averaging 130,000 miles travelled, 162 trips between Denver and Dallas, ignoring dead heading and assuming this was a typical run, this translates to the trailer skirts saving $2,620 in fuel costs, but the reduction in paid freight income equally $2556, for a net annual savings of just $64 (and industry-wide, a likely increase in fuel use, as those beverages would still need to be hauled on a truck somehow).

This shows that this beverage hauler would need to find other tare weight reductions to offset the weight of the trailer skirts, perhaps by choosing a lighter-weight aluminum trailer, and/or moving to wide base tires with aluminum wheels. Investing in such a suite of fuel efficient technologies on the trailer could net this hypothetical beverage hauler cost-effective fuel economy increases without sacrificing paid freight capacity.

5.1.2. Hypothetical Case Study: Furniture Hauler

The hypothetical example illustrated in Figure 24 is of a furniture hauler operating at 65,000 GVWR, who cubes out before they gross out given the size of their load. In this case, the addition of the aerodynamic skirts does not alter the amount of paid freight carried, it only adds net weight to the vehicle. Taking the same route hauling the 800 miles from Denver to Dallas, the operator's typical fuel economy is instead 7.7 mpg (increased 0.07 mpg because of the 14,000 lb lighter freight load of 31,000 lbs.) With the 500 lbs of trailer skirts, total GVWR goes to 65,500 lbs. This added weight reduces fuel economy by 0.25%, but the new trailer skirts improve it by 6%, giving a net fuel economy improvement of 5.75%, and a net improvement in fuel cost of $15.38 per trip.

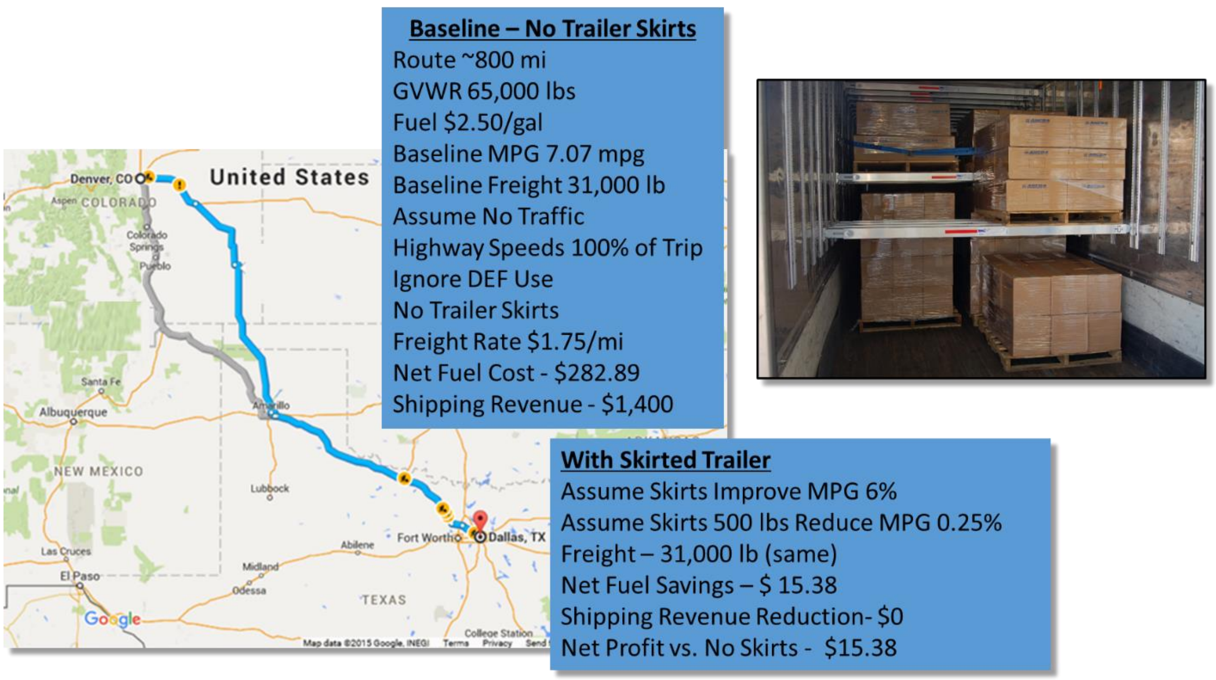


Figure 25 Furniture Hauler Aero vs. Weight Evaluation

Expanding this to a year's operation of 130,000 miles broken into 162 trips, again with the same qualifiers of no dead heading and assuming all trips are the same, the furniture hauler's net annual savings would be $2,492.

In sum, adding trailer skirts saved the beverage hauler just $64 in fuel costs for the year, compared to the $2,492 saved by the furniture hauler. This illustrates how weight and aerodynamics are inseparable when making decisions on how to configure trailers. A weight-conscious fleet will need to find additional significant weight savings in the trailer body to rationalize also adding the trailer skirts. But less weight-sensitive fleets, like the case of the furniture hauler, can realize substantial paybacks with an aerodynamic device like trailer skirts from day one.

5.2. Aerodynamic Technology Test & Analysis Methods

There are many published methods and references for testing or analyzing aerodynamics technology for tractor/trailer configurations. The fact that there is such multitude of testing methods, each with unique contexts and applications, makes comparing between them on paper challenging and confusing, and extrapolating their findings to the real world even more so. Fleets need to feel confident in how a technology will perform in their operations, in order to be assured that they will enjoy a payback that covers the cost of adopting new technologies. But, especially for aerodynamic technologies, given the hundreds of interrelated factors which will determine their ultimate performance, it can be hard to know which test data is most relevant to a fleet, and how closely test findings will match real world performance.

The NACFE Determining Efficiency Confidence Report, available at www.truckingefficiency.org , discusses these methods in detail. The report identifies key factors to consider in reviewing test information, comparing results between methods and in expanding those results to real world experience.

Each of the methods for estimating aerodynamic drag can and typically do produce different results for a vehicle as illustrated in Figure 26 from the 2013 SAE COMVEC Plenary presentation on Heavy Duty Tractor/Trailer Aerodynamic Testing Technology. Each method will have its own precision value with respect to the specific test procedure. The relevance of that specific test procedure with respect to estimating the specific real world operational values may not be known.

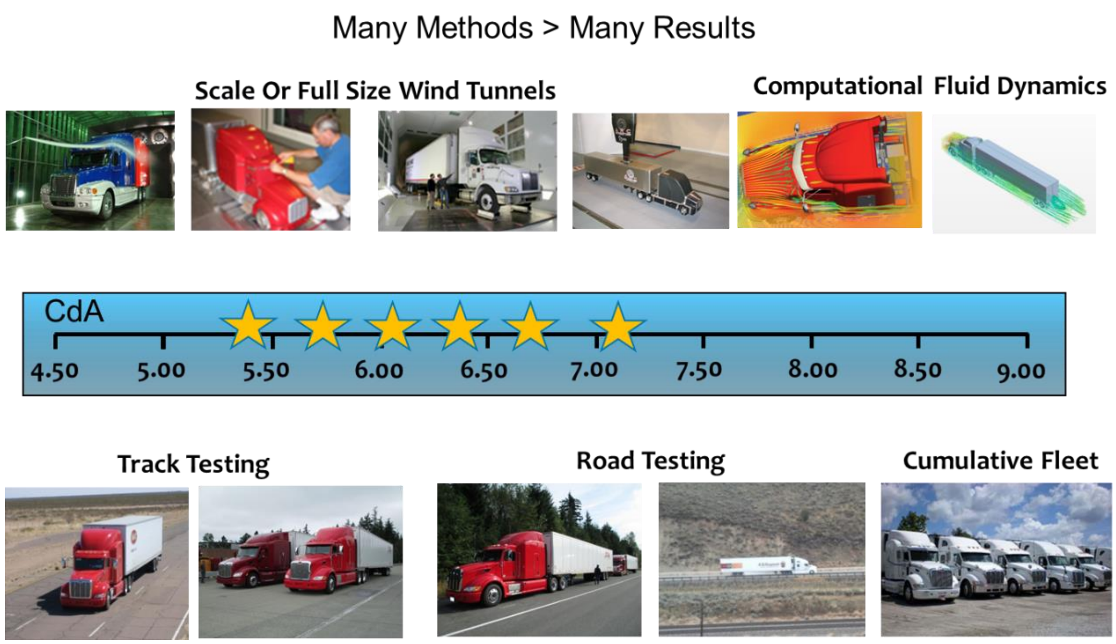


Figure 26 Aerodynamic Evaluation Has Many Different Methods Producing Different Results

The EPA documented one example of this in the Regulatory Impact Analysis for the Phase I Green House Gas Rules. They attempted to pick a particular tractor/trailer configuration and evaluate it using coastdown testing, various scale models in wind tunnels (including a full scale one), and with different Computational Fluid Dynamics analyses. One of the immediate challenges is that each of these approaches is actually measuring different metrics in different ways. So while they are attempting to arrive at the same value, they are not measuring the same thing. But all the methods can arrive at an estimate of CdA for what was evaluated. EPA published this comparison of results shown in Figure 27.

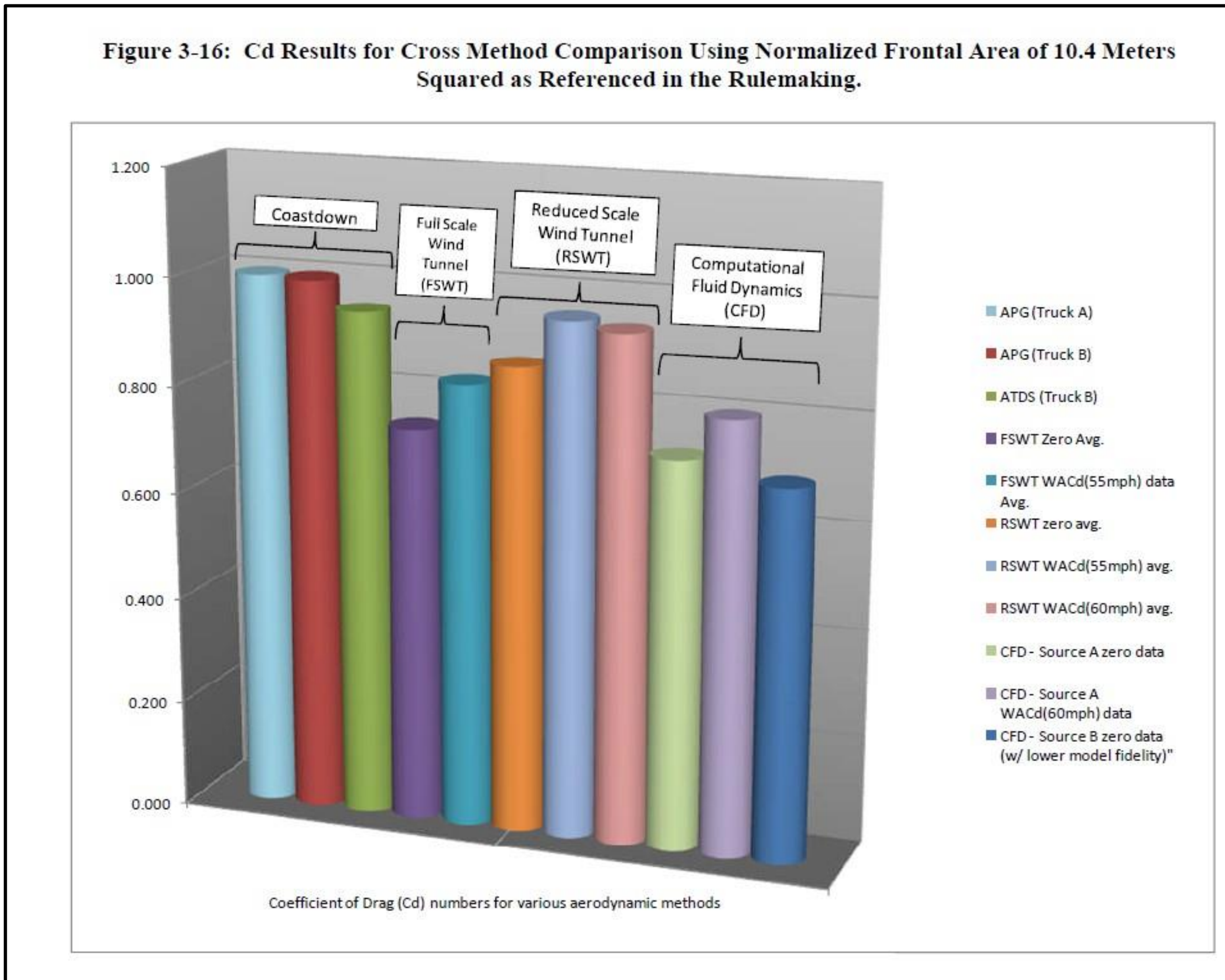


Figure 27 EPA Aero Evaluation Comparisons from GHG Phase I RIA

Each test method was done with an appropriate level of integrity and attention to detail, and for each method, some level of precision was obtained. This highlights that each method used correctly can and will provide different results for what is considered the same vehicle.

As tools, all these methods have their usefulness and some are more appropriate at different times in a development of tractor/trailer configuration. Their utility is really in making comparisons such as "is this new design better than that old design?" These are termed A-to-B comparisons.

What fleets considering trailer aerodynamics need to know is that every test and analysis methodology is some abstraction of the real world, because modeling and controlling the real world is very difficult. Each method has some degree of simplifying assumptions or artificially controlled environment built into it, so that results can be repeatability obtained (i.e. "precise"). For example, wind tunnels eliminate natural and unpredictable cross wind conditions by testing inside of a controlled space. In other testing methods systems, the actual measured data is not aero drag force, but rather fuel consumption weight or volume, or road load based on vehicle deceleration rate data, and from these data points the aero drag force is estimated by being "backed into" from what is left over when all the other factors are estimated.

For reference, a short list of some of the more relevant aerodynamic testing methods is provided here. Note that each of these methods can spawn various permutations, as end users often must make simplifying assumptions or other engineering judgement calls on test configurations or environmental constraints to obtain adequate statistical precision.

- SAE J1321 Fuel Consumption Test Procedure Type II
- SAE J1526 Fuel Consumption In-Service Test Procedure Type III
- SAE J2971 Aerodynamic Device and Concept Terminology
- SAE J2978 Road Load Measurement Using Coastdown
- SAE J2966 Guidelines for Aero Assessment Using CFD
- SAE J1252 Wind Tunnel Test Procedure for Trucks & Buses
- SAE J3015 Reynolds Number Simulation Guidelines and Methods
- SAE J1264 Fuel Consumption Test Procedure Type I
- SAE Jxxxx Constant Speed Test Procedure for Trucks & Buses
- SAE J1263 Road Load Measurement Using Coastdown
- SAE J2263 Road Load Measurement Using Anemometry and Coastdown
- EPA Phase II Road Load Measurement Using Constant Speed Torque
- EPA Phase II Coastdown Test procedure
- EPA Phase II CFD Analysis methodology
- EPA Phase II Wind Tunnel Test Methodology
- TMC RP1102A Type II Fuel Consumption
- TMC RP1109B Type IV Fuel Consumption
- TMC RP 1103A In-Service Fuel Consumption Type III Test Procedure
- TMC RP1106A Evaluating Diesel Fuel Additives for Commercial Vehicles
- TMC RP1111B Relationships Truck Components & Fuel Economy
- TMC RP1118 Fuel Savings Calculator for Aerodynamic Devices
- TMC RP1114 Driver Effects on Fuel Economy
- TMC RP1115 Guidelines for Qualifying Products Claiming a Fuel Economy Benefit
- EPA/NHTSA 40 CFR§1037.521 GHG Phase I Revised Coastdown
- EPA/NHTSA 40 CFR§1037.521 GHG Phase I CFD
- EPA/NHTSA 40 CFR§1037.521 GHG Phase I Wind Tunnel
- CARB Wind Tunnel Test Procedure
- Others

Additionally, qualitative assessment methods exist, such as high-level fleet operations reporting of fleet or individual fuel economy (miles driven vs. fuel gallons purchased), or the dashboard feedback on fuel economy gauges, or engine data downloads.

5.3. Precision vs Accuracy

A fundamental point of confusion in interpreting the testing data of efficiency technologies (and in industry publications generally), is that the terms "accuracy" and "precision" are often used interchangeably with respect to reported results, when in fact these are two quite different metrics.

Precision is the ability to repeat a test or analysis and get the same result; it is a measure of the statistical spread of repeated results from the same exact test or analysis, and is typically represented as a bell curve, as shown in Figure 28. Fleets place a value on the precision of performance results, and should use the uncertainty values given to compare the results of multiple different tests. For example, if Test 1 has a value of "0.5 ± 0.15," and Test 2 has a value of "0.75 ± 0.15," the precision difference between these values would be 0.25 ± 0.30.

Meanwhile accuracy, also called "bias," refers to how closely a test value matches the "true" real world value. So, for example, since the real world value of the aerodynamic drag factors of a truck is unknown, the "accuracy" of any testing method is likewise unknown. Since the absolute value of the aerodynamic drag coefficient of a vehicle is not known, any evaluation methods, even those that have received extensive scrutiny and improvement over the last decade, will necessarily be an estimate with respect to the real world. Measuring the specific aerodynamic drag of a tractor/trailer has required significant controls, assumptions and simplifications, and often the measurement systems themselves introduce further variations in results. Figure 28 shows accuracy (bias) as the difference between the test result and the true reference value.

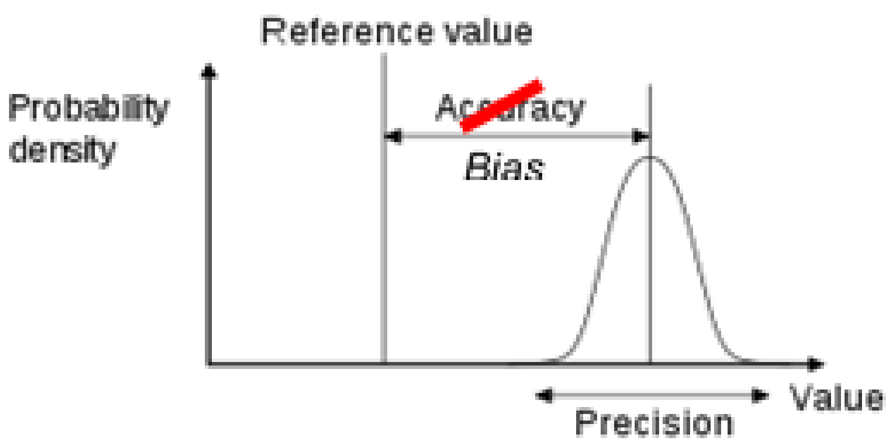


Figure 28 Precision vs. Accuracy

Why is accuracy often so difficult to measure? That is, why is the real world reference value so often unknown? Because all measurement systems require a standard reference system, but there is no standard reference vehicle for aerodynamics or other efficiency technologies. An easy corollary from everyday experience is color - all of the sample swatches in Figure 29 are clearly different colors, yet could be described as "green," even, for some color blind people, the one on the right which most would describe as brown or yellow.

Figure 29 Different examples of Green

To add accuracy to any measurements of color, a method that describes color based on the wavelength of the light is used (Figure 30). In this system of reference values, each of the "green" swatches shown would have a specific and accurate wavelength that could be used to refer to it.

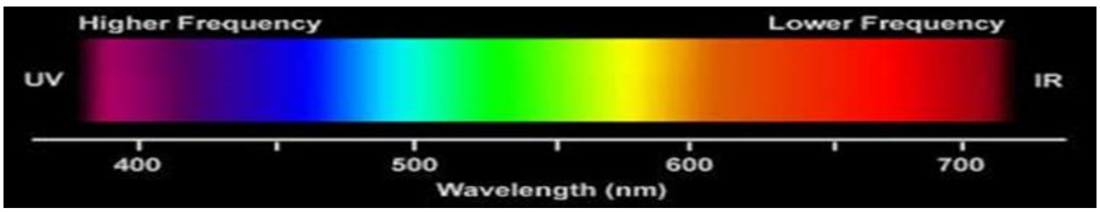


Figure 30 Colors Accurately Differentiated As Specific Wave Lengths of Light

Another example of an accurate absolute reference is a common tape measure or ruler. An inch or centimeter will be the same on every device, and if it is not, it can be easily deemed inaccurate, and by what degree. The accuracy of every length was once evaluated as compared to a specific platinum bar ruler stored in Paris, but is now defined internationally with respect to a particular accurately determined wavelength of light.

5.4. Impact of Real World Factors and Impossibility of Accuracy of Aerodynamics Testing

A key thing for fleets to understand is that no one can currently measure the actual absolute value of the reference vehicle for any tests of aerodynamics, so accuracy will never be obtained the way it could be with the examples of time or color in the previous section.

Instead, engineers calculate aerodynamic drag forces using this equation: $D = C_d \rho A V^2/2$

Where D is the aerodynamic drag force, Cd is the dimensionless drag coefficient, ρ is the density of the air, A is the vehicle cross sectional reference area and V is the relative vehicle velocity, which must be squared, then divided by two. The velocity value includes both vehicle speed and atmospheric wind effects like crosswinds.

A way to visualize aerodynamic drag is that as truck speed increases, so does the air pressure in the space into which it is being forced. Proportionately lower pressure exists behind the truck, creating a space that is vacuum-like in comparison.

However, air density is significantly affected by temperature and altitude; colder air is less dense, and higher altitude air is less dense. Many test methods try to limit test conditions to standard atmospheric conditions at sea level and at a nominal warm temperature. Others attempt to correct actual test data back to these conditions. But since not all evaluations are done at sea level and in the real world, these values vary from day to day and location to location. The difference in reported drag coefficient between a winter test at a facility in Arizona versus standard atmospheric conditions can exceed 0.5% just from altitude and temperature differences. End users of aerodynamic evaluation data should take care to understand what conditions are being reported in the evaluations.

Figure 31 Width Based Reference Area for a Navistar ProStar with Van Trailer

The reference area, A, is likewise somewhat arbitrarily selected as a common factor in aerodynamic comparisons. One specific area used in evaluations is the width based reference area value. A way to visualize this is that it is the area of the shadow a vehicle would make on a wall directly behind the vehicle if the light were projecting from directly ahead of the vehicle. These values can differ. For example, a tractor pulling standard van trailers would differ from those pulling flat beds. Even for the same configuration, different sources may assign significantly differing values for area. The Phase I EPA Green House Gas GEM emissions final modeling tool assigned a frontal area of 10.4 m^2 to all high roof sleeper tractors with standard van trailers. This value was revised by the EPA from an initial draft proposed value of 9.8 m^2. Computer analysis of one typical production tractor and trailer by an OEM showed this value was 10.6 m^2. The original EPA proposal resulted in drag coefficient difference greater than 8%. The final published value differs by nearly 2% for that one vehicle. Valid aerodynamic comparisons between different vehicles require the vehicles to have the same reference areas. Differences in defining area and vehicle changes that alter areas can confuse and complicate aerodynamic comparisons.

It is not appropriate to directly compare aerodynamic drag factors where there are significant differences between vehicle geometries. So for example, aerodynamic comparisons of double trailers to singles, day cabs to sleeper cabs, straight trucks to tractor/trailers, etc. all require extra detail and effort. While the cross sectional areas may appear similar, the lengths are substantially different. Similarly, aerodynamic comparisons between full-scale vehicles and sub-scale models are not consistent unless they are appropriately similar, meeting what is called geometric similitude. Care must be taken when the geometries being tested differ from the expected full-scale vehicle.

Rearranging the drag force equation gives one for the dimensionless drag coefficient.

$$C_d = \frac{\rho A V^2/2}{D}$$

Again, the math highlights that drag coefficient depends on air density, which depends on temperature and pressure, which vary by altitude, seasons and location. Drag coefficient is much affected by vehicle relative velocity, which includes ambient winds, crosswinds and other aerodynamic factors in addition to vehicle speed. Choice of reference area also determines reported drag coefficients. The drag force is estimated from measurements and is very dependent on the evaluation method. These differences will be discussed in subsequent sections of this report.

The equation for aerodynamic drag force, and the rearrangement for drag coefficient should highlight that aerodynamic drag is always a factor when a vehicle is in motion. However, the shades of real world differences accumulate and can be significant. What is needed in the future is an industry agreement on an absolute reference vehicle and a concerted effort by all to correlate each method to this absolute standard, along with continuous improvement and refinement of measurement methods to better match real world. We are not there now, but innovation is constantly in process and we may get there in the next decade.

5.5. Variance among Aerodynamic Device Manufacturer Information

The NACFE research into trailer aerodynamic devices highlighted that the available information published by the device manufacturers varies greatly in content, format, and detail. The lack of uniform information on aerodynamic devices makes it difficult for fleets to compare between them. In preparing this Confidence Report, NACFE attempted to survey all of the manufacturers listed for trailer aerodynamic devices on EPA's SmartWay Verified Devices website. We requested from them what we recommend to be a minimum amount of information on the supplier's device and company.

NACFE recommends that customers request the same information from their aerodynamic device suppliers when performing their own evaluations. To this end, NACFE has provided a form as an example of what NACFE feels is the minimum a customer should request and be provided by an aerodynamic device supplier (see next page).

In discussions with fleet owners and operators, additional information may be desired in order to clarify the specifics of the tested vehicle configurations. These factors would include the specific vehicles used in the evaluations

- Specific tractor make, model and option content used in the evaluations
- Specific trailer make, model and option content used in the evaluations

Additionally, fleets may wish to request details of the specific test method facilities and details of the evaluation conditions or assumptions such as average wind conditions, peak gusts, temperature, and altitude of test. Some suppliers provide this in the form of test reports and may have links to this information on their websites.

NACFE's feedback from fleets is that greater confidence in reported performance comes from greater transparency of the aerodynamic information provided by the device supplier.

Trailer Aerodynamic Device Requested Information Form

EPA Officially Listed Device Name: _____ ____ ____ ____
Alternative Device Names Used by the Manufacturer: _ ____ ____ ___ ____ __

EPA SmartWay Verified Aerodynamic Device Listed Category (shown below):

- 9% Elite Combination: __
- 5% Trailer Under Device: __
- 5% Trailer Rear Fairing: __
- 5% Other Trailer Device: __
- 4% Trailer Under Fairing: __
- 4% Trailer Rear Fairing: __
- 4% Trailer Other Device: __
- 1% Trailer Under Fairing: __
- 1% Trailer Rear Fairing: __
- 1% Other Trailer Device: __
- Not Listed by EPA Yet: __
- EPA Archived SmartWay Device: __

EPA SmartWay Verified Trailer Aerodynamic Device Listed Verification Method(s) (shown below):

- SmartWay Verifications Pre-2014: __
- Wind Tunnel (2014) Method: __
- Coastdown (2014): __
- SmartWay Track Test (2014): __
- CFD (Supplement): __

Indicate Any Other Test Methods Used and Mile-Per-Gallon Improvement Estimated

- Wind Tunnel: ____ ____ ____ ____ __
- Computation Fluid Dynamics (CFD) Analysis: ____ ____ ____ ___ _
- Track Test: __ ____ ___ ____ _____
- Fleet Testing: ___ ____ ____ ___ ____

Trailer Aerodynamic Device Information

- Installed Weight for one trailer set (lbs): ___________________________
- Retail Cost to equip one trailer ($ USD): __ ____ ____ ____ ____
- Installation Labor (man-hours): ___ ____ ____ ___ ____
- Estimated Annual Maintenance Cost ($ USD): _ ____ ____ ____ _____
- Standard Warranty Coverage: ___________________________
- Primary Materials Used: ____ ____ ___ ____ _

Include web link address to a publicly available photo or brochure on the specific device:

5.6. Trailer/Tractor Ratio and Trailer Aerodynamics

The investment decision of whether or not to adopt trailer aerodynamic devices is impacted directly by two key factors: the fleet's trailer/tractor ratio and the fleet's dead-heading ratio. The first relates to how many miles a given trailer device will actually see in a period, while the second relates to how many of those miles actually are traveled while carrying freight. Note that these two qualifiers may be absent in reporting of individual technology performance estimates, but fleets will need to account for them.

The national industry-wide trailer/tractor ratio is reported by the Truck Trailer Manufacturers Association, TTMA. The average ratio reported in the last few years has varied between 2 and 4 trailers for each tractor, but that average hides the fact that some fleets operate with ratios of 1.5 to 1, and others may have 9 to 1. A review of 2011 company Form 10-K data submitted to the Securities and Exchange Commission by some large publicly traded fleets showed an average of 3.9 as seen in Figure 32. In sum, the industry-wide average is not important, what will matter for estimating fuel savings is the ratio of each individual fleet.

	Revenue Equipment			Average Age	
Company	Owned Tractor	Contracted Tractor	Owned Trailers	Tractor	Trailer
J.B. Hunt Transport Services, Inc.	9,109	1,178	75,019	2.8	4.4
Knight Transportation, Inc.	3,509	467	8,986	1.7	5.3
Marten Transport Ltd.	2,233	48	4,124	2.6	2.4
Old Dominion Freight Line, Inc.	5,830		22,685	5.4	9.1
PAM Transportation Services, Inc.	1,691	79	4,643	2.6	
Quality Distribution, Inc.	642	2,339	4,010	4.4	12.0
Swift Transportation Co.	11,044	4,100	50,555	3.7	
USA Truck, Inc.	2,304	110	6,318	2.3	5.9
Werner Enterprises, Inc.	6,600	600	21,918	2.4	
Totals	**42,962**	**8,921**	**198,258**		

Figure 32 Tractor/Trailer Data from 2011 SEC Filings

The tractor/trailer ratio will indicate the trailers actual annual mileage; for each fleet, the return on investment from the adoption of trailer aerodynamics. Aerodynamic trailers that do not move do not offer improved performance or fuel savings. One large fleet contacted by NACFE for this Confidence Report calculates their ROI for trailers in "miles to payback" rather than months, noting that some of their trailer fleet see an average of only 24,000 miles per year while their tractors see 115,000 to 130,000 miles per year.

A hypothetical fleet that averages 4 trailers for every tractor, so each trailer, on average, will see 1/4 of the highway miles seen by the tractor. This in turn means that in order to obtain the SmartWay-advertised 9% improvement in trailer/tractor highway fuel economy performance for a single tractor operated entirely at highway speeds, the fleet must buy four sets of aerodynamic trailer skirts and boattails for each tractor. This information can be translated to an ROI curve with respect to installing trailer aero devices linked directly to the tractor/trailer ratio (Figure 32).

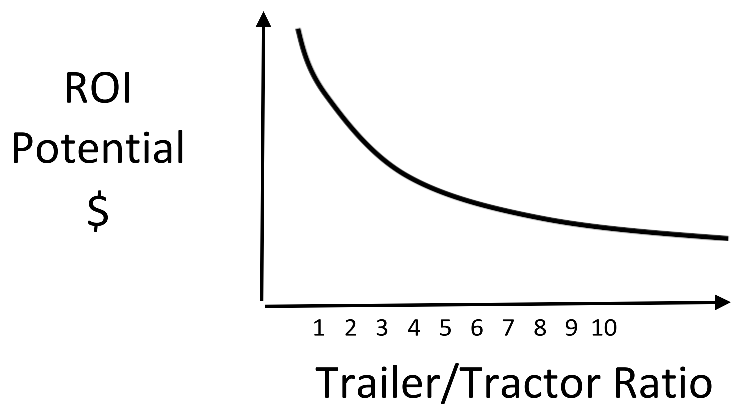


Figure 33 Trailer Aero ROI Depends On Trailer/Tractor Ratio

Fleets that operate refrigerated trailers generally have lower trailer/tractor ratios, perhaps 1.25. However, these trailers can be more complicated with side doors and access ramp requirements, plus the additional equipment required for the refrigeration system. But if these units do see a significant amount of highway miles, the refrigerated fleet can still realize a swifter return on investment from trailer aerodynamic devices than a van fleet that might average a trailer/tractor ratio of 4.

Dead-heading, (driving empty of freight), is another significant qualifier on the fuel efficiency gains offered by trailer aerodynamic devices. The amount of dead heading at each fleet is sensitive information, but some publicly available information such as SEC Form 10-K data puts averages around 13% of driven miles, though each fleet will differ. This is where fleets may consider viewing performance in terms of freight efficiency as a much more meaningful than looking at simply fuel economy, as trailers that haul no freight have zero freight efficiency.

A company that has a high percent of dead heading should overall have higher fuel economy than an equivalent fleet that has a lower dead-heading percent, because moving freight requires more fuel than driving empty. Freight efficiency, however, directly includes the amount of freight along with the fuel economy to give freight tons per mile.   The lower dead-heading fleet would show higher net freight efficiency. This freight efficiency factor also addresses loaded trailer efficiency factors where one fleet may average 65,000 lbs gross vehicle weight per trip while another averages 80,000 lbs GVWR.

However, Confidence Reports focus on fuel efficiency, as this figure will be more constant for a given vehicle, rather than varying highly from fleet to fleet.

The trailer/tractor ratio and the dead-heading percentage are two significant business qualifiers to estimating the effectiveness of freight and fuel efficiency improvement technologies. End users of performance evaluation data need to factor in data from their own actual operations when calculating the return on investment for these technologies, and likely should focus on freight efficiency metrics.

5.7. Reliability and Durability

The U.S. EPA SmartWay program does not specifically address structural requirements for trailer aerodynamic devices, for example, there are no specific minimum loads or stress cycles, durability, etc. In addition, the EPA/NHTSA Phase I Green House Gas regulations do not apply to trailers, while the draft Phase II rules under consideration likely will include trailers and installed aero devices, and will likely require that they "meet emission standards over the expected service life of the vehicles." Various state and federal road safety requirements do require proper maintenance and safe operation, as described by DOT Federal Motor Carrier Safety Administration FMCSA regulations.

Title 49 CFR§ 396.7: Unsafe operations forbidden.

- General. A motor vehicle shall not be operated in such a condition as to likely cause an accident or a breakdown of the vehicle.
- Exemption. Any motor vehicle discovered to be in an unsafe condition while being operated on the highway may be continued in operation only to the nearest place where repairs can safely be effected. Such operation shall be conducted only if it is less hazardous to the public than to permit the vehicle to remain on the highway.

Vehicles operated in Europe require underride protection mandated for trucks over 3.5 tons per European Council Directive 89/297/EEC (ECD 1989) to prevent pedestrians, bicycle riders, and motorcyclists from falling under the wheels of a vehicle when it turns as reported by the U.S. DOT in the June 2015 Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel Efficiency Technologies and Alternative Fuels In Medium- and Heavy-Duty Vehicles (DOT HS 812 159).

However, while not specifically defined in current U.S. regulations, aerodynamic device structural integrity is hugely important to both device providers and fleets considering adoption. The safe road operation of commercial vehicles requires that aerodynamic devices be robust enough to survive normal daily operations, and should be subject to regular driver inspection and other audits. To save both time and money, the industry prefers lower maintenance and repair requires; aerodynamic devices must be as robust as other vehicle systems. Future emissions regulations linked to trailers will likely reinforce that aerodynamic trailer devices be properly maintained for the service life of the vehicle. European regulations on pedestrian underride protection may also influence future U.S. rulemaking.

5.8. Tire and Brake Temperatures and Aerodynamic Devices

Brakes and tires are cooled by a combination of convection, radiation and conduction. Aerodynamic devices can modify the airflow over the brakes and tires resulting in slightly higher operating temperatures. EPA track tests have seen wheel hub temperatures increase 10-15 degrees Fahrenheit on trailers with skirts installed compared to non-skirted trailers. While 10-15 degrees may sound like a lot, a University of Michigan Transportation Institute study, The Influence of Braking Strategy on Brake Temperatures in Mountain Descents, documented brake temperatures on a non-aerodynamically equipped 80,000 GVWR tractor/trailer as reaching 350 F to 500 F while descending a long grade and pulsing the brakes, so at such high temperatures and with such a wide range the addition of skirts is actually a small impact overall. Still, a 2012 National Research Council Canada study, Review of Aerodynamic Drag Reduction Devices for Heavy Trucks and Buses, offered advice for the adoption of wheel covers, saying that it is necessary to evaluate the effect on brake cooling "to ensure they do not restrict air flow to the brakes" – this is likely relevant for any aerodynamic treatments to the trailer.

6. Trailer Aerodynamic Technologies

There are three primary "areas of opportunity" to address aerodynamic drag on a trailer, as shown in Figure 34 and as outlined by the EPA in Figure 35 – they are at the front of the trailer, at the underside of the trailer, and at the back of the trailer. In some cases, there is also small space for devices to go on the sides and the roof, and there are also aerodynamic devices for wheel ends. These devices are generally described as "fairings," which refers to any aerodynamically shaped surface. The general industry prioritizes adding trailer aerodynamic devices on the underbody, followed by the rear, followed by the gap, based on observation of on-highway use and discussions with manufacturers and fleets.

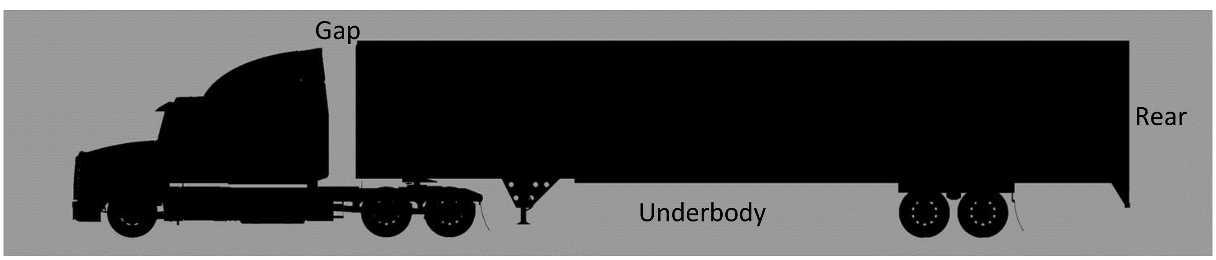


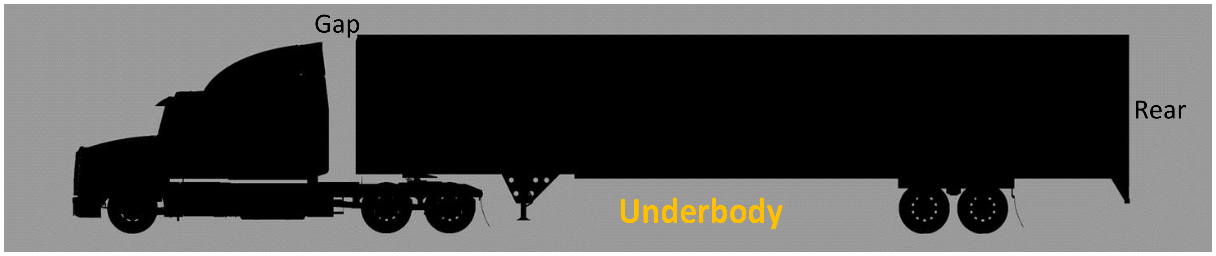
Figure 34 Three Primary Aerodynamic Opportunity Areas

Table 2-69 Aerodynamic Technologies for Box Trailers

LOCATION ON TRAILER	EXAMPLE TECHNOLOGIES	INTENDED IMPACT ON AERODYNAMICS
Front	Front fairings and gap-reducing fairings	Reduce cross-flow through gap and smoothly transition airflow from tractor to the trailer
Rear	Rear fairings, boat tails and flow diffusers	Reduce pressure drag induced by the trailer wake
Underside	Side fairings and skirts, and underbody devices	Manage flow of air underneath the trailer to reduce turbulence, eddies and wake

Figure 35 EPA's Description of Primary Trailer Aerodynamic Technologies

6.1. Underbody Devices



Trailer skirts are the most popular devices for addressing aerodynamic drag in the underbody. While some argument can be made that various rear devices may off fuel savings equivalently to those of some underbody systems, the underbody systems are perceived by fleets and drives as having fewer challenges in operational environments, since they are not “in the way” of moving freight in and out of the dry van trailer. This is not necessarily the case with some compartmentalized refrigerated trailers with side access doors where the access ramps may store underneath the trailer.

All trailer underbody skirts serve to extend the trailer side walls much closer to the ground, preventing wind from ducking in under the trailer and running into the non-aerodynamic trailer bogie. Figure 36 shows a typical set of wind streamlines taken at the height of the axles. The streamlines for an un-skirted trailer will bend after passing the tractor tires and go underneath the trailer and directly impinge on the bogie, increasing drag (the green area). Figure 37 illustrates how skirts keep the air flow efficiently aligned with the flow on the trailer sides.

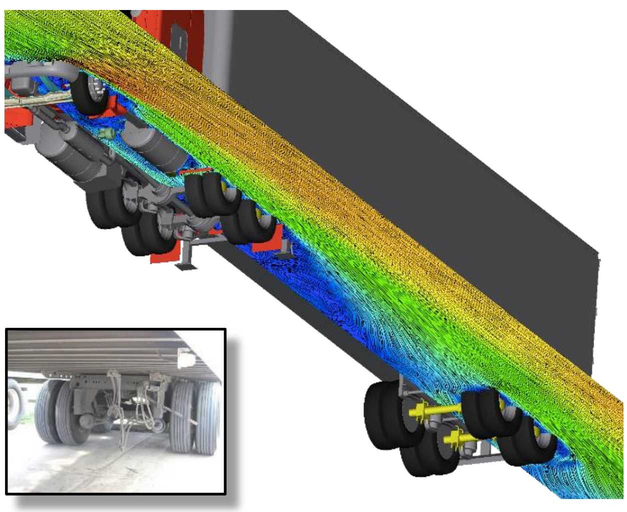


Figure 36 Streamlines for an Un-Skirted Trailer (PACCAR)

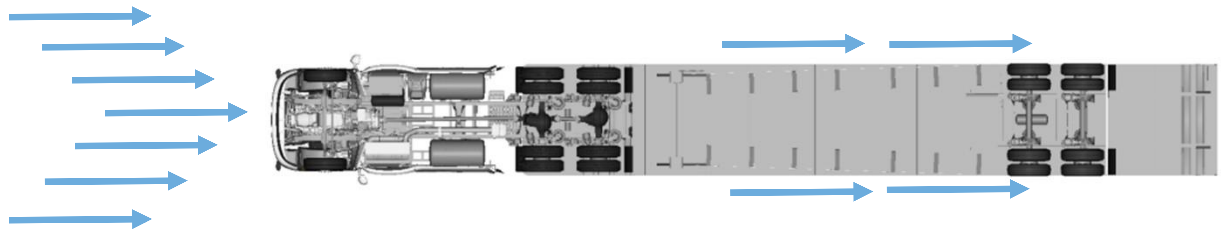


Figure 37 Trailer Skirts Keep Air from Impacting Trailer Bogie

The simple view in Figure 37 seems obviously an improvement for the aerodynamics of the trailer. But this aerodynamic benefit gets more complicated when the ambient winds are not aligned with the tractor and trailer. Figure 38 illustrates that air flow in some trailer areas can flow underneath the un-skirted trailer and not increase drag, whereas that same air flow would hit a skirted trailer and actually increase drag after all. In still other situations the ambient air flow will hit the trailer bogie just as before. All that is to say that the effectiveness of trailer skirts changes with the relative angle of the wind to the moving truck.

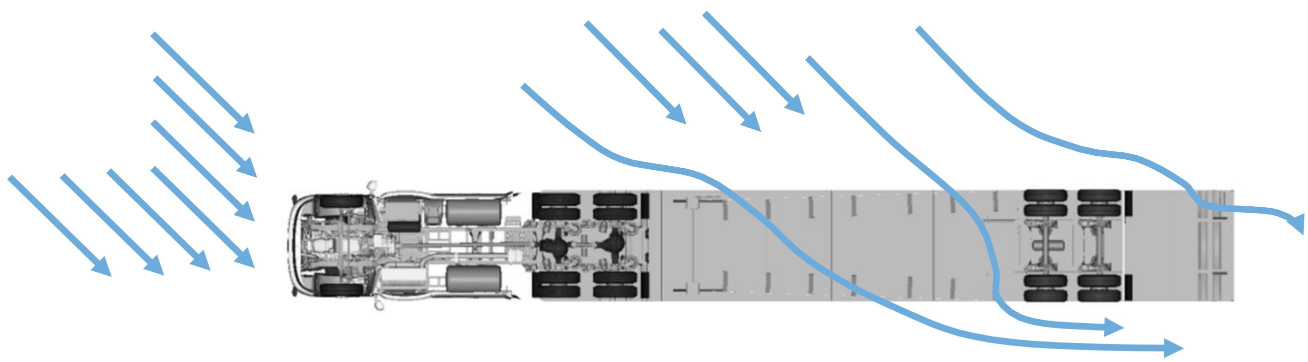


Figure 38 Off-Axis Un-Skirted Trailer Air Flow Example

This illustrates the fact that aerodynamic trailer devices will not be beneficial in every single situation. The goal of adoption is that they will provide a net benefit over the course of all of the operational conditions. That implies that statistics are involved to predict expected performance which in reality will continually vary. This is perhaps most easily understood by looking at what aerodynamicists call a yaw curve, a wishbone shaped graph showing drag as a function of wind angle. The example shown in Figure 39 is from a 2004 historical overview by Kevin Cooper of the National Research Council of Canada, Commercial Vehicle Aerodynamic Drag Reduction Historical Perspective as a Guide. The graph plots drag coefficient versus the yaw angle of the vehicle into the wind. In the wind tunnel, this is done by rotating the vehicle on a platen as shown in the picture. Each wishbone curve represents the drag coefficient at each wind angle for different configuration of devices.

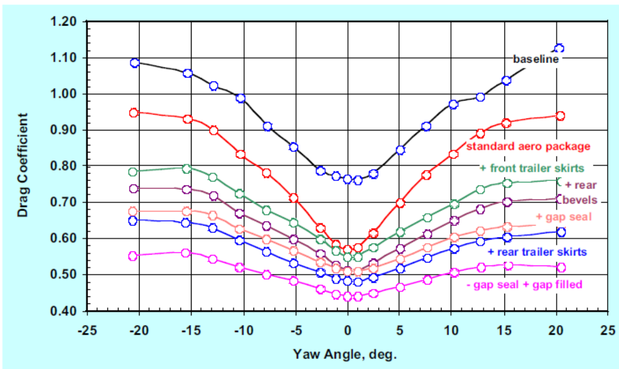


Fig. 8: Low-drag Development of the NRC Tractor-trailer

Figure 39 Drag Varies by Wind Yaw Angle (NRC)

The variability of actual wind speeds and angles is unpredictable, but over time, weather measurements can be averaged to come up with a way to approximate and estimate average conditions. Aerodynamicists report results as Wind Averaged, which usually means they have taken nationally averaged wind conditions and applied a probabilistic weighting to each drag value at each angle to come up with an average estimated drag coefficient. Details on this can be found in SAE J1252 and background on it is discussed in a 1988 report by Kenworth and published by SAE titled Heavy Duty Truck Aerodynamics, report SP-688 (see also SAE 87001).

Although skirts will vary in performance from ambient wind conditions, on balance the decades of extensive research and actual field performance finds that skirts will benefit most operations by reducing overall fuel use. The absolute value of the savings will differ by user and depends on many factors which are described in more detail in the NACFE Determining Efficiency Confidence Report at www.TruckingEfficiency.org.

The designers of trailer skirts focus on providing cost effective, light weight, robust designs so that they hold up, especially as they are a very publicly-visible technology. The trucking industry is not forgiving of devices that are easily damaged and require constant repair or replacement. Another key factor determining the industry’s perception of skirts is their installation time and required headcount, as many installations occur in the aftermarket.

The majority of skirts on the market today are flat sheet materials bracketed to the underside of the floor structure of the trailers. The example shown in Figure 40 is by Utility Trailer. Sheets can be composite, metallic or both. Formed or molded panels are offered by some manufacturers as shown in Figure 41 from Laydon. Molded panels offer an ability to design in stiffness and features like the crank handle stowage recess. The brackets can also be composite plastic or metallic. Much of the innovation in skirts is in material selection and bracket design.

Figure 40 Example Skirt Installation (Utility Trailer)

Figure 41 Formed Skirts (Laydon)

For more skirt design detail, an SAE paper by Naethan Eagles, titled A Parametric Assessment of Skirt Performance on a Single Bogie Commercial Vehicle SAE 2013-01-2415, defines and quantifies several key geometric parameters.

Another type of underbody device can be described as a bogie fairing. In somewhat the same way that a sleeper roof fairing moves the air around the blunt trailer front, these bogie fairings move the air away from the trailer bogies. A leader in manufacturing this type of device is SmartTruck. Their computational fluid dynamics image (Figure 42) shows how this underbody system avoids air flow impinging on the trailer bogie.

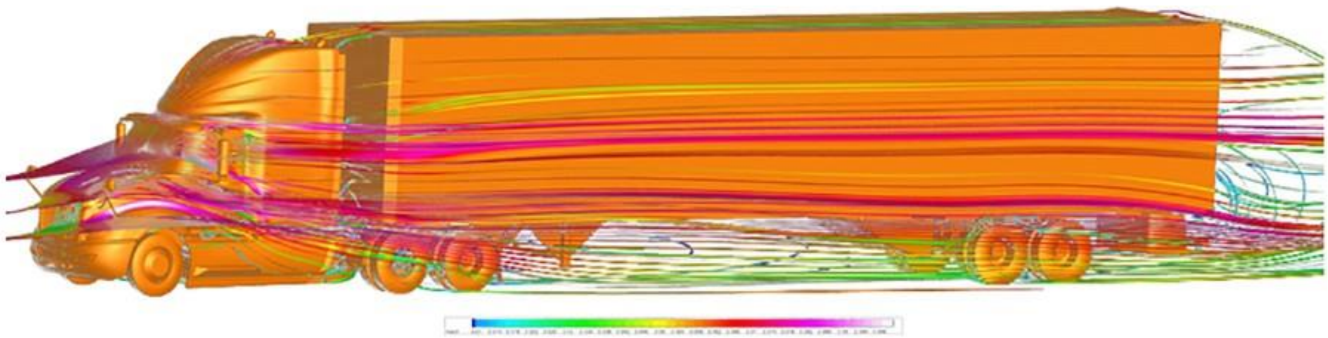


Figure 42 UnderTray Bogie Aerodynamic Improvement (SmartTruck)

The benefit of the bogie fairing type of system is that it provides greater clearance and access under the trailer than with full skirts. But these types of devices alone are generally less capable at reducing overall drag than skirts, and may require additional systems to be installed as shown in Figure 43. The SmartTruck UT-1 UnderTray device generally must be paired with their roof top Aerodynamic Rain Gutter to achieve the SmartWay 5% rating held by many skirt systems, while their UT-6 system has the UnderTray, a Rear Diffuser, and the Aerodynamic Rain Gutter all required to get the 5% EPA rating. Similar findings came from independent testing by Performance Innovations Technology, PIT, in tests run in Canada reported by Heavy Duty Trucking in October 2013. They reported that “The test results show that trailers with side skirts consumed an average of 6.69% less fuel than similar vehicles without skirts. Trailers with undercarriage aerodynamic devices consumed 1.43% less fuel on average than similar units without the deflectors.” It is important to note, though that some owner operators shared with NACFE that they had higher performance levels from undertrays. As stated previously, the specific real world results can and do differ from those reported from various controlled testing, and there can be legitimate disagreements on performance.

Figure 43 Various SmartTruck Aerodynamic Parts On Operating Trailer – Bogie Slid In Rear Position – UnderTray, Rear Deflector and Roof Mounted Device

Other examples underbody devices are the Airman Airwedge and the Ekostinger shown in Figure 44.

Figure 44 AirWedge (Airman Systems) and Ekostinger (Ekostinger)

A key takeaway from this example of skirts versus under trays is that fleets should investigate the complete set of parts and installation times that are required with any aerodynamic trailer system before making investments, as the complete system of parts may not be obvious from advertising or media press releases.

Still other new products are reaching market that offer more clear space under the trailers than full skirts. A design discussed in a 2012 in SAE Paper EPA SmartWay Verification of Trailer Undercarriage Advanced Aerodynamic Drag Reduction Technology, SAE 2012-01-2043, uses a series of individual skirts spaced apart under the trailer to effectively accomplish the same performance as a monolithic full surface. The Wabash Ventix DRS system is one similar concept (Figure 45) and is designated as a EPA SmartWay 5% device, similar to full skirts. Wabash's website claims that these can in fact perform better than traditional skirts. Care again should be taken to understand all of the parts in the system, for example this includes a fairing aft of trailer wheels and one ahead of the trailer landing gear where the traditional base solid skirt is only ahead of the wheels and behind the landing gear. Some of the standard full skirts may also be optioned to include these longer installations so a more equivalent comparison can be evaluated.

Figure 45 Segmented Skirt Aerodynamic Devices (Wabash)

A differentiating factor in skirt designs may be the size of the gap between the ground and the bottom edge of the skirt, and whether the bottom pieces of the skirt are solid materials or flexible rubber. Notably, warehouse apron crown clearance can be an issue with skirts, as can servicing access.

Figure 46 Ground Clearance Precaution with Aero Performance (Wabash)

Various manufacturers include a rubber flexible strip at the bottom of the skirts to help close the gap but deal with the occasional real world issues like crown clearance, curbs, railroad crossings, and running over dunnage like pallets and 2x4 wood. Figure 46 shows one example from Wabash, their Duraplate AeroSkirt with a flexible thermoplastic that maintains aerodynamic rigidity but absorbs impacts.

Skirt ground clearance also affects aerodynamic performance. The most aerodynamic installations tested in prototype development have nearly zero ground clearances, but these installations are not practical in the real world unless they can move out of the way in some of the situations just described. An example of such a technology this is the Windyne Flex Fairing shown in Figure 47, which can hinge up while maneuvering around delivery docks, but then fold back into position for on-highway use.

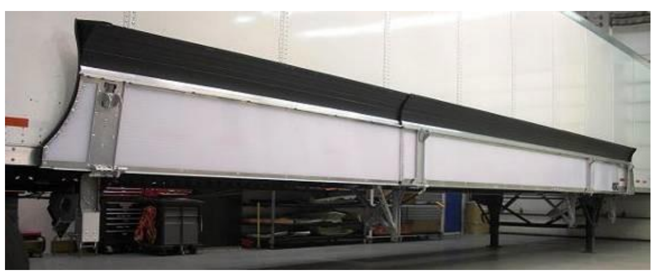


Figure 47 Articulated Skirts Allow Clearance at the Yard (Windyne)

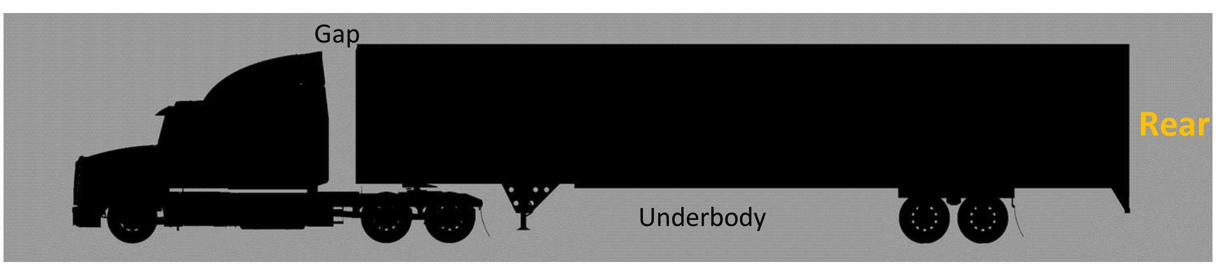
Multiple evaluations have been done over the years on the sensitivity of the ground clearance and skirt length on skirt aerodynamic performance – as length increases, aerodynamic performance improves. But skirts that have too small a ground clearance see a high rate of damage and become less desirable in the market, while skirts that have too high a ground clearance see too little performance gain to justify adoption. One example study from wind tunnel work by Navistar is in SAE 2007-01-1781, Practical Devices for Heavy Truck Aerodynamic Drag Reduction. Ground clearance is one factor that will determine why some skirts on SmartWay's verified list are listed as 1% or better, others 4% or better, and many are at 5% or better.

The real world tends to force iterations in design over time. Two fleets contacted by NACFE said that when skirts were first introduced, everyone who could bend a bracket got into making them, so quality varied. They both also said that skirt quality has significantly improved in the last 5-7 years. The sales feedback process tends to force iteration towards an acceptable balance between ground clearance damage rate and aerodynamic performance. Devices with a longer field history that have been through design improvement may be better tuned to customer's real world requirements than those with less field history.

There is really no standard definition of "minimum clearance," or even of a "trailer skirt," so attention must be paid to detail when comparing different claims, as the devices may not be similar in size or function. It is very unlikely that a manufacturer will guarantee a customer real performance values due to all the variables inherent in real world operations. This is where asking for data on warranty occurrence rates and actual performance from other fleets who are using the devices becomes important when talking to aerodynamic device suppliers.

Fleets should also know that underbody devices can collect ice and snow in winter conditions, and this can impact aerodynamic performance, as well as adding weight to the vehicle and reducing its freight load potential or resulting in overweight fines at inspection stations. This situation is experienced in aircraft so often that they are equipped with a range of systems to prevent ice build-up and are sprayed down with deicing mixes before some winter flights; at present there are no trailer underbody system options that similarly address ice or snow build-up automatically, so fleets must rely on the driver's inspection.

6.2. Rear Devices



Devices to mount at the rear of trailers are generally called boat tails or trailer wake devices. They modify the air flow as it leaves the trailing edge of the side and top surfaces of the trailer. Given that a raindrop is an optimally aerodynamic shape, with the tail of the drop opposite the direction of travel coming to a point, it may seem that the ideal trailer rear shape would come to a similar point. NASA aerodynamicists experimented with this as early as the 1970s as seen in Figure 48 from A Reassessment of Heavy Duty Truck Aerodynamic Design Features and Priorities, NASA/TP-1999-206574.

Figure 48 Trailer End Design Getting to the Point (NASA)

Several more recent research studies have also reached this conclusion; a number of them are described in U.S. Patent 2007 #7,255,387 by Rick Wood. These shapes, however, present many challenges, including that they may exceed overall length rules, or create packaging challenges and issues at warehouse docks. The Federal rules on overall length do allow for adding devices to the rear of trailers under 23 CFR Part 658.16, Truck Length and Width Exclusive Devices, but these devices cannot exceed five feet, cannot carry freight, must be flimsy enough to easily crush in a rear accident, cannot block required lighting, etc. etc. Operationally trailer tails also need to get out of the way during the loading and unloading of freight. The reward for innovating a practical solution into this complex set of requirements is significant aerodynamic drag reduction.

The goal in all rear trailer devices is to reduce the wake field following the trailer, which can affect air some distance from the back of the trailer as shown in Figure 49 and in the computational fluid dynamics graphic in Figure 50 .

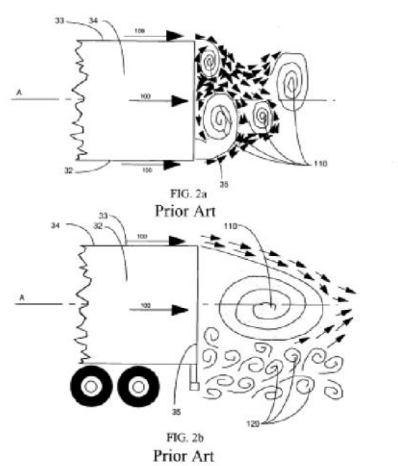


Figure 49 Wake Field Aerodynamics (from Patent US2007/0176465)

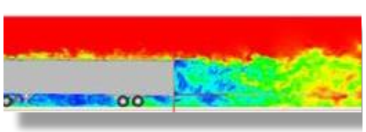


Figure 50 Wake Fields behind Trailers (Exa CFD Image)

The generally smooth air flowing along the large flat sides of the trailers detaches as it passes the sharp rear corners of the trailer box creating a series of vortices which create a low pressure region adding drag to the tractor/trailer as shown in Figures 49 and 50. Generally, the greater the wake field, the more drag the tractor engine has to overcome.

Many concepts have been developed to help get the air to wrap more efficiently around the trailer rear corners, reducing the size of the wake field and thus reducing the drag. Various flat panels, or ramps have been added to the rear edges, similar to Tractor Sleeper Extenders but angled inboard, and ramps of different lengths and angles have been evaluated. In general, the best performance comes from the longest allowable ramp set at an appropriate angle as determined from aerodynamic studies. Various designs trade-off ramp length for other design factors, like ease of device storage, or clearance roll-up door openings for trailers with roll-up doors. Overall this is a very challenging design space to optimize.

One product that has succeeded to capture market share is the Stemco/ATDynamics TrailerTail shown in Figure 51. This system exemplifies the challenges for tail devices. The aero surfaces stow flat against the rear swinging doors of a typical trailer. An innovative and patented origami folding system allows these to easily deploy to their on-highway configuration and lock in place. To re-stow, the driver has to only open the trailer swing door all the way to the side. The TrailerTail folds itself back up flat in the process of swing the trailer door around. With the doors in their latched open position, the TrailerTail requires no additional width when backing into tight freight docks. Upon leaving the dock, the driver has to normally close and secure the trailer doors, so there are nearly no additional steps required. The series of photos in Figure 51 show various stages of the TrailerTail operation. The driver can choose to have the TrailerTail stay in its stowed position or he can deploy it. An automated system for deployment has also been developed.

Figure 51 TrailerTails

Market penetration of this device has grown such that a random sampling of trucks in 2014 driving on the Dallas-Oklahoma City corridor found that 3%-5% of trailers were equipped with TrailerTails. That same random sample found that 15%- 30% of trailers had skirts, including all of the TrailerTail-equipped vehicles observed. Few trailer gap devices were spotted. In the 2015, NACFE Annual Fleet Fuel Study, 19% of the new trailers bought by the 14 surveyed fleets had boat tails of some model, showing that many early adopters are increasing their purchase of these devices. While these numbers are somewhat anecdotal, the trend reinforces earlier statements that the priority for equipping trailers with aerodynamic devices is the underbody, then the rear, and finally the front.

Highlighting this growing opportunity, Wabash Trailers has recently developed their own trailer rear devices, the AeroFin and AeroFin XL devices shown in Figure 52. These devices, like the ATDynamics Trailer Tail, focus on adding no additional steps to the driver's operation, but the Wabash ones are always deployed when the swing doors are closed, requiring no decision by the driver.

Figure 52 Wabash AeroFin and AeroFin XL Rear Aero Devices (Wabash)

The SmartTruck group also offers a trailer rear package called TopKit Trailer Tail System, shown in Figure 53, with a SmartWay designation as 5% or above. This system improves how the air transitions from the trailer's top and sides to the wake region by modifying the trailer'sharp rear corners. The roof mounted device also improves the air crossing a rain gutter that exists on the top rear of many trailer models.

Figure 53 TopKit Trailer Tail System (SmartTruck)

Transtex Composite introduced in 2015 a SmartWay-designated tail system called Edge Tail shown in Figure 54. The system extends 30 inches and has an auto deployment method. Transtex Edge Tail is listed by SmartWay as a 4% or above device.

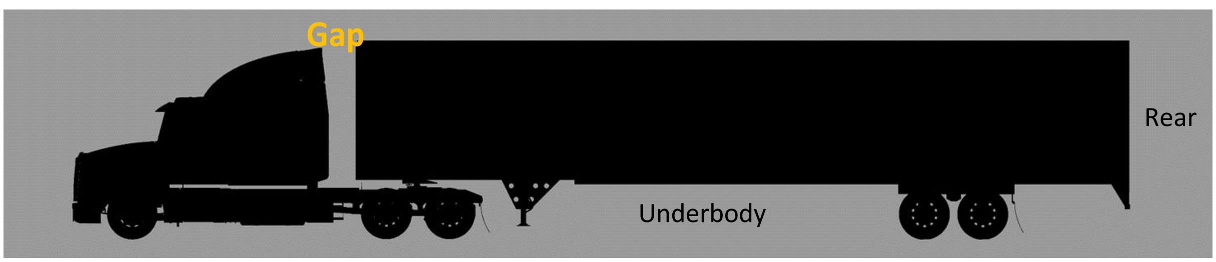
Figure 54 Transtex Edge Tail (HDT)

Reflecting the difficulty of designing a robust trailer rear device, Aerodynamic Trailer Systems patented their inflatable tail solution with work started in 2007. They obtained SmartWay status at 5% or above and sold and fielded it over the years since but have decided to exit the market in late 2015. The innovative concept shown in Figure 55 has potential and may reenter the marketplace in the future.

Figure 55 ATS SmartTail Inflatable Rear Aero System (ATS)

If trucks operate primarily in one prevailing wind orientation, like crosswinds in a North-south mid-west corridor, or aligned winds in an East-West mid-west corridor, tail device performance can vary significantly. A deeper dive into this is found in two SAE papers by Cooper et. al. titled The Unsteady Wind Environment of Road Vehicles, Part One: A Review of the On-road Turbulent Wind Environment, SAE 2007-01-1236, and The Unsteady Wind Environment of Road Vehicles, Part Two: Effects on Vehicle Development and Simulation of Turbulence, SAE 2007-01-1237.

6.3. Gap Devices



Tractor-to-trailer gap management devices are ranked third in adoption priority in large part due to the evolution of the current aerodynamics of SmartWay verified tractors. These highly aerodynamic tractors have high roofs and well-tuned trailing edges such as the cab extenders, trim tabs, and the bridge fairings that are being added to the rear of some roof fairings; such tractor devices have largely reduced the importance of trailer aerodynamic gap devices. These trailer-mounted devices are referred to variously as gap reducers or nose cones, although NoseCone is also a trademark for a particular brand of devices. However, there are still many non-SmartWay tractors in service in North America which are not necessarily equipped with roof fairings. These tractors have long lives of 12 to more than 20 years and multiple uses over many owners. There also is a large inventory of existing trailers. These two factors leave room for gap devices to be more significant contributors to performance than indicated by SmartWay's values.

NoseCone produces a family of devices as shown in Figure 56, from one that softens the blunt top edge of the trailer, to one that improves the exposed front of the trailer, to the full package that includes improved aerodynamic rounding of the trailer edges. These devices have very sound technical roots going back to the 1950s and 1960s, and provide significant savings for day cab tractors, mid-roof sleeper tractors, and older styled conventional tractors. As with the argument for adding trailer rear fairings, continuous improvement and fleets pursuing efficiency gains after they have installed underbody devices will need to consider these options as the next area of opportunity for aerodynamic improvement.

Figure 56 NoseCone Trailer/Tractor Gap Devices

Laydon also makes a trailer Nose Fairing system of parts, shown in Figure 57, which SmartWay lists as 1% or better. A challenge with trailer front and rear devices is that they generally require drilling the trailer surfaces, which makes these installation choices more difficult to change later if desired. This is compared to underbody systems, which currently have access to the floor structural members exposed on the underside of the trailers and providing convenient locations and flanges for clamping brackets, such that no trailer drilling is needed.

Figure 57 Nose Fairing Gap System (Laydon)

EPA lists Carrier Transcold and FreightWing as both having a gap aerodynamic system, Figure 58, similar in function to the Laydon one, but with greater use of metal components. However Freightwing has been acquired by the Ridge Corporation, and this device does not appear now to be offered by either Carrier or Ridge.

Figure 58 FreightWing/Carrier Gap Devices

A different type of trailer gap device uses the natural tendency for air to swirl in the tractor/trailer gap as shown in Figure 59. These natural vortices tend to prevent air from crossing from one side of the trailer to the other, essentially creating virtual fairings. These uniform opposing vortices destabilize towards the top of the tractor/trailer gap. The vortices also collapse as the tractor/trailer gap increases in length, so trailers with fifth wheel settings too far back will not see the aerodynamic benefits.

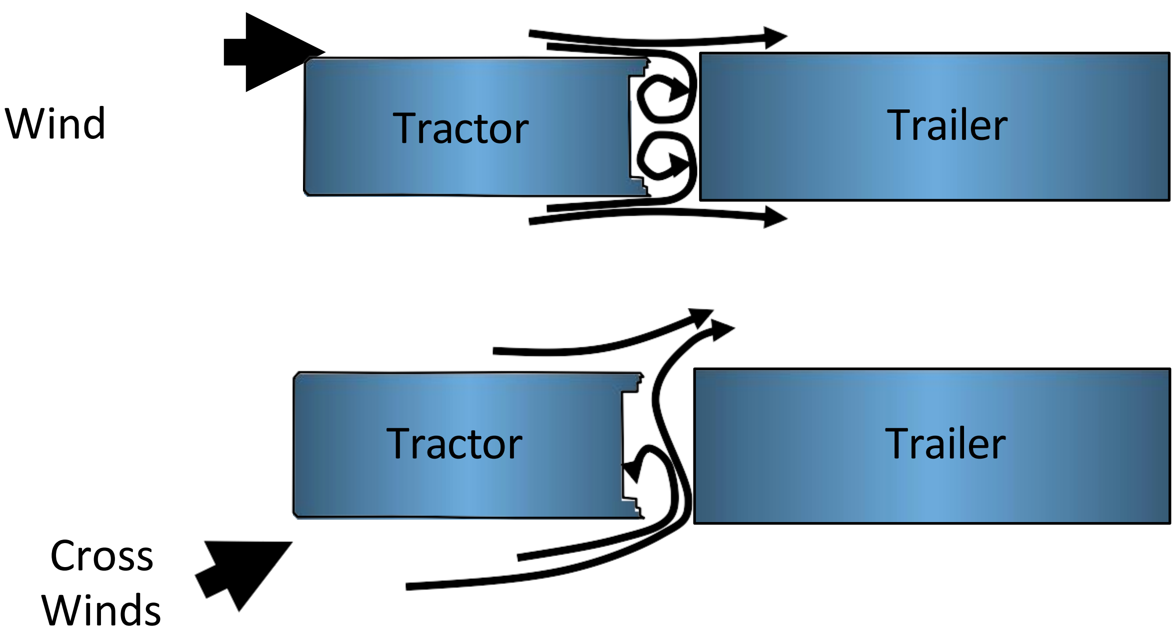


Figure 59 Gap Vortex Management Devices

Figure 60 Vortex Stabilizer Device (Laydon)

One example of a device to help maintain these vortices is the Laydon Vortex Stabilizer shown in Figure 60. The device, by itself, is not SmartWay designated, but can be part of a complete Elite package. As previously discussed, the evolution of aerodynamic tractors has significantly improved tractor-to-trailer gap air flow and with shorter fifth wheel settings, this type of device is less necessary. For longer gap settings that may be required due to axle loading, there may be benefits from this type of device, especially in cross-wind conditions. Many types of devices have been evaluated similar in purpose to this one, with positive results, but they are currently very rarely seen on-highway.

6.4. Wheel Covers

A variety of manufacturers produce aerodynamic wheel covers for use on both the tractor and trailer wheels. The aerodynamics associated with rotating tires and wheels are complicated by many factors including the type of ground surface, the wheel deformation as it rotates, variations in tread patterns, interactions with other tires, the presence or absence of fenders, the presence of mud/rain flaps, the presence or absence of chassis and trailer skirt fairings, and more. Small benefits can be shown in very controlled wind tunnel tests and CFD analyses, but are much more difficult to reliably measure in road and track testing. The consensus opinion is that these devices should be a net benefit to the fuel economy of the vehicle, but the improvement is small enough that it falls into the statistical "noise" of most individual test methodologies. Fleet experience over longer periods of time tends to reinforce that these devices are a net performance benefit, but, again, finding proof can be challenging. The National Research Council of Canada Test Report from 2012 titled Review of Aerodynamic Drag Reduction Devices for Heavy Trucks and Buses, NRC report CSTT-HVC-TR-205, concluded "modest aerodynamic improvements may be achieved with the use of wheel covers and slotted mudflaps."

The devices are generally described in advertising and media as 1% or better type fuel economy devices. As with other claims, these values may relate to a specific controlled test condition and methodology and the real world improvement may be less.

A 2012 SAE Paper, EPA SmartWay Verification of Trailer Undercarriage Advanced Aerodynamic Drag Reduction Technology, SAE 2012-01-2043, documents well the evaluation of a Solus Wheel Cavity Cover, shown in Figure 61. The device attained a SmartWay rating of 1% or better in concert with various short trailer skirts. A key requirement for wheel covers is the need for drivers and inspectors to be able to view and access the wheels. This Solus device addresses this by providing an access hole.

Figure 61 Solus Wheel Cavity Cover

The FlowBelow company produces a closed wheel cover that can be readily removed by pushing the center release button as shown in Figure 62. One challenge, however, with making wheel covers devices easily removable is that it also can facilitate theft when the vehicle is parked.

Figure 62 FlowBelow Wheel Cover Access

The RealWheels Corporation offers a combination of wheel cover products that includes a closed wheel cover version with clear panels to be able to view inside the wheel space as seen in Figure 63.

Figure 63 RealWheels with Viewing Panes

Steer axle wheels can also have covers. These are more rarely seen in the field than tractor drive axle and trailer bogie wheel covers.

The cost, weight and installation time of wheel covers is relatively small compared to other investments. One set of four covers for a trailer complete with mounting bracketry may add 20 to 50 pounds to the trailer. Long-term durability and maintenance of wheel covers, as with all heavy truck equipment, is still a factor to consider. Devices offered as listed options from trailer and tractor manufacturers may have had additional durability testing beyond supplier's testing and field data. The robustness of any system is fair game to discuss with the supplier and NACFE recommends asking vendors to provide mean time to failure or similar information to help assess durability and predict total cost of ownership.

6.5. Aerodynamic Mud Flaps

Figure 64 Example Exposed Wide Mud Flap (Badger)

A variety of mudflap alternatives have been on the market for some years offering improved aerodynamic performance and fuel economy savings. As with the wheel covers, it can be challenging to prove significant savings with current testing methods. And again, the general consensus is that these devices should be beneficial but the savings are hard to statistically prove in individual controlled tests, while fleet evaluations include many other factors that confuse isolating the benefits to just the mud flaps. The NRC comment again applies: “modest aerodynamic improvements may be achieved.”

One critical aspect of mud flap aerodynamics is specifying the correct width of mudflap for the wheels. Differences exist between wide-base singles and duals, so that one size mud flap does not fit all. A mud flap that is too exposed to the air flow in fact will create significant drag and downstream issues (Figure 64).

Aerodynamic mud flap concepts range from simply venting the flap to actually introducing louvers and aerodynamic surfaces.

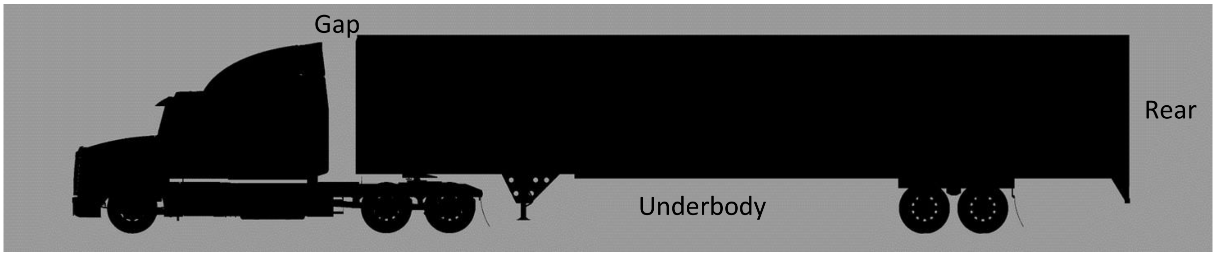
Figure 65 Simple Vented Flap

An example of a simple vented flap is shown in Figure 65. Vent Variations get progressively more complex, for example the Fleet Engineers Mud Flap with actual louvered surfaces in Figure 67. Taking this further is the Mirrex Louvered Mud Flap shown in Figure 66.

Figure 66 Louvered Flap (Mirrex by Vortex Splash Guards)

Figure 67 (Fleet Engineers)

6.6. Vortex Generators



The general market place priority for adding trailer aerodynamic devices is Underbody, Rear, then Gap, based on observation of on-highway use and discussions with manufacturers and fleets. Skirts are the most popular devices in this region of the trailer. While the concept was briefly introduced in the section on Gap technologies, a new product offering for the whole trailer is a vortex generator, which is basically a flow control device instead of fairing, and is offered as the VorBlade Wing system shown in Figure 68. SmartWay lists this system as 5% or better, but VorBlade's public information does not clearly on define all the parts that are used for this designated configuration. The system uses a series of individual devices mounted on the roof and other devices mounted on the trailer sides to moderate cross wind conditions, which VorBlade claims is where the drag reduction occurs. The devices add height and width to the trailer but are exempted from Federal height and width constraints as energy conserving devices. However, U.S. bridge height infrastructure is less forgiving of height exemptions, so caution is advised with these devices. This is new technology and there has not been significant market penetration as of 2015.

Figure 68 VorBlade Wing System

Meanwhile Aeroserve Technologies LTD Airtab vortex generators, shown in Figure 69 have been on the market for over a decade. These devices are easily added to trailers and tractors through adhesive backing. Some fleets report mpg improvement from installing devices on tractors and trailer rear edges, while others have not realized measureable improvement and industry testing has mixed conclusions.

Figure 69 Aersoserve Technolgies LTD Airtabs

The SmartWay verified list also includes the Nose Cone Mfg. Co. AeroTrak VG Pro which is no longer offered, as they responded, "Over the road analysis of the technology did not support the test submitted to us as verification."

6.7. Refrigerator Units

It should be noted that refrigerated trailers have what effectively serves a trailer gap reducing device in the modern trailer refrigeration unit. EPA recognized this in their GHG Phase II draft Regulatory Impact Analysis released in 2015, stating that the "The transport refrigeration unit (TRU) commonly located at the front of refrigerated trailers adds weight, has the potential to impact the aerodynamic characteristics of the trailer, and may limit the type of aerodynamic devices that can be applied." The agencies are proposing to recognize box trailers that are restricted from using aerodynamic devices in one location on the trailer as "partial-aero" box trailers."

6.8. Smaller Details

While skirts dominate as the leading candidate for single device selection, the DOE SuperTruck programs highlighted that attention to a range of small details can produce measureable improvements. Fleets that make the effort to address details, like matching mud flaps to tire widths, relocating license plates to avoid blocking air, adding wheel covers, etc. accumulate savings over time due to the miles multiplier on even small gains that may not be measurable in controlled tests. Comments from one NACFE fleet were that these companies also instill a performance culture, that they are motivated to make performance improvements at all levels and that leaves a positive impression on their drivers.

An example of a smaller detail is the Bumper Bullet offered by Kodiak Innovations (Figure 70) which rounds the leading edge of the ICC bumper.

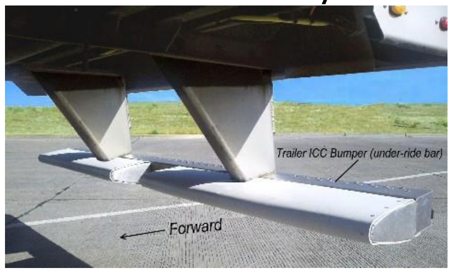


Figure 70 Bumper Bullet (Kodiak Innovations)

6.9. Combinations of Technologies

Where is the greatest opportunity on the trailer? Each area can reduce its drag with the addition of aerodynamic devices, but as each device is added, the performance of other devices will be impacted. Generally, the reason for this is that air flow over each device changes the operating conditions for the other devices. The performance of a combination of devices will not simply be the additive total of each device operating alone as they may interact positively or negatively. Both industry and government aerodynamicists have repeatedly shown that the maximum aerodynamic improvement comes from a combination of sealing the tractor/trailer gap, from sealing the trailer underbody, and from adding a boat tail – basically acting on all three of the key areas of drag identified. These very-optimized trailers have been demonstrated by OEMs in Europe and the U.S., as shown in Figure 71, most recently with the Department of Energy SuperTruck Program vehicles which achieved a greater-than 50% freight efficiency improvement, with mile-per-gallons demonstrated in the 10-12 mpg range.

Figure 71 Optimizing Trailer Aerodynamics to the Extreme - Recurring Themes

The example graph in Figure 73 was reported in Understanding Practical Limits to Heavy Truck Drag Reduction, a 2009 SAE Paper 2009-01-2890. The testing is based on 25% scale model wind tunnel test examples of which are shown in Figure 72. This specific graph shows that the greatest drag reduction, (the lowest curve in green), came from having aero devices in all three regions and maximizing their drag reduction. While there is no guarantee the multiple devices will actually be more beneficial than individual ones in absolutely 100% of all operational situations or configurations, addressing the aerodynamics of all three points of drag should give the greatest fuel savings for the vast majority of fleets.

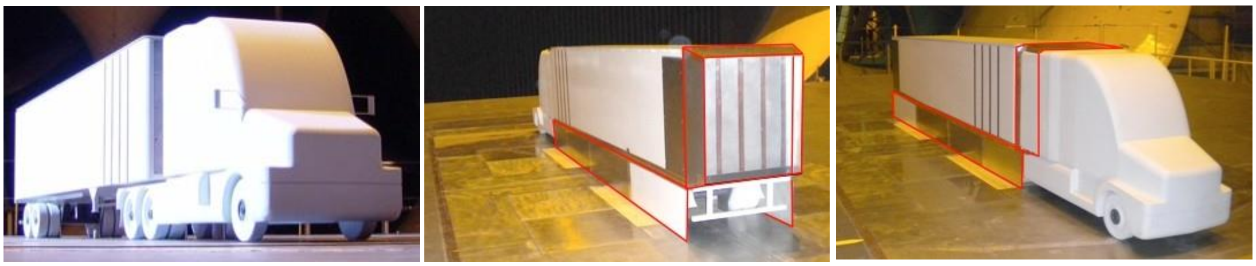


Figure 72 Scale Model Wind Tunnel Tests of Typical Aero Options

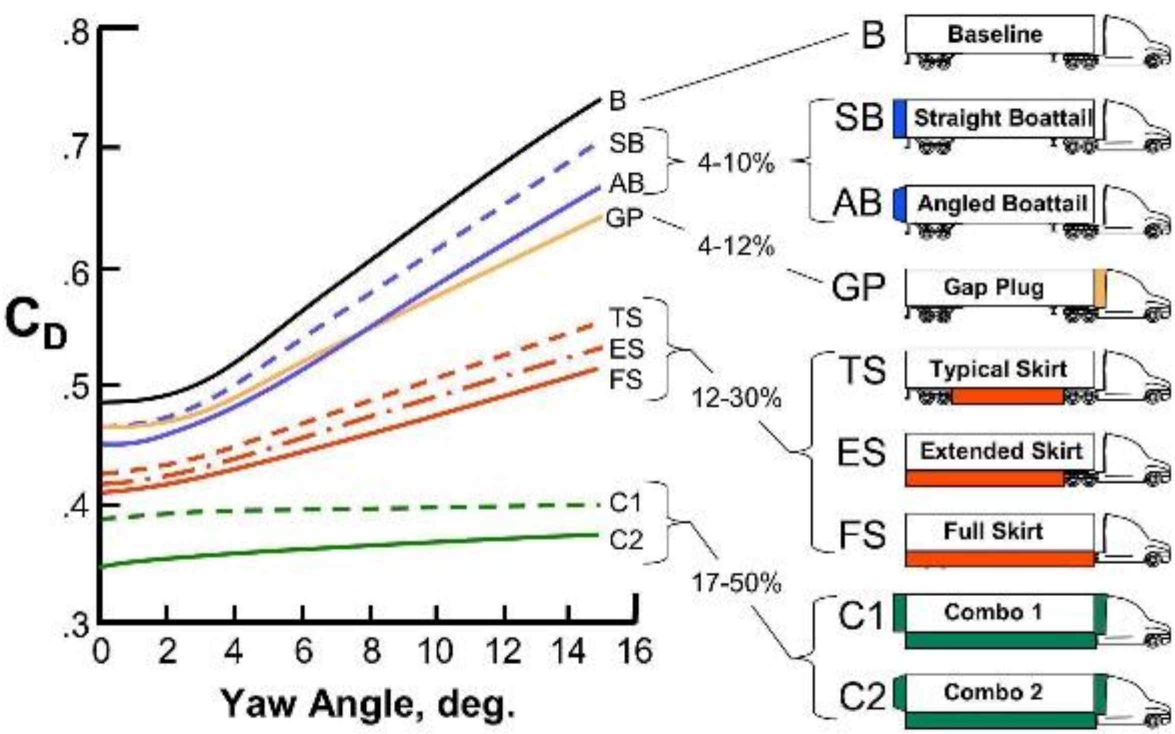


Figure 73 Best Aero Performance Comes From Treating All Three Opportunity Areas

A joint program from 2007 of the DOE National Energy Technology Laboratory and the Truck Manufacturers Association OEMs, entitled “Test, Evaluation, and Demonstration of Practical Devices/Systems to Reduce Aerodynamic Drag of Tractor/Semitrailer Combination Unit Trucks,” has a number of similar examples to that shown in Figure 73, generated via wind tunnel tests, CFD, track, and on-road testing. One example set of data from that report for wind-tunnel-tested combinations of aerodynamic devices is shown in Figure 74. This graph also highlights, as the overall report itself concludes, “The total drag reduction as a result of device combination was not always equal to the sum of an individual device’s drag contribution.”

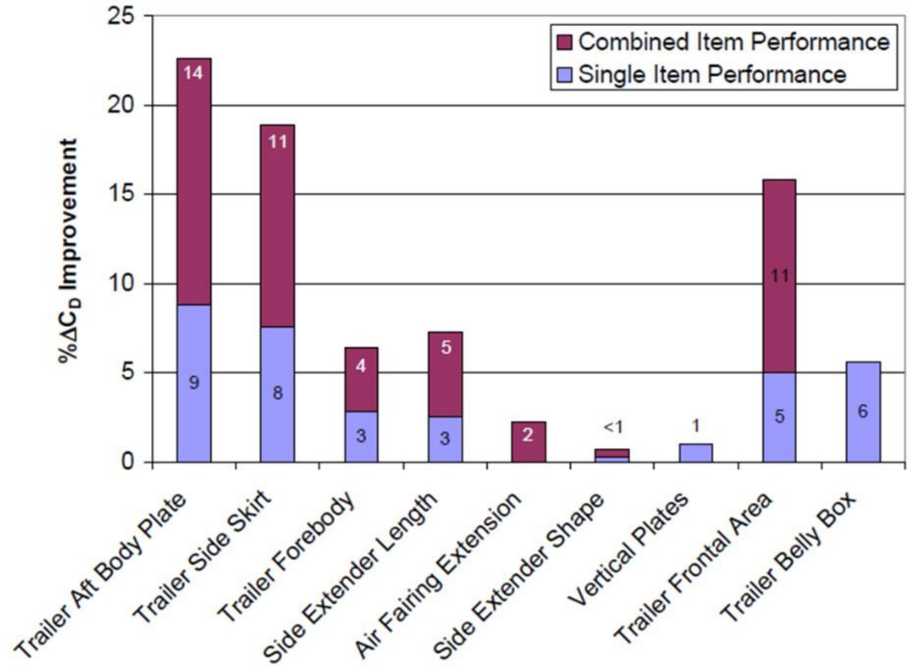


Figure 74 Total Aerodynamic Improvement May Be Greater Than Sum Of Parts

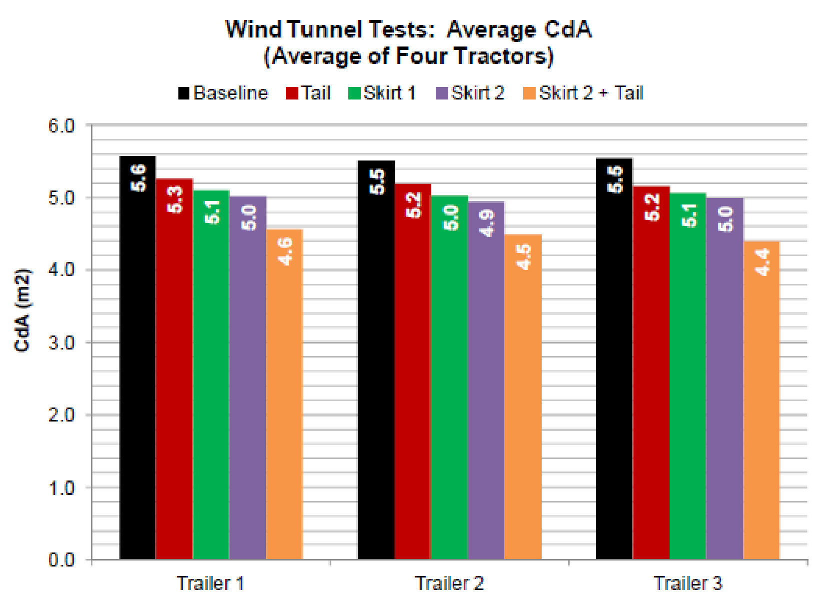


Figure 2-18 Variation in Performance of Trailer Devices due to Trailer Manufacturer

Figure 75 Recent Multiple Trailer Aero Device Testing for EPA

More recent work by EPA and NHTSA published in their 2015 GHG Phase II Regulatory Impact Analysis (RIA) , Figure 75, shows again that combining devices, in this case using both an underbody fairing skirt and a rear fairing tail, tends to reduce overall drag in a synergistic way and in this case found greater savings than the sum of the individual savings of each device alone.

But the EPA/NHTSA GHG Phase II RIA also documented that values varied “depending on tractor type, device manufacturer and test method.” This is shown in Figure 76, a graph published in the 2015 GHG Phase II RIA. The variation in results due to variables like tractor type, test method, and manufacturer is expected and the reasons for this variation is discussed in detail in the Determining Efficiency Confidence Report at www.TruckingEfficiency.org. Likewise, the rules recognize that “It is important to note that the cruise speed results presented in SmartWay do not necessarily represent performance that would be observed in real world operation.”

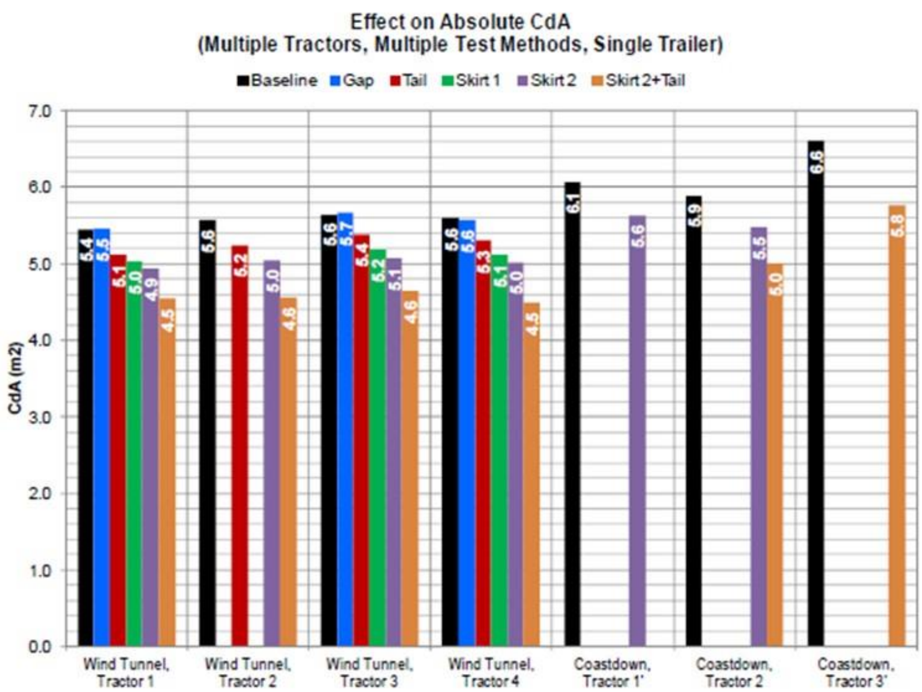


Figure 2-19 Variation in Aerodynamic Performance of Trailer Devices due to Tractor Manufacturer and Test Method

Figure 76 Tractor Choice Can Alter Results

The EPA and NHTSA explained that relative aerodynamic performance improvement deltas were less variable than absolute values from these tests, noting "the fact that an absolute test would require a specific standard tractor for testing to ensure an apples-to-apples comparison of all trailer test results and a delta CdA approach makes it possible to allow device manufacturers to perform tests on their devices and have them pre-approved for any trailer manufacturer to apply on their trailers." Recall from prior discussion on the challenges of adoption – no national reference tractor/trailer exists.

EPA has simplified combining listed devices and allowing end users to simply add categorized ratings to achieve differing SmartWay levels. The SmartWay rules are thus a mix of science and bureaucracy to achieve a manageable process.

7. EPA SmartWay

The establishment of an official national categorization system for aerodynamic device configurations is a significant accomplishment of the EPA SmartWay program. While accuracy and precision are likely to continue to be debated and improved on, the SmartWay program provides a common mechanism for cataloging performance of commercial aero device configurations. Having a standardized evaluation system is the start of any improvement process. The EPA SmartWay system promotes further substantive discussions on improving both the devices and subjecting the measurement tolerances and methodologies to greater scrutiny. The SmartWay system also subjects itself to the relentless forces of continuous improvement.

Where in the 1980s fleets could experiment with a single change, like adding a roof fairing, now nearly every model year has a multitude of changes affecting fuel economy. Deconstructing a truck's performance gains and losses from each new technology has become increasingly more challenging given all these vehicle changes and since many diverse systems are concurrently changing.

Measurements of fuel economy capture the overall performance of the truck, and will be the net result of all the changes to the vehicle. The performance of individual systems can and does interact with the performance of other systems. For example, reducing the aerodynamic drag on a tractor/trailer rig reduces the load on the engine, which in turn reduces the demands on the cooling systems and thus reducing accessory loads for fan engagement. On the other hand, vehicles with more aerodynamic devices installed may be demanding more from their braking systems, as such vehicles will have less drag to help slow a truck, and will accelerate faster on downhill grades, both requiring more from braking. Trucks with both adaptive cruise control systems and substantial aerodynamic devices installed will require less fuel to maintain speeds but possibly also more brake use to avoid excessive speeds or to maintain separation distances with other vehicles.

7.1. Evolution of SmartWay Designations

Estimating specific performance gains for each and every vehicle in every operational environment is extremely difficult, likely impossible. The EPA SmartWay program originally settled on estimating performance of packages of devices in what constitutes, for all practical purposes, a good, better, best ranking system that bases its test and analysis on one specific highway cruise speed steady state condition, effectively 60 mph operation on a dry track at least 1.5 miles in circumference, in temperatures between 41°F and 95°F, with average cross winds below 12 mph, gusts below 15 mph, and a 53' dry van trailer and payload at 46,000 lbs. This track testing method means testing was without traffic, and that roadside infrastructure and vegetation was unique to the test facilities. To demonstrate that a tractor met SmartWay's original fuel efficiency requirement, it had to be tested using the Joint TMC/SAE J1321 Fuel Consumption Test Procedure Type II RP J1321, as modified by the EPA. Even though the EPA documentation and their published statements stated that testing was to follow J1321, they accepted data that did not meet J1321 criteria; this failure may have resulted in low-performing technology being SmartWay verified.

The OEMs initially identified a limited number of specific best-performing aerodynamic tractor models to constitute those offered as SmartWay tractors when that designation system was launch. These included the International Prostar, Mack Pinnacle, Freightliner Columbia, Volvo VN 780, Peterbilt 387 and the Kenworth T2000. Any new models designed after that point had to be EPA-approved by meeting or exceeding the fuel efficiency performance of at least one current SmartWay-certified sleeper-cab tractor model, of any make from any manufacturer. In sum, the initial SmartWay designation system offered a simple, binary, "this is better than that" definition for the public, by identifying performance as either being SmartWay designated or not.

For example, the SmartWays aerodynamic designation system, recognizing the complexity of estimating solely the aerodynamic performance of a vehicle, defines aerodynamic vehicles in terms of their physical attributes, seen in Figure 77, rather than by specific performance gains. Under SmartWay definition, an aerodynamic vehicle has a roof fairing, rounded crown & grille, sloping hood, aerodynamic bumper, aerodynamic mirrors, tractor and trailer skirts, cab extenders, trailer gap reducers and trailer boat tails. The SmartWay designation also includes non-aerodynamic requirements, such as Model Year 2007 or later engines, low rolling resistance tires and idle reduction technologies.

Figure 77 SmartWay Program Establishes National Aerodynamic Benchmarking System

The challenge with both this attribute-based definition and the use of a single testing protocol is that each fleets results will differ some around those findings, based on a host of factors. For example, tractor/trailer highway speed limits in California are limited to a maximum of 55mph, whereas in Texas it can be 75mph and even as high as 80mph. Data compiled by the Insurance Institute for Highway Safety shows a wide range of posted highway speeds in Figure 78. There is also much variability in secondary roads.

	Max Truck Speed Limits						
	55	60	65	70	75	80	85
Number of States	2	1	9	22	10	4	1

Figure 78 Variation n Posted Truck Highway Speed Limits

Regional ambient conditions vary considerably between, say, Gulf Coast states and the northern Rocky Mountain States; harsh winter conditions have significant effects on vehicle fuel economy performance. The interaction of traffic also has a significant effect on the performance of aerodynamic technologies, both because it will determine average route speeds and because air flow from the other vehicles directly impacts the performance of a truck. A vehicle may be in traffic 50% or more of the time – the controlled testing does not account for these and many other variables, because in order to get consistent, repeatable results in controlled tests, real world variables must be minimized. The more reality added to the testing conditions, the greater the inconsistency in results.

Feedback from fleets contacted by NACFE showed that actual performance gains from SmartWay configured vehicles could be as little as 1/2 to 1/3rd of EPA's SmartWay published estimates. But they were still mpg gains, and the initial SmartWay configuration designation has largely been substantiated as an improvement over non-SmartWay vehicles. In the years since launching the designation, EPA clarified that approved vehicles were SmartWay Designated, and discouraged use of the term "certified".

However, though recent years have seen advances in standardized, controlled test approaches, work remains to be done to help fleets to bridge the knowledge gap between tests and in-fleet performance. Many fleets still employ simple rules-of-thumb, and may be dismayed when they adopt a technology that does not perform how they expect. The EPA has also established and maintained an official catagorizing system for aerodynamic devices, and created a EPA SmartWay Technology Package Savings Calculator. The system recognized that meeting the minimum SmartWay requirements could be done with a combination of technology choices, and also recognized that fleets could go well beyond the minimum by adopting all of the technologies. The tool provides a savings estimate for a collection of technology choices and could be used to prioritize whether one configuration was better than another. Beyond that, the estimations are based on the original single operating point testing and therefore remain subject to real world variablity.

Along with recognizing the fact that fleets need more information to extrapolate controlled testing data to their real world operations, the EPA and industry both recognized that performance-based definitions were required to improve SmartWay, and EPA has worked with industry and research groups to develop improved methodology and rules. In parallel with this, the Society of Automotive Engineers initiated multiple Task Forces working on revisions to industry-approved fuel economy and aerodynamics testing standards to improve data quality and precision. The Truck Maintenance Council also worked to improve performance evaluation methods. EPA issued new SmartWay performance based definitions and rules in 2015.

7.2. Current Designations

The EPA, through the SmartWay program, has defined commercial aerodynamic devices and categorized them in terms of performance contributions used on 53' van and refrigerated trailers.

For trailers, the new EPA definitions in 2015 expanded on prior ones, including refrigerated 53' van trailers along with the 53' dry vans originally included. They finalized expanded testing-verification methods to include an enhanced track test, wind tunnel testing, coastdown testing, and computational fluid dynamics (CFD). Trailer aerodynamic devices that demonstrate fuel savings in SmartWay testing are identified as SmartWay-verified and are listed, along with SmartWay-verified low-rolling resistance tires, on EPA's SmartWay website's technology verification page:

- www.epa.gov/smartway/forpartners/technology.htm (See also Appendix A).

The published data now segments aerodynamic devices into performance thresholds approved by EPA from supplier-submitted information to achieve fuel savings of 1%, 4%, 5% and 9% or more in the context of EPA's approval processes. The EPA clarifies though that these fuel economy improvement estimates are ranges, listed below, and not specific numbers, and that they should be taken in the context of the specific test method, reinforcing the variability that can be expected in the real world.

- 1% (1%-3.9% fuel savings)
- 4% (4%-4.9% fuel savings)
- 5% (5%-8.9% fuel savings)
- 9% (9% and higher fuel savings)

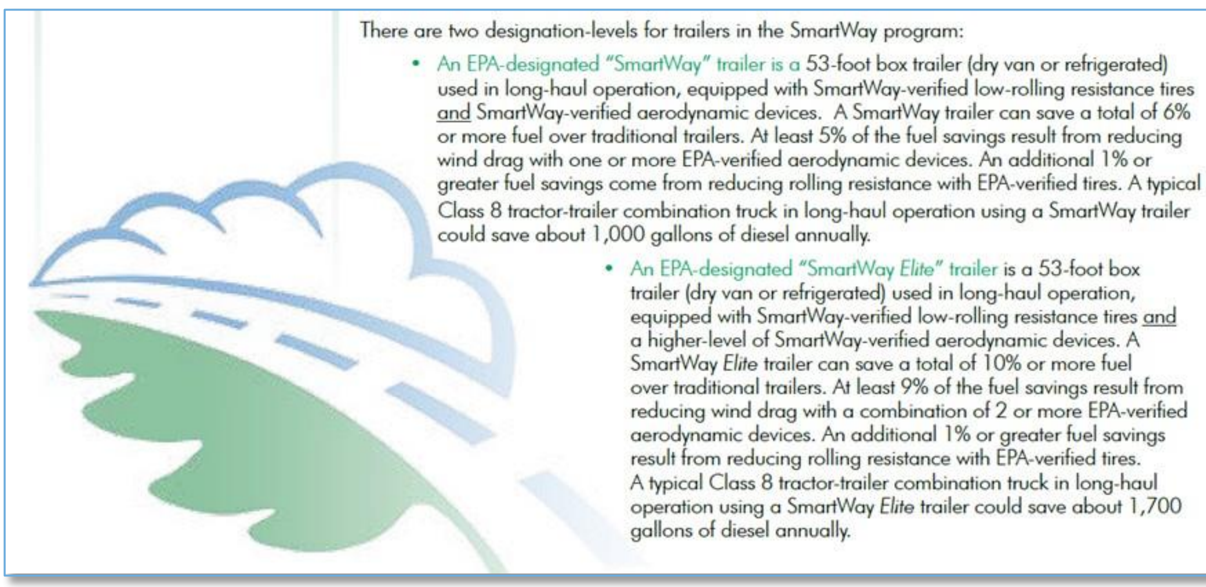
In order to receive SmartWay designation, technology manufacturers must supply the EPA with supporting testing/verification methodology to document their performance as either tested pre-2014 (grandfathered in), post 2014 Wind Tunnel, Coastdown or SAE J1321 Track testing. Note that the post 2014 methods have yet to be fully defined and published and suppliers are working to interim EPA direction.

Specific to trailer aerodynamic devices, the EPA states that:

> "Front fairings and gap reducers provide the smallest benefit of the aerodynamic technologies considered. Skirts and boat tails come in ranges of sizes and vary in effectiveness. For the purpose of this analysis, the agencies grouped these two technologies into "basic" and "advanced". Basic boat tails and skirts achieve SmartWay's verification threshold of four percent at cruise speeds. Advanced tails and skirts achieve SmartWay's five percent verification. These technologies can be used individually, or in combination. The overall performance of a combination of devices could be nearly additive in terms of the effectiveness of its individual devices. Some devices may work synergistically to achieve greater reductions or counteract and provide less reduction."

Two important qualifiers on these EPA comments are needed. First, in some cases, combining different devices could result in worse performance. Also, these EPA SmartWay conclusions are in the context of past national average wind conditions, which might vary as future weather patterns evolve.

Additionally, EPA increased their "complete trailer" (including tires, aero, etc) designations to two, with the minimum EPA-designated "SmartWay" trailer offering 6% or better net fuel savings and a higher-performing "Smart-Way Elite" designation offering 10% or greater fuel savings, described by EPA in Figures 78 and 79.


There are two designation-levels for trailers in the SmartWay program:

- An EPA-designated "SmartWay" trailer is a 53-foot box trailer (dry van or refrigerated) used in long-haul operation, equipped with SmartWay-verified low-rolling resistance tires and SmartWay-verified aerodynamic devices. A SmartWay trailer can save a total of 6% or more fuel over traditional trailers. At least 5% of the fuel savings result from reducing wind drag with one or more EPA-verified aerodynamic devices. An additional 1% or greater fuel savings come from reducing rolling resistance with EPA-verified tires. A typical Class 8 tractor-trailer combination truck in long-haul operation using a SmartWay trailer could save about 1,000 gallons of diesel annually.
- An EPA-designated "SmartWay *Elite*" trailer is a 53-foot box trailer (dry van or refrigerated) used in long-haul operation, equipped with SmartWay-verified low-rolling resistance tires and a higher-level of SmartWay-verified aerodynamic devices. A SmartWay *Elite* trailer can save a total of 10% or more fuel over traditional trailers. At least 9% of the fuel savings result from reducing wind drag with a combination of 2 or more EPA-verified aerodynamic devices. An additional 1% or greater fuel savings result from reducing rolling resistance with EPA-verified tires. A typical Class 8 tractor-trailer combination truck in long-haul operation using a SmartWay *Elite* trailer could save about 1,700 gallons of diesel annually.

Figure 79 SmartWay Trailer & Elite Trailer Definitions

Summary of EPA-designated SmartWay Trailer Configurations

	SmartWay Trailers	**SmartWay *Elite* tTrailers**
Trailer Types	53-foot box trailers (either dry vans or refrigerated trailers) used for long haul operations	53-foot box trailers (either dry vans or refrigerated trailers) used for long haul operations
Aerodynamic Devices	One or more SmartWay-verified aerodynamic devices totaling at least 5% fuel savings	Combination of two or more SmartWay-verified aerodynamic devices totaling at least 9% fuel savings
Low Rolling-resistance Tires	SmartWay-verified low-rolling resistance tires totaling at least 1% fuel savings	SmartWay-verified low-rolling resistance tires totaling at least 1% fuel savings
Total Fuel Savings	**6% or greater**	**10% or greater**
Per Trailer Annual Fuel Savings	Approximately 1,000 gallons of diesel per year	Approximately 1,700 gallons of diesel per year

For more information: www.epa.gov/smartway/forpartners/technology.htm or Tech_Center@epa.gov

Figure 80 SmartWay Trailer Configurations

7.3. SmartWay for Tractors

For tractors, EPA's most recent updates have maintained the original system for designating SmartWay tractors. That system requires a 2007 or later model year engine designated to meet emissions standards. The base aerodynamic tractor must be specified at a minimum with:

- Integrated sleeper cab roof fairing
- Aerodynamic mirrors
- Aerodynamic bumper
- Cab side extenders
- Fuel tank fairings
- Low Rolling Resistance Steer & Drive Tires
- No-Idle Options Capable Of Providing 8 Hours Of Idle Free Power and HVAC.
- Optional but Recommended are Lighter Weight Aluminum Wheels

The EPA tractor SmartWay designation system requires the OEMs to provide test and analysis of new proposed SmartWay tractors that support that the new model is as good or better than an existing SmartWay designated model. EPA maintains a list of the OEM models that have been approved for this designation on the EPA website http://www3.epa.gov/smartway/forpartners/technology.htm#tabs-6

However, the open road sees much more than the subset of OEM models listed by the EPA. And even within these models, it is possible to specify optional changes to design such that a tractor is no longer SmartWay compliant. While California mandates SmartWay tractors for pulling 53' dry van and refrigerated trailers (which must also be SmartWay-designated configurations), in other states SmartWay is voluntary. Even within California's rules, there are a number of exceptions which include container trailers, agricultural trailers like cattle haulers, drayage carriers who stay within designated operating distances, oversize loads, etc. The SmartWay tractor may not offer its advertised benefit when applied to other types of trailers. However even these vehicles experience aerodynamic loads whether on urban or highway travel and so California CARB has done testing on vocational trailers and tractors, and as of October 2015 has submitted requests to EPA through their response to the Proposed Phase II GHG Rule Making to include aerodynamic requirements for these other types.

It should be noted that some of the fleets with these other trailer types have experimented themselves with improving aerodynamics, and in some cases have found promise enough to outfit equipment in the field. Examples of some these are shown in Figure 81, such as where front corners show rounding and streamlining, vertical side structural ribs have been reoriented inboard, rear ends show boattail designs, and skirts have been applied to tank units. The desire to improve operating margins by reducing fuel use has been driving these early adopters, as there are yet no regulations requiring these improvements.

Figure 81 Aerodynamic Improvements To Non-Van Trailers

7.4. EPA SmartWay – Elite-Level Packages of Trailer Aerodynamic Devices

As of December 2015, the following combinations have been designated in the SmartWay list as offering 9% or better fuel savings:

- ATDynamics AeroTrailer™ 1 (with TrailerTail® 4x4)
- ATDynamics AeroTrailer™ 2 (with TrailerTail® Trident)
- Laydon 514 Elite Trailer Fairing Package
- Ridge Corp. RAC0012 Skirt + Green Tail RAC0048
- Ridge Corp. RAC0054 Skirt + Green Tail RAC0048
- Ridge Corp. RAC0054 Skirt + Green Tail RAC0048 + Freight Wing Gap Reducer
- Transtex 2332 Skirt + T30 Tail
- Transtex 1932H Skirt + T30 Tail + Dome Gap Reducer
- Wabash AeroFin XL & Ventix DRS ABC Standard
- Wabash Ventix DRS & Wabash AeroFin

As noted, mixing and matching component technologies can have unpredictable impacts. The performance of the individual devices rarely adds directly, and so the sum of parts rarely equals the total performance of the combination. Fleets adopting a mix of devices from different manufacturers should do so with caution if the mix they are pursuing has not been tested as a set by reputable methods. This EPA Elite list of technology packages is expected to grow, but is largely contained by business forces, as packages are generally created by the suppliers of those devices. Competing companies may not wish to package sets with technologies from other suppliers. Thus the EPA will need to evaluate mechanisms for approving "home grown" fleet trailer aerodynamic device combinations, so that the fleets can be credited as SmartWay Elite level even where no supplier or group of suppliers has offered and tested that same package of technologies. For administrative simplicity the current rules allow fleets to select from listed devices and simply add their performance gains to achieve an Elite configuration if one is not listed. This is for administrative simplicity, as stated, not all combinations actually add in this simple manner and some combinations may actually subtract.

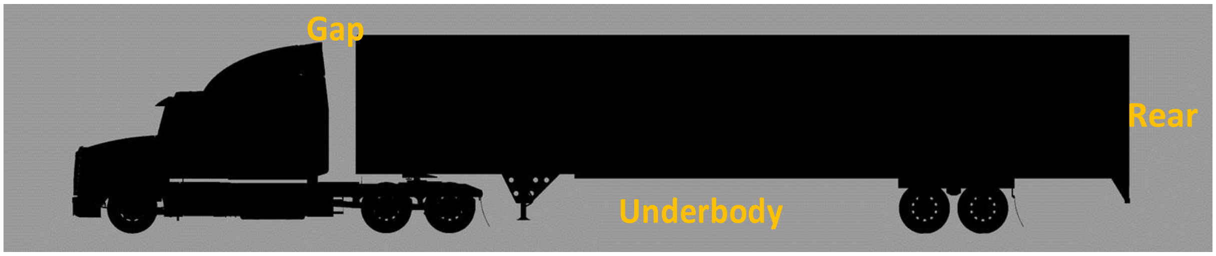
It should be noted that most of the current EPA SmartWay-listed Elite packages have been so designated based on subscale wind tunnel testing. The extrapolation of that wind tunnel data to fuel savings in the real world has yet to be validated.

In December 2015 NACFE conduced one of their signature Trucking Efficiency workshops at the Automotive Research Center (ARC) in Indianapolis for a group of fleets, dealers, suppliers, and industry representatives. As part of the event, ARC conducted wind tunnel tests on a 1:8 scale aero tractor (Figure 82) and dry van trailer vehicle. Starting from a basic configuration, they added trailer skirts, a trailer tail, a trailer front gap device and finally wheel covers. This was all accomplished within one day, and results were shared with the participants of the workshop before the day was over. The exact results cannot be shared here due to agreements with the component suppliers, but this Confidence Report can report that the results were directionally correct with expectations. The tested component combination

Figure 82 ARC Wind Tunnel

represented four different suppliers, so is not be an identified SmartWay combination. The skirts were found to be the most beneficial aerodynamic addition, followed by the rear tail device, the front gap reducing device, and lastly the wheel covers.

7.5. Non-SmartWay Verified Devices



The trailer aerodynamic device industry consistently produces new ideas and repurposes old ones depending on the market sensitivity to fuel economy and other regulatory factors. This inventiveness has been somewhat cyclical since the oil crisis of the 1970s. What is different today is that federal and state regulations are creating categories of approved devices versus all others. This does not mean that new non-SmartWay-verified technologies are unacceptable for use – they may simply be in the process of being tested to be added to lists, or their contributions may be individually too small to be measured by current test methods. Such devices may need to be combined with other systems to create approved sets of devices, and perhaps are just waiting for some group to take on the work of getting them approved. Certainly there will also be some non-SmartWay-verified technologies that have poor performance or otherwise are not worth investing in.

With California, Oregon and other states mandating or looking to mandate the adoption of trailer aerodynamic devices based on SmartWay designations, and with the Federal EPA and NHTSA likewise looking to mandate SmartWay trailer aerodynamic devices as part of Phase II GHG emission reduction regulations, combined with the fact that trailers tend to have long lives of up to25 years, the business question for fleets is whether it is worth investing in a non-SmartWay device for its possible efficiency gain, but risking that it may not be an approved device, or only choosing SmartWay0approved devices and risking that the performance for their specific operations is less than expected.

NACFE's view from interviews with industry leaders is that some form of SmartWay compliance will be expected on new trailers, and existing rules in California are already mandate retrofitting of compliant devices to older trailers, so fleets should focus their technology choices on SmartWay approved systems. This insight should, in turn, incentivize manufacturers of non-approved devices to pursue SmartWay designation. Barring that, there is the opportunity for fleets to package their own combinations of devices and pursue SmartWay designation for them on their own or through third-party groups. Many of the trailer manufacturers already support multiple trailer aerodynamic device options at their customer's behest, sometimes offering devices that compete with their own in-house designs. These vested parties may also be potential advocates for new SmartWay designations of non-approved sets of devices as fleets' requests.

8. Fleet & Operator Comments on Trailer Aerodynamic Devices

NACFE surveyed fleets on their experiences with Tractor and Trailer Aerodynamic Devices for its two Confidence Reports on Aerodynamics. Even with fuel prices at unpredictable lows this year, NACFE found that fleets are continuing to invest in aerodynamic devices for their trailers.

The large fleets ultimately each do their own testing before investing in large orders, because the reported testing by vendors and other agencies are conducted under controlled "perfect conditions" not representative of real world. Fleets do see benefits in the controlled tests, as they let them compare devices for relative performance, but they discount the findings by as much as 50%. One fleet stated that "if the EPA estimate is 6% then the actual real world numbers would be 3%," another stated "easily 50% less" in real world.

One of the fleets interviewed has migrated from robust undertrays that are low maintenance, (described as hard to damage "anvils" where the goal was primarily to be compliant with California trailer rules), to now spec'ing the best-performing skirt packages as determined by their own rigid evaluations including CFD analysis, wind tunnel tests and their own version of SAE J3015 Type II on-road testing on representative routes.

No matter the testing methods chosen, the overall perception of the savings offered by trailer aerodynamics is positive; as one fleet shared, they are "really effective devices now." This can even be seen in driver behavior in the trailer yard: when contract drivers are picking up trailers, one commented that "they always grab a skirted trailer" when given the choice.

Fleets contacted stated that aero device construction, designs, and materials had all vastly improved in the past 5 to 7 years, mainly to become both lighter and more robust. The fleets NACFE contacted stated that they expect aerodynamic device purchases to last for the life of the trailer, which varies based on each company's trade-in polices, but can be seven to more than ten years. Some fleets felt that drivers have also become more accustomed to having aerodynamic devices, and when combined with fuel economy incentive programs, actually really appreciate having them.

But fleets also pointed out that the conditions that can cause damage have not changed, many of the docks and aprons are of older configurations that are more challenging on devices, and visibility on tail devices is a consistent challenge.

Fleets were uniform in stating that drivers need devices that "require no driver interaction," as in their experience, if the driver has to do something, then it will not work 100% of the time. One fleet declared that "Any statement that starts with '*All the driver has to do is ..…..*' should be questioned" Fleets were particularly critical of tail devices that required driver interaction to open or close, stating that it was common to see such devices not deployed on highway, or easily suffering damage in truck stop parking lots. One fleet stated that "tails are amazingly strong" and can cause damage to light poles and garage doors. It is clear that tails need to be passive devices that deploy and stow automatically with no driver involvement. One fleet, when asked what could industry do better stated, "trailer tails will be much more important in EPA GHG Phase II – they need to be better designed, lighter, more effective and automated."

Fleets with driver fuel economy tracking and incentive programs were generally more positive about low aerodynamic device maintenance costs – drivers were more likely to care for the aerodynamic devices if they saw their benefit in accessing fuel efficiency incentives but methods for fuel economy tracking varies across the industry. Some fleets use ECM data and others use pumped fuel vs. miles driven, still another used “dispatched miles.” Fleets stated that ECM data is good for driver training and feedback, but care must be taken as ECM data can vary in its precision. One fleet stated “ECM data is not necessarily correct. There are errors when comparing across the board,” so they use fuel pumped and miles driven as the official data for mpg calculations.

Anecdotal feedback from drivers suggests that aerodynamic-equipped trailers are generally less taxing, and maintain their lane with less frequent steering correction by the driver. Several drivers contacted by NACFE confirmed that aerodynamic-equipped trailers were more stable in most situations, and one fleet volunteered “some of their drivers prefer the stability of the trailers with aero devices.”

Another contributor to driver fatigue is ambient noise level; anecdotal feedback is that the more aerodynamic tractors tend to have lower interior noise levels. Driver fatigue with respect to aerodynamics is a future opportunity for more definitive study by TMC, SAE and other industry affiliated research groups.

Regarding the impact of trailer aerodynamics on resale values, feedback from one major trailer manufacturer was that currently the addition of such devices is “not a factor” with respect to whether resale values of trailers see any premium or loss associated with installed aerodynamic devices.

Regarding the weight of devices versus the fuel economy gains from aerodynamics, one fleet stated that when they started using them in 2009-2010, skirts weighed 250 lbs. per set and are now just 130 lbs. per set, will simultaneously have become better designed to be more robust. In that fleet’s view, the “aero benefit clearly outweighs weight increase”.

Across the board, interviewed fleets have been investing in trailer skirts as their first choice for aerodynamic improvements. But now having done that, they are now looking at next steps, and are debating the merits of tails versus other options, even perhaps some on the tractors. Fleets are sensitive that trailer investments depend on trailer mileage. One fleet estimated that their average on-highway annual trailer mileage was 24,000 miles while their tractors would see 125,000 to 135,000 miles per year. For most fleets, trailer investments can have much longer payback periods, leading one fleet to measure trailer payback not in terms of time but in terms of miles, using the expression “miles to payback” as a better metric.

Fleets are sensitive to managing the trailer gaps, and some have moved to fix fifth wheels to standardize trailer gaps. Fleets told NACFE that the gap treatments on the front of trailers pulled by newer sleeper tractors with minimal gaps do not pay for themselves. But where a larger gap is needed for maneuverability with many daycabs or due to axle loading needs, these devices are more commonly used.

Finally, fleet fuel economy data mining is an area that can be challenging, particularly with respect to trailer devices. The nature of trailer use generally prohibits controlled testing over long periods on dedicated routes. As one fleet stated, occasionally they can find a dedicated point A to point B then back to point A shipping lane, but more often they see “A-to-B-to-C-to-D-to-Z” trailer routing, which precludes collecting uniform data.

9. Perspectives for Future Systems

One thing that became very clear to the study team in the course of compiling this Confidence Report is that trailer aerodynamic technologies and strategies are constantly and rapidly evolving. The options discussed previously are all currently available on the market today, and most are mature with a good track record of functionality, though they may be more or less economical depending on the specifics of a fleet's operations. The following sections captures some likely future developments in technologies for improving freight efficiency through trailer aerodynamics?

Active Flow Control Systems

The current trailer aerodynamic device market is dominated by add-on fairings. These tend to be passive, robust devices that alter the trailer shape to reduce drag. As these devices saturate the market, the next phase of aerodynamic refinement will include active systems which can adapt and respond to conditions to better optimize performance. For example, fairings may reposition themselves automatically, based on the local ambient wind conditions, vehicle speeds and/or traffic. More sophisticated solutions might inject or remove air to manipulate flow for better performance.

On-Board Aerodynamic Sensing

Obtaining accurate current conditions for a vehicle has been primarily limited to simple factors like ambient temperature. Advances in on-board vehicle anemometry (actual relative wind speeds and angles), fuel use, and load-sensing technologies will open up new opportunities to optimize vehicle operations based on real-time aerodynamic factors. Current work on precise fuel flow meters and laser based anemometry for limited track testing will evolve into marketable options for use in daily operations. The ability for the tractor/trailer to be more self-aware is fundamental to this and other future improvements.

Aero Adaptive Cruise Control and Routing Systems

Cruise controls are becoming more sophisticated, with the ability to maintain set distances to other vehicles using a variety of sensing technologies and real time data. These systems will eventually mature to include aerodynamic factors to optimize fuel efficiency. Enabling this will be innovations in on-board vehicle aerodynamic instrumentation as well as cloud-based real-time local environment and traffic data combined with route planning and terrain mapping. For example, a hauler may choose an alternate route and set speed from Dallas to Chicago based on a better fuel economy projected from cross wind conditions, vehicle aerodynamics, terrain, traffic and desired time of travel, rather than just the information available today about traffic or roadwork.

Automation Systems

Vehicle automation is a growing automotive technology set that will migrate into trucking. Tractor OEMs have already displayed working prototypes that minimize or eliminate human driver control. These current systems include efforts to optimize for fuel efficiency. They generally do not yet address including aerodynamic factors. Simplistic platooning concepts improve aerodynamics by maintaining two vehicles at a prescribed separation distance, but as yet, do not optimize that distance based on aerodynamic inputs. Predictive cruise control systems adapt vehicle speeds to terrain to optimize fuel economy, but struggle with adapting to surrounding traffic and do not yet adapt to ambient weather conditions. Future innovations will incorporate these real-world situations and prioritize vehicle operation possibly similar to how some cars can have multiple suspension settings or performance settings depending on driver selection.

Trailer Geometry Morphing

Kneel-down suspension systems have an ability to alter the critical cross sectional area seen by the wind to reduce drag. Other technologies can morph the shape of the trailer roof or side to achieve performance gains. An example would be a system that lowers the rear of the trailer roof when at speed, taking advantage of trailer space not typically filled with freight, but still ensure the trailer is accessible to allow forklift access when docked.

Trailer/Tractor Ratio Reduction

Advancements in routing and load management software systems could decrease the number of trailers required for sustainable operations, which would improve net freight efficiency per active trailer, as each would be on-road a greater percentage of time. A company with a 4:1 trailer to tractor ratio means each trailer only sees ¼ of the annual mileage, hence only ¼ of the possible aerodynamic efficiency gain from any investment in new technologies. But the core issues of the tractor/trailer ratio is more complex than just supply and demand for freight hauling. Trailers are also used as temporary warehousing in many operations creating WIP inventory and artificial factory floor space that may not be tracked as such. Businesses need to evaluate their entire supply chain systems to spot opportunities to improve freight efficiency. Innovations in business data mining and analysis tools can result in fuel savings thanks to aerodynamics.

Dedicated Truck Highways and Lanes

The interaction of automobiles and trucks results in greater usage of braking systems and accelerations/decelerations, which reduce fuel efficiency. Several efforts are studying the use of dedicated truck highways or lanes. These concepts can improve aerodynamics by establishing more uniform operations and reducing acceleration/deceleration events.

Hybrid Electric Vehicles

Conventional cab-behind-engine-tractors designs conform to practical needs that put the cooling modules, fans, engine and transmission in one line. This likewise dictates the position of the driver and cab. Electric motors could greatly change this paradigm, allowing for a significant reshaping of the tractor and opening up opportunities for revised trailer designs. An example of what may be possible can be found in the Peterbilt/Walmart concept and the Volvo concept shown in Figure 83.

Figure 83 Electrics Offer Shape Change Possibilities (Peterbilt/Walmart/Volvo)

Combining Technologies

Taking the automation of vehicles forward to one conclusion, the future may see the driver operating a drone terminal similar to the driving simulators currently in use shown in Figure 84. This may allow the tractor and trailer to be completely redesigned. An example of such a tractor can be found in current port container carriers that operate robotically or remotely, as shown with the Toyota AGV unit in Figure 85.

Figure 84 Driving Simulator Could Be Drone Controller (TranSim)

Figure 85 Container Handler (Toyota)

Concepts that combine automation technology, hybrid electric technology, aerodynamic feedback systems, and dedicated highway lanes could make possible significant trailer redesign as the Renault example shows in Figure 85. Taking it further, road trains are possible with independent units connecting and disconnecting in transit as conceived in this Volvo slipstream concept in Figure 87.

Figure 86 Possible 70 Foot Aero Trailer with Drone? (Renault)

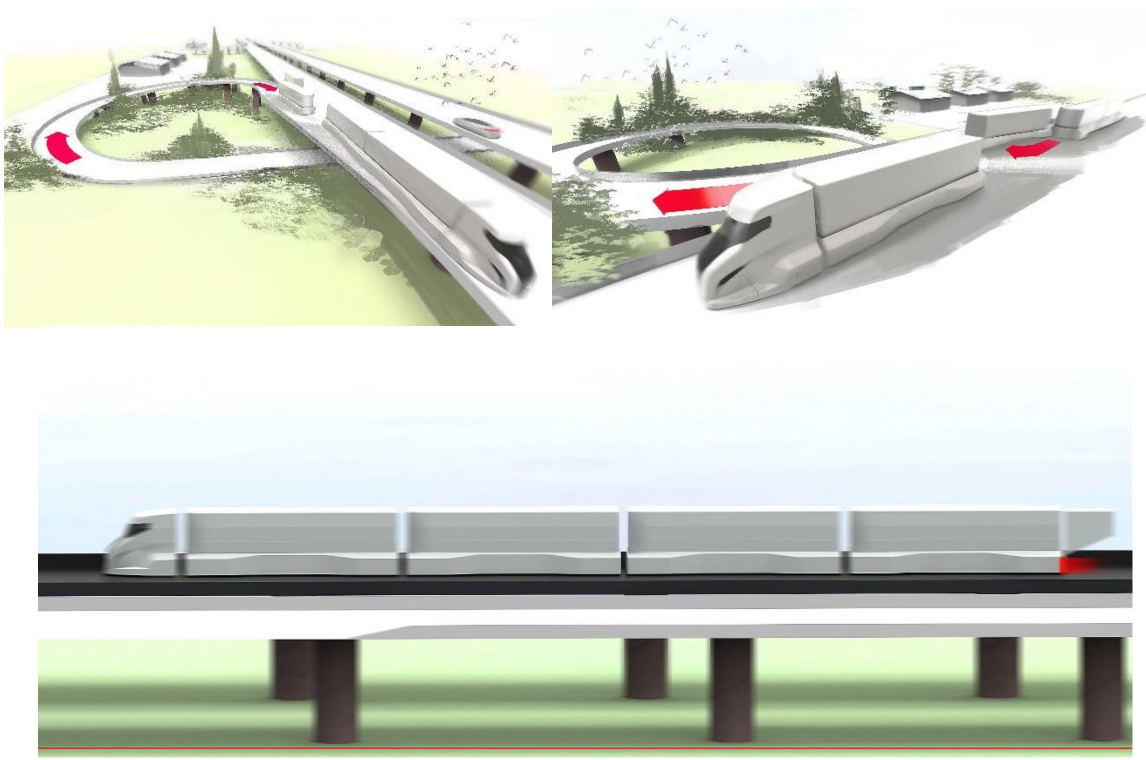


Figure 87 Volvo Slipstream Road Train

9.1. Near-term: Platooning, Long Combination Vehicles, and Longer Trailers

A report on how to improve trailer fuel efficiency would be incomplete without a discussion of alternatives to the ubiquitous 53' dry van trailer. Technology is rapidly improving the ability of vehicles to analyze and adapt to surrounding traffic conditions. Devices like adaptive cruise control, collision avoidance systems, automatic braking systems, GPS-based predictive cruise control, automatic routing, platooning and proposed autonomous vehicle technologies all can improve safe vehicle operations while offering other benefits to a fleet's bottom line.

Improving the ratio of tractors to freight hauled will eventually require allowing growth in use of longer combination vehicles. While the addition of a second 53' trailer to a vehicle increases its drag versus a single trailer unit, the net freight efficiency is dramatically improved by doubling the freight carried and halving the number of required tractors and tractor mileage. These advances will need to be tied to changes in highway policies on size and weight. They will need to mitigate public safety concerns through innovations inherent in the automation technology development.

Due to such concerns, the one area that government, industry, and public groups have made little progress on since the STAA Act in 1982 is making any significant increase in the amount of freight carried per tractor. Where the other freight hauling industries including ships, airplanes, and trains, have all dramatically increased freight per crew and freight per motive unit, U.S. trucking has made no significant progress.

What are the differences between an operation with two tractors each pulling one 53' van trailer, or an operation with one tractor pulling two 53' van trailers in a Long Combination Vehicle (LCV) configuration? A recent SAE paper, 2015-01-2897, Aerodynamic Comparison of Tractor-Trailer Platooning and A-Train Configuration, highlights that for a wide range of key comparison factors, the double has significant advantages over two singles as outlined in Figure 87, including for safety. John Woodrooffe of the University of Michigan Transportation Research Institute and others have presented data showing that accident rates are based on number of driven miles and number of vehicles. Both these factors are halved by use of a double trailer versus two singles, with corresponding decreases in accident rates. Canadian, Oregon and Idaho operations with LCVs have documented that accident rates for LCVs are not significantly different than those of singles, so reducing the number of miles driven by half and the number of vehicles being driven by half has a direct reduction on accident rates. These same reports on actual LCV operations in Canada, Oregon, and Idaho have shown no significant difference in infrastructure maintenance costs while documenting significant reductions in cost of operations, fuel used, and corresponding reductions in emissions.

The discussions on LCVs has proponents and detractors, but there is little argument that significant fuel economy gains and freight efficiency gains are possible with LCVs. Rather than discussing, for example, the benefits of saving 200 pounds by switching from Steel to Aluminum on a part, or of gaining 5% on fuel economy by adding aerodynamics to a trailer, the discussion in the future could be around the benefits of adding 30,000 pounds of freight to the same tractor.

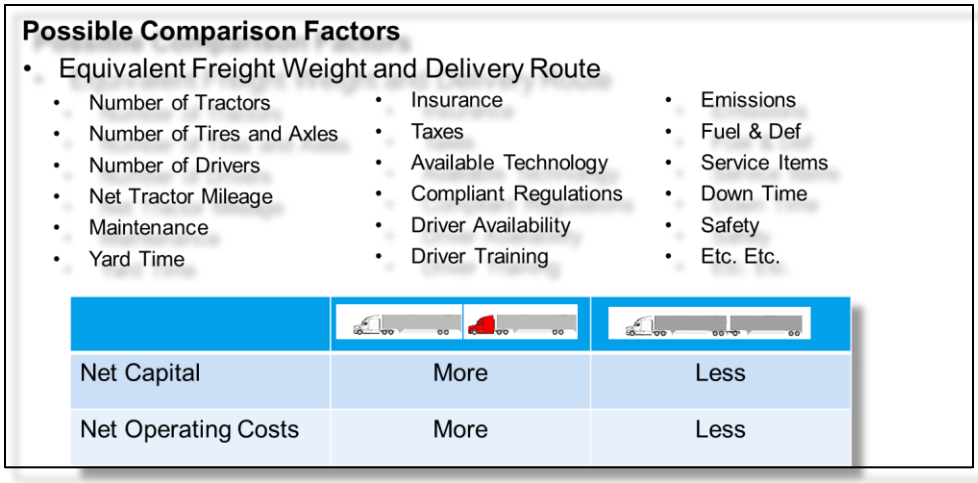


Figure 88 Comparison Factors (Mihelic)

10. Estimating Payback

It is critical to evaluate the total cost of ownership of adopting a particular technology. Most fleets estimate the payback using various financial models. A simple payback calculator is included with this Confidence Report publication package and can be downloaded as a spreadsheet at http://truckingefficiency.org/trailer-aerodynamics. This tool can be used to understand the payback on an investment in any aerodynamic or combination of aerodynamic devices. The study team suggests monetizing all benefits and consequences of adoption in order to be as comprehensive with this financial impact of adoption.

A screenshot of the output of the Calculator is provided on the next page.

As stated earlier, it is important to estimate the fuel efficiency performance that a fleet believes it will experience given their specific duty cycle of speed, routes, etc. The Technology and Maintenance Council is developing and excellent tool to help with this challenge of determining the payback of trailer aerodynamic devices, specifically using time at various speeds for a fleet's duty cycle to predict the payback of such devices. The tool is being developed under TMC RP1118 Fuel Savings Calculator for Aerodynamic Devices, with an expected publish date of later in 2016.

NACFE Study Payback Calculator: Trailer Aerodynamics Devices

Yellow boxes are for user inputs

Device(s) Name				**Notes:**
Number of Tractors	1	1	1	Can be used per tractor or for all in the fleet
Number of Trailers	3	5	3	
Miles per year per tractor	100,000	100,000	100,000	
Miles per year per trailer	33,333	20,000	33,333	
Benefits				
Fuel Economy				
Current fuel economy	6.0	6.0	6.0	
Gallons consumed per mile per trailer	5,556	3,333	5,556	
Fuel mpg improvement for device(s)	3%	3%	3%	
Gallons fuel saved per trailer with device	$ 166.67	$ 100.00	$ 166.67	
Cost of fuel per gallon over time	$ 3.00	$ 3.00	$ 4.00	
Fuel dollars saved per year per trailer	$ 500.00	$ 300.00	$ 666.67	
Other specific benefits	$ -	$ -	$ -	Includes any other benefits. E.g. Operating equipment in California, etc.
Total benefits per trailer	**$ 500.00**	**$ 300.00**	**$ 666.67**	
Costs				
Upfront Costs				
Cost of Aero Device(s)	$ 700.00	$ 700.00	$ 700.00	
Installation Labor (when not factory installed)	$ 50.00	$ 50.00	$ 50.00	
Total Installed Cost	**$ 750.00**	**$ 750.00**	**$ 750.00**	
Annual Costs				
Mainenance costs with device	$ 25.00	$ 25.00	$ 25.00	
Other specific costs				Includes any other costs E.g. Driver retention or attraction issues
Total annual costs per trailer	**$ 25.00**	**$ 25.00**	**$ 25.00**	
Payback in months	**18.9**	**32.7**	**14.0**	
Payback in trailer miles	**52,632**	**54,545**	**38,961**	

Dated: February 26, 2016
Notes:

11. Summary, Conclusions Recommendations and Prioritizing Actions

11.1. Summary

Extensive insights into fleet decision making on trailer technologies were recently assembled in another report, a fleet survey by Ben Sharpe of ICCT and Mike Roeth of NACFE in the February 2014 ICCT/NACFE white paper "Costs and Adoption Rates of Fuel-Saving Technologies for Trailers in the North American On-Road Freight Sector". That report provided a table (Figure 89) summarizing cost and adoption rates.

Table 6: Summary of interview responses on trailer technology costs and level of adoption

Technology	Fuel Savings	Cost to End User		Typical Payback Time	Adoption in New Trailer Sales
		High	Low		
Side skirts – average	3%	$1,100	$700	1-2 years	40%
Side skirts – best	7%			< 1 year	
Boat tails – average	3%	$1,600	$1,000	2-3 years	3%
Boat tails – best	5%			1-2 years	
Gap reducers	1%-2%	$1,000	$700	2-5 years	Minimal
Underbody devices	2%-5%	$2,200	$1,500	2-5 years	3%
Low rolling resistance dual-sized tires	1%-3%	Data on costs and payback time inconclusive			50%
Wide base single tires	2%-4%	Data on costs and payback time inconclusive			10%
Tire pressure monitoring systems	1%	$1,000	$750	1-2 years	10%
Automatic tire inflation systems	1%	$1,000	$700	1-2 years	30%

Figure 89 Cost & Adoption Rates (ICCT/NACFE)

The ICCT white paper also presented these key findings with respect to trailer aerodynamic devices:

- The cost of trailer side skirts have decreased substantially over the past 3-5 years. Current costs for trailer aerodynamic technologies – particularly side skirts – have decreased significantly in recent years, due to far more market entrants driving cost competition and much higher deployment volumes reducing cost per unit. From the interview responses, it is estimated that costs for side skirts have dropped roughly 70% compared to cost estimates that were compiled as part of the 2010 National Academy of Sciences study that investigated fuel efficiency technologies for commercial vehicles. A consensus position from the interviewees was that California's tractor-trailer GHG regulation has been the primary driver for the rapid uptake and cost reductions of technologies but that an increasing number of fleets are adopting these aerodynamic devices because of attractive economics as well as improvements in the reliability and durability of products.
- Among aerodynamic technologies, side skirts have had the largest rate of adoption, while the uptake of underbody, rear-end, and gap reduction devices has been more limited. Interview responses and sales data show that side skirts are the dominant trailer aerodynamic technology, with boat tails and underbody devices making up a much smaller percentage of the market. The study team estimates that approximately 40% of new box trailers are sold with side skirts. Uptake of both underbody and rear-end devices is estimated to be roughly 3% of new box trailer sales, while sales of gap reducers have been fairly negligible and primarily limited to fleets that pair their trailers with day cabs.
- Roughly one-quarter of all trailers on the road in the U.S. have at least one aerodynamic technology (e.g., side skirts, underbody device, or boat tail). Feedback from trailer and component manufacturers gives evidence of a robust market for aerodynamic technologies for both new and used trailers. The responses from these industry experts suggest that about one-quarter of all trailers operating in the U.S. have at least one aerodynamic enhancement.

11.2. Study Conclusions

This report focuses primarily on sleeper tractors pulling van trailers on-highway in North America. It describes both individual and combinations of technologies and practices available to fleets in pursuit of fuel economy improvement, operating cost reduction, and green house gas emissions decrease through the use of trailer aerodynamic devices.

The study team found the following conclusions with respect to fleets, truck and trailer OEMs, manufacturers and others concerning the adoption of trailer aerodynamic devices.

- <u>Trailer aerodynamic devices save fuel.</u> There is significant data, showing fuel savings for the various technologies. The priority for device adoption by fleets is skirts, tails, front and then other devices. Operators look to large fleets and mimic their technology decisions where these fleets have done sufficient testing before making the investments. In other cases, operators look to various research groups, laboratories, and independent evaluators to get aerodynamics guidance. Many other sources exist for aerodynamic device performance data; Device manufacturers, Tractor and Trailer OEM's, EPA SmartWay, Test organizations, Government agencies, NGO's and professional organizations like SAE and TMC. The EPA SmartWay program has made noteworthy progress since its inception in 2004, providing the industry with a structure for cataloging and ranking trailer aerodynamic devices. It should be considered a foundation for further improvement in performance evaluation.

- Devices have matured and will continue to improve. Skirts have become lighter, less expensive and more robust improving their payback. Other devices are maturing but need continued development to improve their total cost of ownership. There is a widespread recognition of the further improvements and efficiency gains that stand to be achieved in trailer aerodynamics and tire technologies. In the interviews conducted for the ICCT report, all of the component suppliers of aerodynamic technologies spoke of their technology development activities and next-generation products that will offer enhanced quality and fuel savings. One of the aerodynamic device manufacturers asserted that its third-generation product, would offer roughly an additional 40% reduction in aerodynamic drag over its second-generation product, and nearly a 100% improvement over its first-generation product. This and other anecdotes provide evidence that important innovations continue to materialize in trailer efficiency technology.
- Unique challengers exist. These include trailer to tractor ratio limiting the miles per trailer, some cases of the trailer aerodynamics purchaser not buying the fuel and lastly, devices should be driver passive: no driver interaction is required to deploy or stow. Solutions to these three challenges may include:
    - Limiting the trailer to tractor ratio, using trailer tracking and other tools will help increase the miles per trailer to improve payback.
    - Creative incentives for tractor owners to share savings of pulling aerodynamic trailers is an example to limit the issue of the split incentive on purchasing devices.
    - Devices that must be manually deployed/stowed have inherent procedural failure points, as drivers may not activate/retract the devices when/as needed. Next steps for suppliers of these systems are therefore to focus on robust and automated deployment and retraction methods.
- Performance for each fleet is difficult to determine. Performance of any device is subject to many variables and each operator will likely have their own experiences. But the standardized test methods are directionally useful in evaluating different devices and combinations of devices. Trailer aerodynamics and freight efficiency improvement have advanced significantly since the 1970s oil crisis first brought them to the industry. A range of products are now readily available that offer proven savings. As these products have matured, so has the industry's understanding of the need for improvements in how fuel efficiency performance is measured and allocated. Advances in test and analysis continue to be made, but the tools available today tend to report performance judged under controlled, focused, operating conditions rather than representing the full range of operations possible in industry. These standardized methods are important and relevant, but end users of the data still need to adapt those results for their own specific operations. The greater a fleet's operations vary from the controlled test conditions, the less beneficial the tests and analyses will be for them to make investment decisions and performance preductions. Although most fleets can measure tractor efficiency very closely, they do not have the tools to monitor the trailer efficiency at all.
- Regulations will drive greater adoption. GHG Phase II and CARB rules will drive much greater adoption of trailer aero devices in the near future, taking them from being add-on options to being standard equipment. The pending Phase II EPA/NHTSA Green House Gas Emissions rules

are likely to significantly influence trailer aerodynamic technology adoption. The present government plan is for these rules to be issued by the end of 2016, with applicability as soon as 2018 or 2019. California's existing CARB rules, which are linked to EPA SmartWay designated technologies, are already influencing some investment decisions. However, the primary motivation for aerodynamic technology investment remains a business one, with tractor trailer fleets demanding a two year or less payback for technologies.

11.3. Recommendations

The study team has the following recommendations for those engaged in adopting or providing aerodynamic devices.

- Both aerodynamic device suppliers and fleet end-users need to have better communication on performance. Fleets should ask more questions to clarify how performance claims will apply to their specific operations, while device suppliers need to provide better clarity on how the testing was completed.
- Manufacturers and trailer integrators should increase development efforts to improve the total cost of ownership/payback of the devices – lower upfront costs, better performance, lighter weight, less maintenance and driver interaction, better reliability and durability, etc. Creating driver passive devices is also critical.
- Research into advanced aerodynamic techonologies should continue, so that these devices can better meet end-users payback expectations.
- Organizations like SAE, TMC, EPA, CARB need to push for improved aerodynamic assessment and correlation to real world, including having official reference vehicles and improved on-board non-obtrusive methods for assessing aerodynamics of test vehicles so accuracy can be determined, not just precision.

11.4. Prioritizing Actions

Fleets make technology investments by prioritizing the best returns on investment; but once that investment is made, the priority list inherently must be shuffled as the best has been removed (implemented). This continuous reevaluation of technology alternatives highlights a critical fact about aerodynamic devices, namely, the fact that the aerodynamic technologies a vehicle already has installed will largely determine the next ones to consider for making trailer performance improvements. Figure 89 outlines Trucking Efficiency's recommendations for how fleets should prioritize investment in a suite of trailer aerodynamic devices, depending on their own starting point.

If you are currently running this trailer configuration:	**This might be your next best step for better trailer aerodynamics:**
Aero tractor with typical dry van trailer	Add trailer skirts
Trailer with side skirts	Add trailer rear boat tail device
Trailer with side skirts and manually deploying rear boat tail	Convert automatically deploying trailer rear boat tail device to increase time in use
Trailer with side skirts and rear boat tail	Add trailer front nose fairing
Trailer side skirts, rear boat tail & nose fairing	Start investigating other minor areas such as wheel covers, license plate position, and vented mud flaps.
Day cab tractor without air fairings or cab extenders	Add trailer nose dome to the upper front portion of the trailer

Figure 90 NACFE Trailer Technology Recommendations

11.5. Confidence Rating

For each of the Confidence Reports completed by Trucking Efficiency, the various technologies assessed therein are plotted on a matrix in terms of the expected payback in years compared to the confidence that the study team has in the available data on that technology – that is, not only how quickly fleets should enjoy payback on their investment but how certain Trucking Efficiency is in the assessment of that payback time. Technologies in the top right of the matrix have a short payback, usually thanks to their low upfront cost, and moreover are found to have high confidence in those short payback times, usually because the technology is more mature or otherwise has a more substantial track record of results.

Trucking Efficiency is highly confident that all fleets should be considering the aerodynamics of their trailers, and the adoption of devices which will improve those aerodynamics, as a major opportunity to save fuel. The best package of devices to adopt will depend on a fleet's unique duty cycle. But overall, available savings are likely quite high, up to 10%, for the majority of fleets running 53' dry box trailers. Moreover, many regulations are likely to manage the adoption of trailer aerodynamic devices in coming years, so fleets which have not even begun to consider this opportunity will be wise to do so in anticipation of mandates.

Figure 91 Confidence Matrix of Trailer Aerodynamic Device Technologies for On-Highway Van Trailer/Tractors

Appendix A – EPA SmartWay Verified Aerodynamic Trailer Devices

(SeeEPA SmartWay official list, http://www3.epa.gov/smartway/forpartners/technology.htm)

Device Name	Device Category	SmartWay Verifications Pre-2014	WindTunnel (2014) (PDF) (2 pp, 657K, EPA-420-F-15-012, July 2015)	Coastdown (2014)	SmartWayTrack Test (2014) (PDF) (2 pp, 662K, EPA-420-F-15-011, July 2015)	CFD (Supplement)	Website
New Elite Category (9% or Better Fuel Savings)							
ATDynamics AeroTrailer™ 1 (with TrailerTail® 4x4)	9% Elite Combination						www.stemco.com
ATDynamics AeroTrailer™ 2 (with TrailerTail® Trident)	9% Elite Combination						www.stemco.com
Laydon 514 Elite Trailer Fairing Package	9% Elite Combination						www.laydoncomp.com
Ridge Corp. RAC0012 Skirt + Green Tail RAC0048	9% Elite Combination						www.ridgecorp.com
Ridge Corp. RAC0054 Skirt + Green Tail RAC0048	9% Elite Combination						www.ridgecorp.com
Ridge Corp. RAC0054 Skirt + Green Tail RAC0048 + Freight Wing Gap Reducer	9% Elite Combination						www.ridgecorp.com
Transtex 2332 Skirt + T30 Tail	9% Elite Combination						www.transtexcomposite.com
Transtex 1932H Skirt + T30 Tail + Dome Gap Reducer	9% Elite Combination						www.transtexcomposite.com
Wabash AeroFin XL & Ventix DRS ABC Standard	9% Elite Combination						www.wabashnational.com
Wabash Ventix DRS & Wabash AeroFin	9% Elite Combination						www.wabashnational.com
5% Fuel Savings or Better							
Aerofficient Fixed side fairing (with landing gear wrap panel) model SFHGW (formerly FFGW)	5% Trailer Under Fairing						aerofficient.com
Aerofficient Fixed side fairing (with landing gear toe in panel) model SFHTI (formerly FFTI)	5% Trailer Under Fairing						aerofficient.com
Aerofficient Fixed side fairing (hinged, straight	5% Trailer Under Fairing						aerofficient.com

angle) Model SFHS							
AeroTech Fleet Products Bracketless Trailer Skirt	5% Trailer Under Fairing						www.aerotechcaps.com
ATDynamics-Transtex Trailer Side Skirts	5% Trailer Under Fairing						www.atlanticgreatdane.com www.transtexcomposite.com
Atlantic Great Dane AeroGuard Side Skirt (AGD400-43)	5% Trailer Under Fairing						www.atlanticgreatdane.com
Brean Marketing, Inc. ArrowShield	5% Trailer Under Fairing						www.breanmarketing.com
Carrier Transicold Aeroflex Fairing	5% Trailer Under Fairing						www.trucktrailer.carrier.com
Composite Building Systems SmartWind Trailer Skirt	5% Trailer Under Fairing						cbsstructures.com
Fleet Engineers Aero Saver Trailer Skirt	5% Trailer Under Fairing						www.fleetengineers.com
FreightWing Aeroflex Trailer Skirt	5% Trailer Under Fairing						www.ridgecorp.com
Hyundai Translead EcoFairing V-1	5% Trailer Under Fairing						translead.com
Hyundai Translead EcoFairing V-2D	5% Trailer Under Fairing						translead.com
Hyundai Translead EcoFairing V-2R	5% Trailer Under Fairing						translead.com
Hyundai Translead EcoFairing V-2I	5% Trailer Under Fairing						translead.com
Kodiak Innovations AeroCurtain (Original and ALG Installation options)	5% Trailer Under Fairing						kodiakinnovations.com
Laydon Composites 8 Panel Skirt	5% Trailer Under Fairing						www.laydoncomp.com
Laydon Composites 7 Panel Skirt	5% Trailer Under Fairing						www.laydoncomp.com
Laydon Composites Curve	5% Trailer Under Fairing						www.laydoncomp.com
Laydon Composites Hybrid 248 (Intermodal)	5% Trailer Under Fairing						www.laydoncomp.com
Laydon Composites Hybrid 259 Skirt	5% Trailer Under Fairing						www.laydoncomp.com
Prime Inc. EcoFeather Trailer Side Skirt	5% Trailer Under Fairing						www.primeinc.com
Ridge Corp. GreenWing RAC0012 - Front Radius	5% Trailer Under Fairing						www.ridgecorp.com
Ridge Corp. GreenWing RAC0031 - Straight Angle	5% Trailer Under Fairing						www.ridgecorp.com
Silver Eagle Aero Saber	5% Trailer Under Fairing						www.silvereaglemfg.com

SOLUS Air Conqueror Performance Split Skirt SSP I (14-0-6)	5% Trailer Under Fairing						www.solusinc.com
SOLUS Air Conqueror Performance Split Skirt SSP II (16-0-6)	5% Trailer Under Fairing						www.solusinc.com
SOLUS Air Conqueror Performance Split Skirt SSP III (18-0-6)	5% Trailer Under Fairing						www.solusinc.com
TrailerBlade Model 715	5% Trailer Under Fairing						www.trailerblade.com
Transfoil Systems Transfoil	5% Trailer Under Fairing						www.transfoil.com
Transtex 1932H Skirt	5% Trailer Under Fairing						www.transtexcomposite.com
Transtex 2330 Skirt	5% Trailer Under Fairing						www.transtexcomposite.com
Transtex 2332H Skirt	5% Trailer Under Fairing						www.transtexcomposite.com
Truckfairings.com Skirt by A&T Clutch Components	5% Trailer Under Fairing						www.atclutches.com
Utility Trailer USS 120A	5% Trailer Under Fairing						www.utilitytrailer.com
Utility Trailer USS 120A-4	5% Trailer Under Fairing						www.utilitytrailer.com
Utility Trailer USS 160	5% Trailer Under Fairing						www.utilitytrailer.com
Wabash Ventix DRS (formerly called AeroSkirt MAX)"	5% Trailer Under Fairing						www.wabashnational.com
Wabash Ventix DRS Standard	5% Trailer Under Fairing						www.wabashnational.com
Wabash DuraPlate AeroSkirt TL273 and Wabash AeroSkirt CX (GRP Material option)	5% Trailer Under Fairing						www.wabashnational.com
Wabash DuraPlate AeroSkirt TL Straight	5% Trailer Under Fairing						www.wabashnational.com
Wabash DuraPlate AeroSkirt TL	5% Trailer Under Fairing						www.wabashnational.com
Windyne Flex-Fairing	5% Trailer Under Fairing						www.windyne.com
ATDynamics TrailerTail rear trailer fairing	5% Trailer Rear Fairing						www.stemco.com
ATDynamics TrailerTail Trident	5% Trailer Rear Fairing						www.stemco.com
ATS Integrated Automated System (WindTamer with	5% Trailer Rear Fairing						www.ats-green.com

SmartTail)							
Avantechs Inc VorBlade Wing (with Crosswinds Mitigator subsystem)	5% Other Trailer Device[a]						www.vorblade.com
Nose Cone Mfg. Co. AeroTrak VG Pro	5% Other Trailer Device[a]						www.nosecone.com
SmartTruck TopKit Trailer Tail System	5% Trailer Rear Fairing						smarttruckaero.com
SmartTruck UT-1	5% Trailer Under Fairing						smarttruckaero.com
SmartTruck UT-6	5% Trailer Under Fairing						smarttruckaero.com
4% Fuel Savings or Better							
Kodiak Innovations AirPlow	4% Trailer Under Fairing						kodiakinnovations.com
Laydon Composites 6 Panel Skirt	4% Trailer Under Fairing						www.laydoncomp.com
Ricconics Radius 3524 Skirt (formerly called TNJ Enterprises Radius Trailer Skirt)	4% Trailer Under Fairing						www.ricconics.com
Ricconics Radius 3523 Skirt	4% Trailer Under Fairing						www.ricconics.com
Ricconics Radius 3520 Skirt	4% Trailer Under Fairing						www.ricconics.com
Silver Eagle Mid-length Skirt (6-panel)	4% Trailer Under Fairing						www.silvereaglemfg.com
Silver Eagle Mini-skirt (5-panel)	4% Trailer Under Fairing						www.silvereaglemfg.com
SOLUS Air Conqueror Split Skirt SSR I (12-0-6)	4% Trailer Under Fairing						www.solusinc.com
SOLUS Air Conqueror Split Skirt SSR II (12-2-6)	4% Trailer Under Fairing						www.solusinc.com
SOLUS Air Conqueror Split Skirt SSA I (12-4-6)	4% Trailer Under Fairing						www.solusinc.com
SOLUS Air Conqueror Split Skirt SSA II (14-2-6)	4% Trailer Under Fairing						www.solusinc.com
Stormblok Ekostinger Under Trailer Arrow	4% Under Trailer Device						ekostinger.com
Transtex 19-36 Skirt	4% Trailer Under Fairing						www.transtexcomposite.com
Transtex 21.6-36 Skirt	4% Trailer Under Fairing						www.transtexcomposite.com
Utility Trailer USS 120	4% Trailer Under Fairing						www.utilitytrailer.com
Transtex Edge Tail	4% Trailer Rear Fairing						www.transtexcomposite.com

Wabash AeroFin XL	4% Trailer Rear Fairing						www.wabashnational.com
1% Fuel Savings or Better							
Airman AirWedge I	1% Trailer Under Fairing						www.airmansystems.com
AeroVolution inflatable boat tail	1% Trailer Rear Fairing						www.aerovolution.com
ATS SmartTail	1% Trailer Rear Fairing						www.ats-green.com
Kodiak Innovations Bumper Bullet	1% Trailer Rear Fairing						kodiakinnovations.com
Slipstreem Aerodynamics Showtime 100 Trailer End Fairing	1% Trailer Rear Fairing						www.slipstreemaero.com
SOLUS Air Conqueror Package SP: 4.9 (WheelCover/AftSkirt/Tail1)	1% Trailer Rear Fairing						www.solusinc.com
SOLUS Air Conqueror Package SP: 3.6 (WheelCover/AftSkirt/Tail2)	1% Trailer Rear Fairing						www.solusinc.com
SOLUS Air Conqueror Package SP: 3.4 (WheelCover/AftSkirt/Tail3)	1% Trailer Rear Fairing						www.solusinc.com
SOLUS Air Conqueror Package SP: 2.4 (WheelCover/AftSkirt)	1% Trailer Rear Fairing						www.solusinc.com
Transtex rear trailer fairing	1% Trailer Rear Fairing						www.transtexcomposite.com
Wabash AeroFin	1% Trailer Rear Fairing						www.wabashnational.com
FreightWing Gap Reducer	1% Trailer Front Fairing						www.ridgecorp.com
Laydon Composites Gap Reducer	1% Trailer Front Fairing						www.laydoncomp.com

a. “Other Trailer Device” is different from the traditional categories of verified aerodynamic devices and may not be suitable for combining with other aerodynamic devices to achieve elite levels of performance. Additional testing may be needed to confirm performance levels for these “Other Trailer Devices” when used in conjunction with other devices.

Appendix B – References

First Occurrence	Reference	Source
Figure 1 U.S. Diesel Fuel Prices	Mihelic, R., "Heavy Truck Aerodynamics Beyond 2025," presentation at SAE 2015 COMVEC Session 15CVA2000 Aero Keynote, Oct. 2015, raw data from DOE.	Contact Author for copy
Figure 2: Trucking Operational Costs per Mile	Roeth, M., North American Council for Freight Efficiency (NACFE) graph from data from American Transportation Research Institute (ATRI), "An Analysis of the Operational Costs of Trucking: 2015 Update," Sep. 2015,	http://atri-online.org/wp-content/uploads/2015/09/ATRI-Operational-Costs-of-Trucking-2015-FINAL-09-2015.pdf
Figure 3: NACFE Fleet Fuel Study Fleets	Roeth, M., North American Council for Freight Efficiency (NACFE), "2015 Annual Fleet Fuel Study," May, 2016,	http://nacfe.org/wp-content/uploads/2015/05/NACFE-2015-Annual-Fleet-Fuel-Study-Report-050115.pdf
Figure 4: Fuel Savings per Truck	Roeth, M., North American Council for Freight Efficiency (NACFE), "2015 Annual Fleet Fuel Study," May, 2016,	http://nacfe.org/wp-content/uploads/2015/05/NACFE-2015-Annual-Fleet-Fuel-Study-Report-050115.pdf
Figure 5: Trailer Technology Adoption (NACFE)	Roeth, M., North American Council for Freight Efficiency (NACFE), "2015 Annual Fleet Fuel Study," May, 2016,	http://nacfe.org/wp-content/uploads/2015/05/NACFE-2015-Annual-Fleet-Fuel-Study-Report-050115.pdf
Introduction Photos	Mihelic, R., Mihelic Vehicle Consulting LLC original photos for this report, Dec. 2015	
Figure 6: Early Aerodynamic Trailers	Helm, M., "Labatt's Streamliner 1947 model," 2009	http://comet166.deviantart.com/art/Labatt-s-Streamlner-1947-model-173768384
Figure 6: Early Aerodynamic Trailers	"Henry Ford Museum August 2012 41 (1952 Federal 45M truck tractor with 1946 Fruehauf semi-trailer)" by Michael Barera. Licensed under CC BY-SA 4.0 via Commons -	https://commons.wikimedia.org/wiki/File:Henry_Ford_Museum_August_2012_41_(1952_Federal_45M_truck_tractor_with_1946_Fruehauf_semi-trailer).jpg#/media/File:Henry_Ford_Museum_August_2012_41_(1952_Federal_45M_truck_tractor_with_1946_Fruehauf_semi-trailer).jpg
Figure 7: Rounded Front Trailers in '30's & 40's	1935 Fruehauf Van Trailer, Coachbuilt	http://www.coachbuilt.com/bui/f/fruehauf/oo1935_fruehauf_van.jpg and http://www.coachbuilt.com/bui/f/fruehauf/fruehauf.htm
Figure 8: 1970's Cab Over Roof Fairing (Hanks)	Image from United States Patent 4,245,862, "Drag reducer for land vehicles," Buckley, Jr. January 20, 1981 also see W. Selden SAUNDERS and Rudkin-Wiley Corporation patents 3,241,876 1966 and 3,309,131 1967	http://pdfpiw.uspto.gov/.piw?Docid=04245862&homeurl=http%3A%2F%2Fpatft.uspto.gov%2Fnetacgi%2Fnph-Parser%3Fsect1%3DPTO2%2526Sect2%3DHITOFF%2526p%3D1%2526u%3D%25252Fnetahtml%25252FPTO%25252Fsearch-bool.html%2526r%3D21%2526f%3DG%2526l%3D50%2526co1%3DAND%2526d%3DPTXT%2526s1%3D4,245,862%2526OS%3D4,245,862%2526RS%3D4,245,862&PageNum=&Rtype=&SectionNum=&idkey=NONE&Input=View+first+page
Figure 9: Horsepower Required To Overcome Opposing Forces	U.S. Department of Energy, "Technology Roadmap for the 21st Century Truck Program," 21CT-001, Dec. 2000, graph attributed to ORNL 2000-06268A/lmh	http://infohouse.p2ric.org/ref/46/45735.pdf
Figure 10: 1985 Kenworth T600	Groner, A. and Provorse, B., "PACCAR, The Pursuit of Quality," 3rd Edition, Documentary Book Publishers, Seattle, 1998, ISBN: 0-935503-24-2	
Figure 11: Significant Evolution In Tractor Shape Started by STAA Legislation	Sherwood, W. , "Wind Tunnel test of Trailmobile Trailers". University of Maryland Wind Tunnel Report No. 85. College Park, MD, April 1974, original Sherwood, A. Wiley, "Wind Tunnel Test of Trailmobile Trailers," University of Maryland Wind Tunnel Report No. 85, June 1953.	
Figure 11: Significant	Peterbilt MY2016 EPIQ Model 579 Tractor –Peterbilt Motors	http://www.peterbilt.com/about/media/2015/

Evolution In Tractor Shape Started by STAA Legislation	Company	453/image/226/
Figure 11: Significant Evolution In Tractor Shape Started by STAA Legislation	Roeth, M., North American Council for Freight Efficiency (NACFE), "2015 Annual Fleet Fuel Study," May, 2016,	http://nacfe.org/wp-content/uploads/2015/05/NACFE-2015-Annual-Fleet-Fuel-Study-Report-050115.pdf
Section 2 Text Reference -Repeal of 55mph speed limit	National Highway Traffic Safety Administration, NHTSA, "The Effect of Increased Speed Limits in the Post-NMSL Era", NHTSA, Feb. 1998	http://www-nrd.nhtsa.dot.gov/Pubs/808-637.pdf
Figure 12: U.S. Diesel Fuel Price History	Roeth, M., North American Council for Freight Efficiency (NACFE), "2015 Annual Fleet Fuel Study," May, 2016,	http://nacfe.org/wp-content/uploads/2015/05/NACFE-2015-Annual-Fleet-Fuel-Study-Report-050115.pdf
Figure 13: Late 1990's Aerodynamic Tractor Launches - (Ford HN80, Kenworth T2000, Freightliner Century, Volvo VN, Peterbilt 387)	Various OEM Brochures and Press Releases from 1990's	*Ford HN80* http://s.hswstatic.com/gif/1990-1999-ford-trucks-39.jpg, *Kenworth T2000* http://www.kenworth.com/media/40396/90th Anniversary_billboard_1996.jpg, *Freightliner Century* http://www.ttnews.com/articles/basetemplate.aspx?storyid=38177, *Volvo VN* http://www.volvotrucks.com/trucks/global/en-gb/aboutus/history/1990s/Pages/VN_and_NH.aspx, *Peterbilt 387* http://www.peterbilt.com/resources/75th_Timeline.pdf
Figure 14: OEM Product Aerodynamic Progression -	Various OEM Brochures and Press Releases from 2005-2016s	
Figure 15: FHWA Freight Efficiency Improvement to 2005	National Academy of Sciences, "Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy Duty Vehicles," National Academies Press (NAP), ISBN: 978-0-309-14982-2, 2010 adapted from Figure 1-3, U.S. average payload-specific fuel consumption. SOURCES: Data from Federal Highway Administration, Highway Statistics Summary to 1995, Table VM-201A, and Highway Statistics (annual releases), Table VM-1, Washington D.C., available at http://www.fhwa. dot.gov/ohim/summary95/vm201a.xlw, accessed Feb. 25, 2010; total tons hauled from Bob Costello, American Trucking Association.	http://www.nap.edu/catalog/12845/technologies-and-approaches-to-reducing-the-fuel-consumption-of-medium-and-heavy-duty-vehicles
Section 2 Text Reference – 2004 Creation of SmartWay Program	About SmartWay, SmartWay Timeline, EPA	http://www3.epa.gov/smartway/about/
Figure 16: 2006 Great Dane/Walmart Prototype Aero Trailer (DOE)	Truck Manufacturers Association (TMA), "Test, Evaluation, and Demonstration of Practical Devices/Systems to Reduce Aerodynamic Drag of Tractor/Semitrailer Combination Unit Trucks FINAL REPORT," Prepared for:National Energy Technology Laboratory Morgantown, West Virginia Contract Number DE-FC26-04NT42117 Prepared by: Truck Manufacturers Association, Apr 2007	http://www.kronosenergysolutions.com/pdfs/DOE-TMAtests.pdf
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Section 3 Text Reference to Determining Efficiency CR	Mihelic, R., et. al., "Determining Efficiency Confidence Report", NACFE, Jan. 2016	www.TruckingEfficiency.org
Figure 17: 2013 Factory Shipments	Americas Commercial Transportation Research Co., ACT graph, "2013 U.S. Factory Shipments," in U.S. EPA Draft Regulatory Impact Analysis, "Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium and Heavy-Duty Engines and Vehicles – Phase 2," EPA-420-D-15-900, Jun 2015	http://www3.epa.gov/otaq/climate/documents/420d15900.pdf
Figure 18: Trailer Type Distribution 2001	Compiled from U.S. Census Bureau data from "Vehicle Inventory & Use Survey (VIUS)," 2002 released in 2003.	https://www.census.gov/svsd/www/vius/2002.html
Figure 19: Typical 53' Van Trailer Is Box Shaped On Purpose	Utility Trailer 4000D-X Trailer Marketing Image	http://www.utilitytrailer.com/trailers/dry-vans/4000d-x-composite/photos-videos and http://www.utilityofnj.com/nj/wp-content/uploads/2014/09/Utility1.jpg
Section 3 Text Reference – EPA testing on minimal trailer differences	U.S. Environmental Protection Agency, "Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2 Draft Regulatory Impact Analysis," EPA-420-D-15-900, Jun. 2015	http://www3.epa.gov/otaq/climate/documents/420d15900.pdf
Figure 20: Optional Equipment Complicates Aero Configuration	Original Art, Rick Mihelic	Contact Author for copy
Figure 21: Aerodynamics of the Cab Affect the Trailer (Exa/Peterbilt)	Exa/Peterbilt CFD Rendered Marketing Image	http://exa.com/sites/default/files/media-module/hv_peterbilt_007_sm.jpg
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Section 4 Text Reference – SAE J2245	SAE International Surface Vehicle Recommended Practice, "Recommended Practice for Splash and Spray Evaluation," SAE J2245, Rev. May 2011	http://standards.sae.org/j2245_201105/
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Section 4 Text Reference – ATA Splash & Spray Guideline 759	American Trucking Association (ATA) Technology & Maintenance Council (TMC), "Splash & Spray Suppression Guidelines," TMC Recommended Practice 759	http://www.trucking.org/ATA%20Docs/About/Organization/TMC/Documents/RP_MANUAL_DESCRIPTIONS.pdf
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Figure 22 Tonnage per Load (ATA and ACT Research)	North American Council for Freight Efficiency, "Confidence Report: Lightweighting," TruckingEfficiency.Org, Aug. 2015 page 19, from ATA And ACT Research	http://www.truckingefficiency.org/tractor-aerodynamics/weight-reduction-tractors
Section 5.1 Text Reference – SuperTruck Right Sizing Options	National Academy of Sciences (NAS), "Review of the 21st Century Truck Partnership, Third Report,", National Academies Press (NAP), ISBN-13: 978-0-309-37710-2, 2015	http://www.nap.edu/catalog/21784/review-of-the-21st-century-truck-partnership-third-report
Figure 23 Aero Design Integration From Discrete Fairing and Sleeper to Integral Aero Sleeper	Peterbilt Model 349, circa. 1986 Kenworth Model T660 Marketing Image 2016	Peterbilt Model 349 http://www.timstrucks.com/349aerotractor.jpg Kenworth T660 http://www.kenworth.com/media/4929/t660_gphoto_1.jpg
Figure 24 Beverage Hauler Aero vs. Weight Evaluation	Google Maps and Bartholdi, J., & Hackman, S., "Warehouse and Distribution Science," Georgia Institute of Technology	www.maps.google.com andhttp://www2.isye.gatech.edu/~jjb/wh-more/sites/Pepsi/Pepsi.html
Figure 25 Furniture Hauler Aero vs. Weight Evaluation	Google Maps and Ancra's Lift-A-Deck II Load Maximizing System	www.maps.google.com and http://ww1.prweb.com/prfiles/2011/02/07/606664/MultiLevelFlexibility.JPG
Figure 26 Aerodynamic Evaluation Has Many Different Methods Producing Different Results	Mihelic, R., "Heavy Duty Tractor/Trailer Aerodynamic Testing Technology," presentation at 2013 SAE COMVEC 13CVA1000 Plenary, Oct. 2013 and Mihelic, R., "Aerodynamic Keynote Panel: Aerodynamic Based Regulatory Activity," presentation at 2014 SAE COMVEC, Aero Keynote Panel, Oct. 2014	Contact Author for copy
Figure 27 EPA Aero Evaluation Comparisons from GHG Phase I RIA	U.S. EPA, "Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles Regulatory Impact Analysis,", document EPA-420-R-11-901, Aug. 2011	http://www3.epa.gov/otaq/climate/documents/420r11901.pdf
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Figure 27 Precision vs. Real World Variability	Custom Graphic for this report based on copyright free images	
Text References Section 5.3 on precision & accuracy	Purdue, "Bias and Accuracy",CHM621, Purdue website	https://www.chem.purdue.edu/courses/chm621/text/stat/relev/bias/bias.htm
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Figure 29 Green Color as an Example of Need for Accuracy Colors	Mihelic, R., "Aerodynamic Keynote Panel: Aerodynamic Based Regulatory Activity," presentation at 2014 SAE COMVEC, Aero Keynote Panel, Oct. 2014	Contact Author for copy
Figure 30 Colors Accurately Differentiated As Specific Wave Lengths	Mihelic, R., "Aerodynamic Keynote Panel: Aerodynamic Based Regulatory Activity," presentation at 2014 SAE COMVEC, Aero Keynote Panel, Oct. 2014, art from https://www.wou.edu/las/106equen/ch462/tmcolors.htm	Contact Author for copy

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Figure 32 Tractor/Trailer Data from 2011 SEC Filings	Data compiled by Rick Mihelic from SEC Form 10-K 2011 postings	https://www.sec.gov/edgar/searchedgar/companysearch.html
Text Reference Section 5.6 on TTMA	Truck Trailer Manufacturers Association, TTMA	http://www.ttmanet.org/
Figure 67 Trailer Aero ROI Depends On Trailer/Tractor Ratio	Original graphic, Rick Mihelic, 2015	
Text References Section 5.7 FMCSA Regulation	49 CFR§ 396.7, DOT Federal Motor Carrier Safety Administration FMCSA	https://www.fmcsa.dot.gov/regulations/title49/section/396.7
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Figure 34 Three Primary Aerodynamic Opportunity Areas	Original Art, Rick Mihelic	Contact Author for copy
Figure 35 EPA's Description of Primary Trailer Aerodynamic Technologies	U.S. Environmental Protection Agency, "Proposed Rulemaking for Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles–Phase 2 Draft Regulatory Impact Analysis," EPA-420-D-15-900, Jun. 2015 page 2-154	http://www3.epa.gov/otaq/climate/documents/420d15900.pdf
Figure 36 Streamlines for an Un-Skirted Trailer (PACCAR)	Mihelic, R., "Aerodynamics of Heavy Duty Trucks," presentation to University of Texas at Arlington (UTA) AIAA & ASME Student Groups, Oct. 2007	Contact Author for copy
Figure 37 Trailer Skirts Keep Air from Impacting Trailer Bogie	Original Art for this report	
Figure 38 Off-Axis Un-Skirted Trailer Air Flow Example	Original Art for this report	
Text Reference Section 6 & Figure 39 Drag	Cooper, K., "Commercial Vehicle Aerodynamic Drag Reduction Historical Perspective as a Guide," National Research Council of	http://link.springer.com/book/10.1007/978-3-540-44419-0 Similar information in

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Figure 40 Example Skirt Installation (Utility Trailer)	Utility Trailer Side Skirt Marketing Photo	Similar photos in current brochure http://www.utilitytrailer.com/download?id=12&referrer=%2Ftrailers%2Fdry%2Dvans%2F4000d%2Dx%2Dcomposite%2Fspecifications
Figure 41 Formed Skirts (Laydon)	Laydon Composites Molded Skirt Marketing Photo	Similar photos in current brochures http://www.laydoncomp.com/trailer-skirts.php
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Figure 42 UnderTray Bogie Aerodynamic Improvement (SmartTruck)	SmartTruck marketing information CFD image	http://smarttruckaero.com/our-story/product-development/
Text References Section 6.1 PIT Test per HDT	Park, J., "Aero add-ons put to the test," Heavy Duty Trucking, Oct. 2013 discussing Performance Innovations Technology, PIT, testing	http://heavydutytrucking.epubxp.com/i/187680-oct-2013/29
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Figure 45 Segmented Skirt Aerodynamic Devices (Wabash)	Wabash National marketing information on Ventix DRS	http://www.wabash-trailers.com/products/trailer-aerodynamics/ventix-drs
Figure 46 Ground Clearance Precaution With Aero Performance (Wabash)	Wabash National marketing information on DuraPlate AeroSkirt	http://www.wabash-trailers.com/products/trailer-aerodynamics/duraplate-aeroskirt
Figure 47 Articulated Skirts Allow Clearance At The Yard (Windyne)	Windyne marketing information	http://www.windyne.com/index.html photo available also HDT Jun 2009, http://www.truckinginfo.com/article/story/2009/06/windyne-develops-aerodynamic-device.aspx
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Figure 48 Trailer End Design Getting to the Point (NASA)	Glezer, C., "From Shoebox to Bat Truck and Beyond – Aerodynamic Truck Research at NASA Dryden Flight Research Center," Monographs In Aerospace History #45 NASA SP-2010-4545, NASA History Office, Washington, 2011	http://history.nasa.gov/monograph46.pdf
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Figure 49 Wake Field Aerodynamics (from Patent US2007 #7,255,387)	Wood, R., "Vortex Strake Device and Method for Reducing the Aerodynamic Drag of Ground Vehicles,"U.S. Patent 7,255,387, 2007	http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=1&f=G&l=50&co1=AND&d=PTXT&s1=7,255,387.PN.&OS=PN/7,255,387&RS=PN/7,255,387
Figure 50 Wake Fields Behind Trailers (Exa CFD Image)	Original example CFD Image from Exa Corporation for Rick Mihelic	Contact Author for copy

Figure 51 TrailerTail Rear Trailer Aerodynamic Device Stemco/ATDynamics	Stemco/ATDynamics TrailerTail origami folding system marketing information	Similar information available at http://www.stemco.com/trailertail-installation/ Original phot from http://4.bp.blogspot.com/-fhWF0hOZ_KQ/T7LlIZwwwAI/AAAAAAAAApE/QTNEJwxFma0/s1600/ATDynamics+8.JPG
Figure 52 Wabash AeroFin and AeroFin XL Rear Aero Devices (Wabash)	Wabash National marketing information on AeroFin XL Tail Device	http://wabash-trailers.com/products/trailer-aerodynamics/aerofin-xl-tail-device
Figure 53 TopKit Trailer Tail System (SmartTruck)	SmartTruck marketing information and original photo by Rick Mihelic, 2013	http://smarttruckaero.com/products-overview/top-kit/
Figure 54 Transtex Edge Tail (HDT)	Transtex Edge Tail as reported in Heavy Duty Trucking, "Transtex Expands Drag-Reducing Product Lineup," HDT Oct. 2014	http://www.truckinginfo.com/channel/fuel-smarts/product/detail/2014/10/transtex-expands-drag-reducing-product-lineup.aspx
Figure 55 ATS SmartTail Inflatable Rear Aero System (ATS)	Aerodynamic Trailer Systems marketing information. Also see Heavy Duty Trucking, "SmartWay Verifies ATS' Aerodynamic System," June 28, 2010	http://www.ats-green.com/ andhttp://www.truckinginfo.com/channel/aftermarket/news/story/2010/06/smartway-verifies-ats-aerodynamic-system.aspx
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Figure 56 NoseCone Trailer/Tractor Gap Devices	NoseCone marketing information	http://www.nosecone.com/
Figure 57 Nose Fairing Gap System (Laydon)	Laydon Composites marketing information	http://www.laydoncomp.com/nose-fairing-vortex-stabilizer.php
Figure 58 FreightWing/Carrier Gap Devices	FreightWing/Carrier Gap Devices	Similar photos at http://www.freightwing.com/common/brochures/Gap-Fairing-2012-Brochure.pdf Transicold/Freight Wing photo from – http://www.theicct.org/sites/default/files/publications/AERO_RR_Technologies_Whitepaper_FINAL_Oct2012.pdf
Figure 59 Gap Vortex Management Devices	Original Art for this report by Rick Mihelic	
Figure 60 Vortex Stabilizer Device (Laydon)	Laydon Composites marketing information	http://www.laydoncomp.com/nose-fairing-vortex-stabilizer.php
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Figure 61 Solus Wheel Cavity Cover	Wood, R., "EPA Smartway Verification of Trailer Undercarriage Advanced Aerodynamic Drag Reduction Technology," *SAE Int. J. Commer. Veh.* 5(2):607-615, 2012, doi:10.4271/2012-01-2043	http://papers.sae.org/2012-01-2043/
Figure 62 FlowBelow Wheel Cover Access	FlowBelow marketing information brochure	http://static1.squarespace.com/static/55c50908e4b0d956fac841fb/t/5615db3de4b04ac9c405a82e/1444272957537/FB-AeroKit-Apr2015-Compressed.pdf

Figure 63 RealWheels with Viewing Panes	RealWheels marketing information	http://www.realwheels.com/aero/styles.html
Figure 64 Example Exposed Wide Mud Flap (Badger)	On road photo	
Figure 65 Simple Vented Flap	EcoFlaps marketing information	http://www.ecoflaps.com/installation.html
Figure 66 Louvered Vented Flap	Mirrex (vented mudflap flap by Vortex Splash Guards) marketing photo, PACCAR	http://www.epaccar.com/xref/SS_Application1.aspx?S=43&P=47&div=k
Figure 67 Louvered Vented flap	Fleet Engineers vented mud flap marketing photo	http://www.ryderfleetproducts.com/fleet-engineers-033-08002/mud-flap-24x30-aero-
Figure 68 VorBlade Wing System	Avantechs Vorblalde marketing information	http://www.shop.vorblade.com/images/VorBladeWing.jpg
Figure 69 Airtabs	Aeroserve Technologies LTD Airtab marketing information	http://www.airtab.com/Site/themed-images/placeholders/360x270/what-are.jpg
Text Reference Section 6.6 AeroTrak	Nose Cone Mfg. Co. AeroTrak VG Pro no longer offered	Personal communication
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Figure 70 Bumper Bullet	Kodiak Innovations Bumper Bullet Marketing Information	http://kodiakinnovations.com/
Figure 71 Optimizing Trailer Aerodynamics To The Extreme – Recurring Themes	Peterbilt Press Release, "Cummins Peterbilt SuperTruck Achieves 10.7 MPG in Latest Test," Feb. 18, 2014 Freightliner Press Release through Overdrive, "Freightliner Unveils Futuristic SuperTruck concept," Mar. 26, 2015 Walmart/Peterbilt Walmart Advanced Vehicle Experience Concept Truck (WAVE), 2015 Peterbilt Marketing Photo, Model 372 Concept, FleetOwner Magazine Jan. 1991 Volvo Concept and Demo SuperTrucks, Gibble, J., "Volvo SuperTruck, 2013 Annual Merit Review," DOE May 2013 and Gravel, R., "SuperTruck – An Opportunity to Reduce GHG Emissions while Meeting Freight Hauling Demands," DOE April, 2015 Mercedes Benz Aero Trailer Concept, Truckinginfo, Sep. 2012 Renault Optifuel Lab Trailer, Commercial Motor, Mar. 2009	Peterbilt SuperTruck at http://www.peterbilt.com/about/media/2014/396/ Freightliner SuperTruck at http://www.overdriveonline.com/photos-freightliner-unveils-futuristic-supertruck-concept/ WAVE at https://www.youtube.com/watch?v=NER9X4_gtYk 372 copy posted at http://www.trucknetuk.com/phpBB/viewtopic.php?f=35&t=98062&hilit=ERGO&start=1140 Volvo SuperTrucks at http://energy.gov/sites/prod/files/2014/03/f13/ace060_amar_2013_o.pdf and http://www.arb.ca.gov/msprog/onroad/caphase2ghg/presentations/1_4_roland_g_usdoe.pdf Mercedes-Benz concept http://www.tuvie.com/mercedes-benz-aero-trailer-concept-drastically-reducing-wind-resistance-and-fuel-consumption-of-semitrailer-tractors/ and http://www.truckinginfo.com/blog/trailer-talk/print/story/2012/09/aero-trailer-could-save-3900-a-year-in-euro-fuel-daimler-engineer-says.aspx Renault Concept at http://www.commercialmotor.com/big-lorry-blog/-and-so-its
Figure 72 Scale Model Wind Tunnel Tests Of Typical Aero Options Figure 73 Best Aero	Landman, D., Wood, R., Seay, W., and Bledsoe, J., "Understanding Practical Limits to Heavy Truck Drag Reduction," *SAE Int. J. Commer. Veh.* 2(2):183-190, 2010, doi:10.4271/2009-01-2890	http://papers.sae.org/2009-01-2890/

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Figure 77 SmartWay Program Establishes National Aerodynamic Benchmarking System	U.S. Environmental Protection Agency, EPA, "Save Fuel, Money and the Environment with a SmartWay Truck," graphic	http://epa.gov/smartway/about/images/sw10-imgs/7.jpg
Figure 78 Variation n Posted Truck Highway Speed Limits	Compiled from Insurance Institute for Highway Safety, IIHS, "Speed Limits," January 2016	http://www.iihs.org/iihs/topics/laws/speedlimits
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Text Reference Section 7.1 SmartWay Technology List	EPA SmartWay Currently SmartWay Verified Aerodynamic Devices Table	http://www3.epa.gov/smartway/forpartners/technology.htm
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Figure 80 SmartWay Trailer Configurations	U.S. Environmental Protection Agency, EPA, "Summary of EPA-Designated SmartWay Trailer Configurations," EPA Website	http://www3.epa.gov/smartway/forpartners/documents/aerodynamic/420f15009.pdf
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Figure 83 Electrics Offer Shape Change Possibilities (Peterbilt/Walmart/Volvo)	Peterbilt/Walmart WAVE Concept – Volvo Concept - Adraque, H., "2040 Volvo VNL Concept Design by Jack Liu," Industrial Design, Mar. 2015	Peterbilt/Walmart WAVE - https://www.youtube.com/watch?v=NER9X4_gtYkVolvo -http://www.designideas.pics/2040-volvo-vnl-concept-design-by-jack-liu/
Figure 84 Driving Simulator Could Be Drone Controller (TranSim)	TranSimVS™ Truck Driving Simulator marketing information	http://www.l-3training.com/applications/land/transportation/transim-truck-driving-simulator
Figure 85 Container Handler (Toyota)	Forkliftaction.com, "Toyota plans AGV exports13505 Toyota plans AGV exports," Sep 2013	http://www.forkliftaction.com/news/newsdisplay.aspx?nwid=13505
Figure 86 Possible 70 Foot Aero Trailer with Drone? (Renault)	Renault Concept	https://s-media-cache-ak0.pinimg.com/236x/09/c1/1d/09c11d8bc75bf9c113108357d7e6be02.jpg
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Figure 90 NACFE Trailer Technology Recommendations	NACFE Original Graphic for this report	
Figure 91Confidence Matrix	NACFE Original Graphic for this report	