Fuel-Efficient Active Flow Control for Tractor Trailers

ATDynamics, Inc.

ICAT Grant No. 08-1

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Acknowledgments

Through the course of this project ATDynamics had help from several parties including but not limited to the following: Avi Siefert of Tel Aviv University, Robert Englar of the Georgia Tech Research Institute, John Collins of the Air Resources Board, Ken Visser of Clarkson University, The New York State Energy Research and Development Authority (NYSERDA), Wal-Mart, and Clint Carrell of the Goodyear Proving Grounds.

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Abstract

The purpose of this project was to explore the commercial feasibility of two separate Active Flow Control (AFC) technologies and compare them to passive aerodynamic drag-reducing technologies verified by the EPA SmartWay Technology Program[1] and available to improve the fuel efficiency of tractor trailers through aerodynamic improvement. At highway speeds aerodynamic drag accounts for more than half of the fuel consumed by a modern tractor trailer, and any device that can reduce this drag has significant market potential. AFC works by pressurizing the low-pressure vortex, or vacuum, that develops behind a box-shaped trailer as it moves forward; in aerodynamic terms, AFC delays boundary layer separation, reducing the intensity with which the vacuum inhibits the trailer's forward motion. AFC has been proven to reduce aerodynamic drag in the lab[2] and in some aeronautical applications[3], but has never been developed to full-scale in the freight industry. ATDynamics collaborated with two different research institutions to develop full-scale prototypes for tractor trailers based upon their respective AFC configurations and then conducted SAE standardized testing of these devices alongside passive drag-reducing devices.

The first technology concept was developed at the Georgia Tech Research Institute (GTRI): a steady flow of air injected at the boundary-layer tangentially to a curved fairing to direct this boundary-layer airflow into a smaller cross-section wake at the rear of a trailer. The second technology concept was based upon technology developed at the Tel Aviv University (TAU) in Israel and was a novel AFC configuration, Suction and Oscillatory Blowing (SaOB): a row of suction holes is used to control the approaching turbulent base layer and a series of pulsating jet ports is used to create flow instability in order to reduce flow separation as the boundary-layer flow traverses the curved fairing. The passive devices used for comparison included skirt fairings to block flow below the trailer and the ATDynamics TrailerTail to physically reduce the size and turbulence of the wake behind a trailer.

The testing was conducted at the Goodyear Proving Grounds located in San Angelo, TX and was performed in accordance with the SmartWay SAE J1321 standard procedure. Modified procedures were used when less runs were deemed adequate to gather significant data for a given technology. The GTRI device showed very little drag reduction in the tested configurations. The TAU device showed some measurable drag reduction of 5%, but the energy input required largely negated this. The passive devices showed significant drag reduction, consistently improving fuel economy by 9% or more. For next steps, ATDynamics determined that the active flow control technologies required more research and development, likely sponsored by further academic or government grants, before private capital

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[1] EPA SmartWay Technology Program - Verified Aerodynamic Technologies, http://www.epa.gov/smartway/technology/aerodynamics.htm

[2] Seifert, A., Bachar, T., Koss, D., Shepshelovits, M. and Wygnanski, I., 1993, "Oscillatory Blowing, a Tool to Delay Boundary Layer Separation", *AIAA J,* Vol. 31, No. 11, pp. 2052-2060

[3] Margalit, S., Greenblatt, D., Seifert A. and Wygnanski , I., “Delta Wing Stall and Roll Control using Segmented Piezoelectric Fluidic Actuators”, (previously AIAA paper 2002-3270), *AIAA J. of Aircraft*, May-June 2004

could fund ongoing commercialization. ATDynamics research partners at TAU identified some potential improvements in the design that could increase drag reduction while decreasing required energy input. ATDynamics and TAU agreed that TAU would continue to address both the efficiency and cost/complexity challenges faced by the TAU technology and that ATDynamics would stay in contact with an Israeli business partner regarding eventual commercialization in the United States if the technology was improved significantly in the laboratory. After testing was complete, ATDynamics concluded that passive aerodynamic equipment solutions remain the best option in the immediate future to deliver maximum fuel savings to the trucking industry and the state of California.

Introduction

This report is the final element of the ICAT grant number 08-1, Fuel-Efficient Active Flow Control for Tractor Trailers. This project was initiated to explore the commercial feasibility of adapting active flow control technologies to the freight industry in an effort to reduce the aerodynamic drag and therefore fuel consumption of freight-hauling trucks. ATDynamics worked with Georgia Tech Research Institute and Tel Aviv University in Israel to identify the current state-of-the-art active flow control configurations and adapt them to full-scale tractor trailers.

Innovative Technology

Active Flow Control (AFC) is a concept originally introduced by Prandtl[4] and developed in the aerospace industry to increase performance of airfoil shapes. AFC uses localized energy injection to delay flow separation around an airfoil which increase lift, reduces drag, and delays stall[5]. Mechanisms to control this airflow include inducing suction to remove the turbulent or low-energy boundary layer along a rigid body and/or injecting high-energy air in certain locations and orientations to alter the airflow. Two separate approaches were studied as part of this project – a steady-blowing approach developed at the Georgia Tech Research Institute (GTRI)[6], and a combined suction and oscillatory-blowing approach developed at the Tel Aviv University (TAU) in Israel.

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[4] Prandtl L, "Motion of Fluids with Very Little Viscosity", Third International Congress of Mathematicians at Heidelberg, 1904, from Bier Abhandlungen zur Hydro-dynamik und Aerodynamik", pp. 1-8, Gottingen, 1927, NACA TM-452, March 1928

[5] Seifert A, Darabi A and Wygnanski I, 1996, "Delay of Airfoil Stall by Periodic Excitiation", J. of Aircraft. Vol. 33, No. 4, pp. 691-699

[6] Englar R, Advanced aerodynamic device to improve the performance, economics, handling and safety of heavy vehicles, SAE paper 2001-01-2072

GTRI Technology

The GTRI technology is based upon ongoing research[7] to increase low-speed lift of airfoil shapes. Bob Englar at GTRI has conducted extensive wind tunnel testing on multiple different aircraft and airfoil shapes and demonstrated a significant increase in lift using the AFC technology. Within the last 5 years he and other researchers at GTRI set about to adapt the technology to drag reduction on freight vehicles. The component application is to have a small fairing at the rear edge of a trailer that is tangential to the sides and top of the trailer and then curves in towards the center of the trailer, which can be seen in the schematic of Figure 1. High-energy air is ejected from a small slot which runs continuously around the leading edge of this fairing and directed tangentially along it, as can be seen in Figure 2 and Figure 3. Figure 4 shows the flow of the functioning device during a test performed as part of the ICAT project.

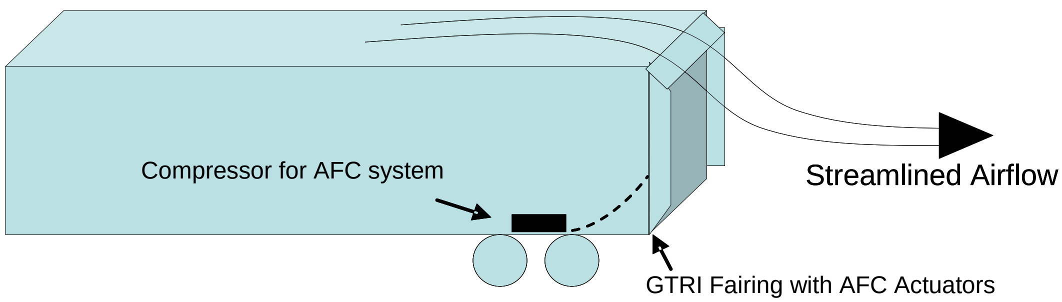

Figure 1. Schematic of GTRI AFC Technology

[7] Englar, R "Improved Pneumatic Aerodynamics for Drag Reduction, Fuel Economy, Safety, and Stability Increase for Heavy Vehicles," SAE paper 2005-01-3627

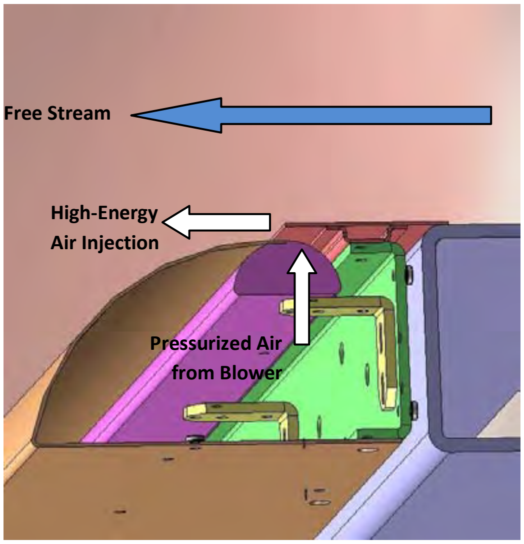

Figure 2. CAD Cross-Section of GTRI Device

Figure 3. GTRI Device Viewed from Side of Trailer Looking Upward

Figure 4. GTRI Device viewed from Rear of Trailer Looking Upward; Blower On, Trailer Stationary

TAU Technology

The TAU technology is based from ongoing research and a patent[8] with aircraft airfoils, as well as recent research[9] with drag reduction of tractor trailers. The system consists of three components: an array of roughly 200 AFC actuators; tubing which supplies the actuators and connects to a pressure source of either the truck pneumatic or electrical system or an independent compressor; and short mounting plates to which the tubing is affixed. The mounting plates enhance the reduction of boundary layer separation achieved by the actuators. They extend from the rear of the trailer to form a hollow cavity that pressurizes as the trailer moves forward, creating a buffer between the trailer and the vacuum left in its wake. This can be visualized in the schematic of Figure 5.

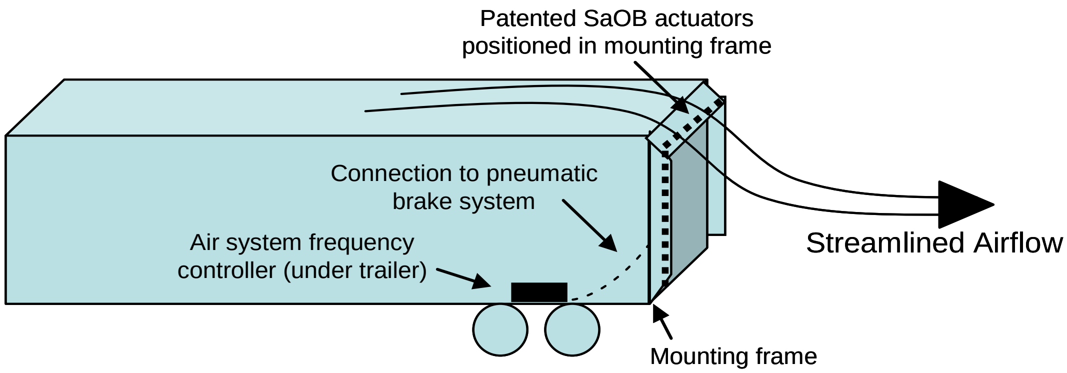

Figure 5. Schematic of TAU AFC Technology

The TAU technology is unique in its use of Suction and Oscillatory Blowing (SaOB) actuators arranged around the top and side edges of the trailer. The SaOB actuator serves as a valve: suction created by a jet-pump ejector moves air downstream to a bi-stable fluidic oscillator that regulates the blowing action. Compared to actuators that are equipped only for blowing, the ejector increases the airflow entrained into the valve by a factor of up to three, providing the SaOB actuator with commensurately superior capacity for pressurization. Meanwhile, two calibrated-length control ports, connected to one another by a passive channel, enable self-oscillating blowing action to be generated without additional moving parts or energy expenditure, as visualized in Figure 6.

[8] Seifert A, Pastuer S, "Method and mechanism for producing suction and periodic flow", US Patent 2006-0048829-A1, Granted 2005

[9] A. Seifert et al, "Large Trucks Drag Reduction using Active Flow Control", from "The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains" International Conference, August 26-31, 2007

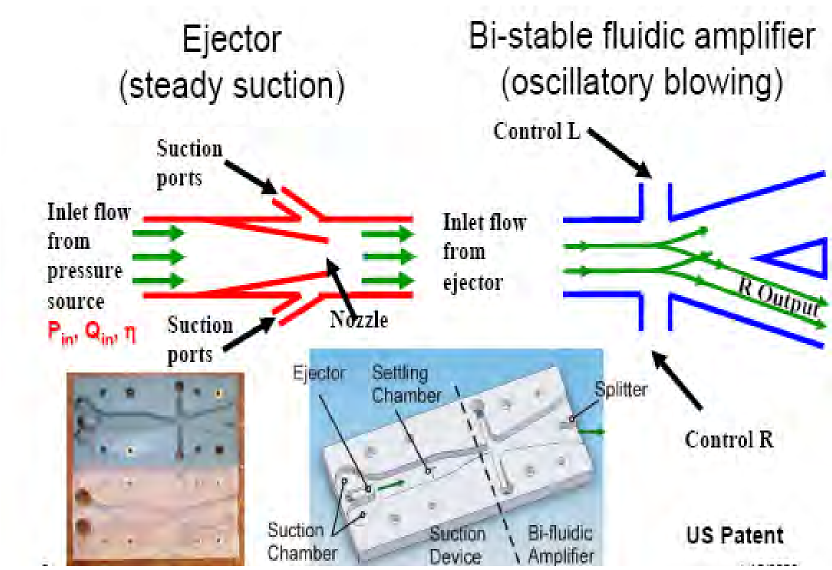

Figure 6. Diagrams of SaOB Actuator

Researchers at Tel Aviv University were granted a U.S. patent for the SaOB actuator in 2006 and subsequently conducted one year of intensive computational fluid dynamic modeling and wind-tunnel testing to demonstrate the efficiency of the SaOB actuator and resolve several questions concerning its application to tractor-trailer aerodynamics. For the configuration that would be used in full-scale prototype, TAU Researchers determined through 2D wind tunnel modeling that the optimal angle of an actuator's blowing slot relative to ambient airflow was 130-132.5 degrees. The results of this testing are shown in Figure 7, and for reference the slot angle can be seen in Figure 8.

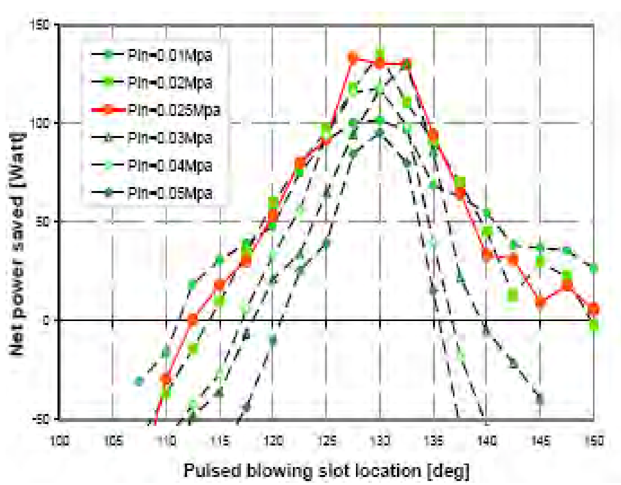

Figure 7. Performance of SaOB actuators at various angles relative to ambient airflow. Power saved from power required to propel a 2D truck model at 25m/s, reference power is 2.57kW.

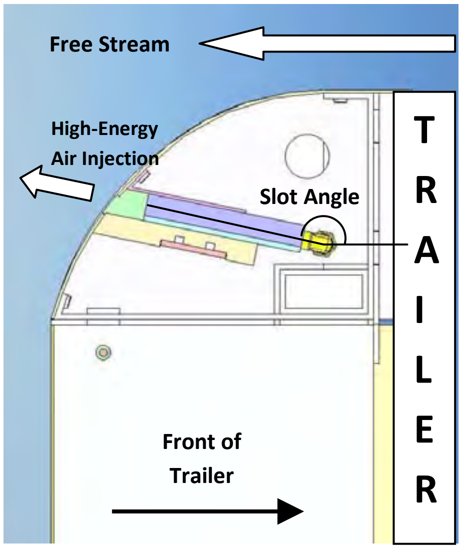

Figure 8. CAD Cross-Section of TAU Device

Furthermore, it was found that an array of SaOB actuators mounted merely to the upper horizontal edge of the rear of a trailer increased net fuel efficiency by nearly 4% in wind tunnel models. These results are seen in Figure 9; it is important to note, optimal driving speed is a function of modifiable characteristics of the SaOB actuators and thus this figure does not represent a fixed optimal speed.

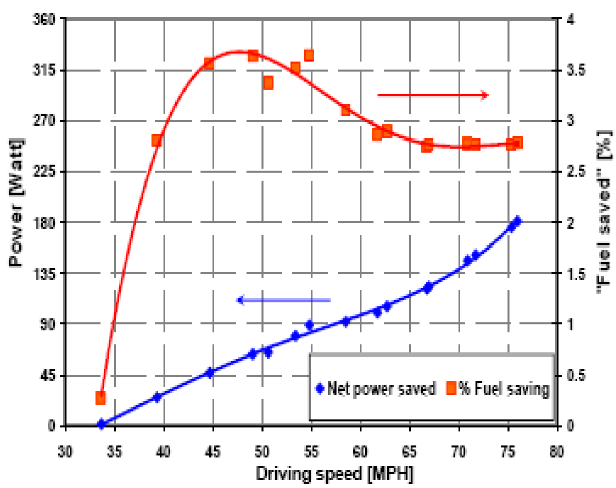

Figure 9. Net power and fuel savings of a single-edge array of SaOB actuators

When the model array was expanded to 4 sides including the lower horizontal edge, this resulted in a substantial additive fuel efficiency gain. Due to cost restrictions, the lower edge was equipped with actuators that featured only steady suction, without oscillating blowing action. This array configuration reduced the drag of the model by a total 20%, corresponding to a peak net fuel efficiency gain of 6% after accounting for the energy consumed by the actuators.

ICAT Project

The purpose of the project was to investigate the use of AFC technology to improve the fuel efficiency of tractor-trailers by 6-10%. This target was based on laboratory measurements of drag reduction for certain devices and took into consideration potential opportunities for further optimization. In order to conduct a complete survey of AFC technology potential, ATDynamics tested designs from Tel Aviv University (TAU) in Israel and from the Georgia Tech Research Institute (GTRI). ATDynamics also compared these technologies to the usability and efficiency gains of passive aerodynamic fairings not requiring active flow energizing. Through the process of prototyping, testing, and analyzing results, ATDynamics determined that significant further development was required to bring AFC technology to a commercial state. The best full scale prototype of AFC drag reduction technology delivered up to a 5% improvement in fuel economy, while the compressor required for operating the device caused a 8% decline in fuel economy, resulting in a net decline of 3% fuel economy. Thus, in the current state of the AFC technology, compressor fuel consumption was greater than the equivalent fuel savings from drag reduction, resulting in a net loss of efficiency. However, due to the complex nature of the AFC systems, there are significant gains in system efficiency that can be made to achieve a net improvement in fuel economy.

Technology Transfer & Prototype Design

Prior to the knowledge transfer, ATDynamics put in place development agreements with both Tel Aviv University and the Georgia Tech Research Institute. With GTRI this consisted of an agreement under which GTRI would share design data they had collected in independent research and in return ATDynamics would share experimental data and application knowledge gathered as part of this project. At the conclusion of this project a more long-reaching commercialization agreement could be entered into if both parties were amenable. Likewise, Tel Aviv University and ATDynamics established a business agreement which could allow the future commercialization of the technology.

GTRI Device Prototype

For the GTRI technology transfer, ATDynamics met with Bob Englar, the primary researcher of the GTRI AFC technology. ATDynamics reviewed prior GTRI research, wind tunnel models, and discussed design options. GTRI determined air source requirements of 4,650 cubic feet per minute supplied at 0.5psi (10.1hp plus losses due to pump efficiency and air transport) were necessary for this prototype. In the interest of conserving cost, the blower from previous related GTRI testing was used for this prototype, and the motor used was the Briggs and Stratton 16hp unit from the TAU device. A mounting structure was fabricated to suspend the blower and motor package from the bottom of the trailer in order to supply the compressor with sufficient airflow, which can be seen in Figure 10.

Figure 10. ATDynamics Full-Scale Prototype of GTRI AFC Device

TAU Device Prototype

For the TAU technology transfer, TAU researchers provided desired internal geometry of the actuators themselves and the desired locations for the suction holes and outlet ports. ATDynamics engineering staff designed a modular device such that the location of the suction holes and outlet ports could be altered by changing covers and/or putting tape over certain holes as seen in Figure 11.

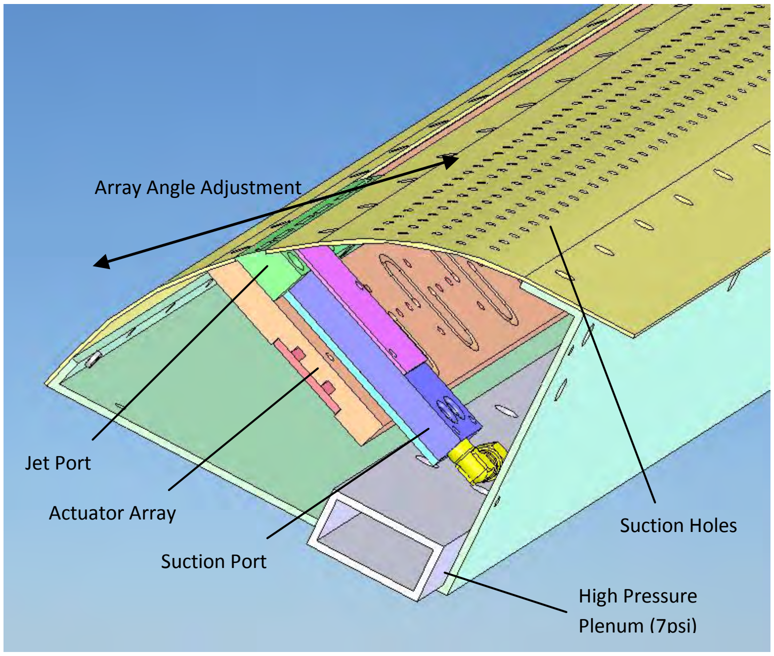

Figure 11. ATDynamics CAD Model of Integrated TAU Actuators - Section View

ATDynamics finalized drawings for all components and identified a cost-effective manufacturing partner for the specialized device components. ATDynamics conducted extensive mechanical engineering work with the manufacturing partner to ensure cost-effective manufacturability for the complex SaOB actuators and the respective mounting frames. ATDynamics completed the assembly of the manufactured sub-components in the ATDynamics prototyping facility, and successfully bench tested the device. The air source requirements for the TAU device were quite different from the requirements for the GTRI device – a much higher pressure and a much lower flow of 212cfm at 7psi (6.5hp plus losses due to pump efficiency and air transport). Thus a specific blower and motor package was sourced from REP Inc: a 36 URAI Roots positive displacement blower powered by a Briggs and Stratton Vanguard 16hp gasoline engine. This package was mounted on the underside of the trailer as seen in Figure 12 and Figure 13, and added approximately 250lbs to the trailer weight.

Figure 12. TAU Device Viewed from Rear of Trailer Looking Upward

Figure 13. TAU Device Rear View

Benchmarking

Passive aerodynamic tail and skirt devices were also assembled to compare with the two active rear drag device configuration. The passive aerodynamic devices chosen for benchmarking were the ATDynamics TrailerTail® and the Transtex trailer skirts. The TrailerTail® and trailer skirts are designed to maximize aerodynamic benefit while not significantly interfering with everyday trucking operations. The TrailerTail® is a 4-sided, hollow-cavity boattail design that extends 48" aft of the rear doors. The Transtex skirts tested were a 23' x 30" skirt. This passive aerodynamic package can be seen in Figure 14.

Figure 14. Passive Technology: Full Aero Package of Trailer Skirts and a TrailerTail

Testing Procedures

In order to achieve a real-world comparison of the technologies in a scientifically controlled manner, the SAE J1321 Type-II testing procedure was selected as the most rigorous fuel savings test method. In summary, the SAE J1321 Type-II testing procedure involves an unchanging control vehicle (C) run through a drive cycle in tandem with a test vehicle (T) to provide reference fuel consumption data. Each run through the drive cycle by the pair of trucks is referred to as a "lap." The test to control ratios (T:C) of fuel consumption are computed for a baseline where T is equipped the same as C, and are computed again under test conditions where T is equipped with the components being tested. The percent difference (PD) between the baseline T:C and the test T:C represent the percent difference due to the test component. The T:C used are averages of a minimum of 3 laps of a course >1.5 miles in length, however 5 miles is recommended. In accordance with the SAE J1321 procedure, a "test segment" consists of three laps in which the T:C of fuel consumption are within 2 percent. The SmartWay update[10] to the SAE J1321 Type-II protocol adds the following provisions:

1. Test must be conducted on a test track, not a roadway.
2. Test track length > 1.5 miles (5 miles recommended).
3. Track must be circular, figure eight, or oval in shape.
4. Track surface must be completely dry and well-maintained; surface typical of highway surfaces (asphalt or cement).
5. Grade change on test track not greater than 2 degrees.
6. Altitude of test facility not greater than 4,000 feet above sea level.
7. No precipitation on the test track for duration of test.
8. Ambient air temperatures at the test track must be between 5 C to 35 C (41 F to 95 F) provided that the air temperature during the entire test does not fluctuate more than 30 degrees F (approximately 16.6 C).
9. Wind speed at the test track cannot exceed 12 mph for duration of test.
10. Wind gusts at the test track cannot exceed 15 mph for duration of test.
11. Top speed of test drive cycle not to exceed 65 mph.
12. Test trailer configuration must be a typical dry box semi-trailer, 53' long, 102" wide, and 13' 6" high.
13. Trailers must be the same model and similar age, mileage and condition.

[10] SmartWay Research and Testing, http://www.epa.gov/smartway/manufacturers/testing.htm

14. Each trailer must have the same test payload. The combined weight of the trailer and payload must be approximately 46,000 pounds, +/- 500 pounds.

15. Test payload must be loaded over axle to be consistent with federal bridge laws. Payload must be secured so it does not shift during the test.

16. Tires must be inflated to manufacturer-recommended maximum cold inflation pressure prior to start of test.

17. Tires must be as similar as possible in size and condition, and have accumulated at least 500 miles wear-in prior to start of test.

18. The tractor-trailer gap must be as similar as possible on both pairs of trucks, as measured from the back of the tractor to the front of the trailer.

19. If testing a candidate tractor against a current SmartWay tractor model for the purpose of demonstrating SmartWay eligibility, the two tractors must have substantially similar drive train and power train configuration, including gear ratio, engine horsepower and size, transmission type, lubricant type, rear axle ratio, accumulated mileage, emissions aftertreatment system, etc.

20. If testing trailer modifications or trailer aerodynamic equipment, test tractors must be equipped with features typical of line haul combination trucks – e.g., high roof fairing, side cab extender fairings, and aerodynamic profile.

21. EPA must review and approve the test plan and the vehicle configurations prior to testing.

22. EPA reserves the right to review all test data and to reject any test it determines was not conducted in accordance with these provisions and/or SAE J1321, or otherwise not credible according to good engineering judgment.

ATDynamics conducted a survey of the testing facilities in the US that were capable of completing the SAE J1321 Type-II testing. The Goodyear Proving Grounds in San Angelo, TX was selected based upon the likelihood of favorable weather during March, the facility's experience with SAE fuel economy testing, the exclusive access to Wal-Mart's fuel economy test fleet, and the competitive cost to complete the testing. Wal-Mart collaborated with ATDynamics and provided their roll door-type trailers, which had been used in controlled test conditions previously, for the testing.

The SAE J1321 Type-II protocols require running a test vehicle and a control vehicle simultaneously to provide reference fuel consumption data, which achieves fuel consumption accuracy within +/-1%. The trucks and trailers met all SAE Type J1321 standards, with all tires inflated to 110psi and loaded to 46,000 lbs (total including trailer and payload). The test vehicle conditions can be found in Figure 15; however at the time of writing, specific trailer unit number/make/model used for testing the active devices was not available. All trucks and trailers were baselined according to SAE Type J1321 standards with three runs of over 40 miles used to baseline the trailers. Run-averaged fuel consumption was calculated from weighing a calibrated tractor fuel tank before and after each run. All SAE J1321 Type-II protocols for environmental conditions were satisfied for this test, however during Wednesday's testing the winds exceeded limits allowed by EPA SmartWay standards for SAE tests thus all subsequent results were all recorded with the qualifier that wind speeds were beyond the EPA limits. The run distance was for this course was 41.33 miles from 5 laps on an 8-mile test track.

The Goodyear Tire and Rubber Company Confidential 4/27/2010

Test Vehicle Information

Truck		Truck	
Unit Number:	7-0081	**Unit Number:**	7-0345
Make:	International	**Make:**	International
Model:	ProStar	**Model:**	ProStar
Mileage:	13,239	**Mileage:**	4,400
VIN:	2HSCUAPR38C566211	**VIN:**	2HSCUAPR38C687028
Engine Model:	Cummins / ISX400 ST	**Engine Model:**	Cummins / ISX400 ST
Trans Model:	Fuller 10-speed FR15210B	**Trans Model:**	Fuller 10-speed FR15210B
Axle :	Americor w/ ratio-2.64	**Axle :**	Americor w/ ratio-2.64

Trailer	
Unit Number:	310078
Make:	Vanguard
Model:	53'

Trailer	
Unit Number:	310045
Make:	Vanguard
Model:	53'

Tire Configuration

All Test Tractors: Steers- Michelin XZA3 - 275/80 R22.5
Drives- Michelin XDN2 - 275/80 R22.5

All Test Trailers: Bridgestone R195 - 295/75 R22.5

Comments: All Trailer tandems were set in the 4th hole unless otherwise noted. The air gap between the front of the trailer and the back of the Tractor was set to 43 inches.

Goodyear Proving Grounds
San Angelo, TX

Figure 15: Goodyear Proving Grounds Test Equipment Specifications

The AFC devices had the added element of fuel consumption by the motor and blower package. Before the start of each run, a technician would fill the gasoline blower motor up to a calibrated mark and then weigh the fuel jug. After each run, the same jug would be used to refill the gasoline motor and another weight would be recorded. The difference in the weights was used to determine how much fuel was consumed during the run to power the blower. Figure 16 shows the testing schedule of the GTRI device, Figure 17 shows the testing schedule of the TAU device, and Figure 18 shows the testing schedule of the passive devices. Individual device configurations were tested either following the SAE type II protocol, or with modified SAE type II protocol with less runs to move through testing of less desirable device configurations.

	Run	Blower RPM (start)	Blower RPM (finish)	Fuel Weight (before fill)	Fuel Weight (after fill)	Gasoline Used (lbs)	Equivalent Diesel Used (lbs)	T/C Ratio (before gas is counted)	Comments
Mon	1	2220	2240	24.34	17.74	6.600	6.455	0.9042	Outlier
	2	off	off	N/A	N/A	N/A	N/A	0.9504	Good run
	3	off	off	N/A	N/A	N/A	N/A	0.9332	Good run
	4	off	off	N/A	N/A	N/A	N/A	0.9486	Good run
Tue	5	2220	2220	24.2	19.6	4.640	4.538	1.0203	Outlier
	6	2210	2220	19.6	14.9	4.640	4.538	0.9628	Good run
	7	2210	2430	14.9	10.3	4.620	4.518	0.954	Good run
	8	2220	2110	25.4	20.8	4.560	4.460	0.9524	Good run
Fri	9	N/A	N/A	N/A	N/A	N/A	N/A	0.928	Baseline, outlier
	10	N/A	N/A	N/A	N/A	N/A	N/A	0.9888	Baseline, outlier
	11	N/A	N/A	N/A	N/A	N/A	N/A	1.0582	Baseline, outlier
	12	N/A	N/A	N/A	N/A	N/A	N/A	0.9618	Baseline, good run
	13	N/A	N/A	N/A	N/A	N/A	N/A	0.9598	Baseline, good run
	14	N/A	N/A	N/A	N/A	N/A	N/A	0.9531	Baseline, good run

Figure 16. Testing Schedule: GTRI Device

As can be observed the first runs were rejected as outliers, and the last few runs on Friday were used to examine the effects of lower driving speeds (all official test points were gathered at 65mph).

The testing performed with the TAU device was structured to collect as many data points as possible in the limited testing time available in the interest of creating a broad performance landscape of the technology. Thus testing was performed with a modified SAE J1321 procedure of each data point only being tested once instead of the standard three runs, allowing for an increase in the number of configurations tested. The 22 configurations tested included changes to the inlet pressure, the location and number of suction holes uncovered, and the location of the outlet ports to arrive at different configurations.

	Run	Blower RPM (start)	Tank Pressure (start) (psi)	Blower RPM (finish)	Tank Pressure (finish) (psi)	Suction Pressure (Pa)	Duct Pressure (psi)			Oscillation Frequency (Hz)	Cover Set	Suction Holes Exposed	Fuel Weight (before fill)	Fuel Weight (after fill)	Gasoline Used (lbs)
							Lower Vertical	Upper Vertical	Middle Top						
Wednesday	0	off	N/A	off	N/A	N/A	0.0	0.0	0.0	N/A	3	5	N/A	N/A	N/A
	1	2125	4.3	2120	4.3	-300	4.0	3.8	4.1	80	3	5	25.6	23.2	2.400
	2	2670	6.2	2670	6.2	-165	5.8	5.5	5.8	100	3	5,4	22.3	18.6	3.740
	3	2450	5.3	2430	5.3	-75	5.0	4.7	5.0	80	3	5,4,3	17.3	14.1	3.200
	4	2110	4.3	2110	4.3	-55	4.0	3.7	4.0	70	3	5,4,3	26.1	23.7	2.440
	5	2110	4.3	2110	4.3	-60	4.0	3.7	4.0		3	5,4,3	23.7	21.1	2.560
	6	2670	6.2			-130	6.0				3	5,4,3	21.1	17.4	3.680
Thursday	7	off	N/A	off	N/A	N/A	0.0	0.0	0.0	N/A	2	5,4	N/A	N/A	N/A
	8	2430	5.3	2430	5.3	-116	5.1	4.8	5.1	85	2	5,4	25.8	22.9	2.960
	9	2670	6.2			-156	6.0			100	2	5,4	22.9	19.2	3.660
	10	2670	6.2	2670	6.2	-390	6.0			100	2	5	19.22	15.58	3.640
	11	2960	7.4	2870	7.1	-152	6.8	6.0	6.6	105	2	5,4	25.44	21.4	4.040
	12	2900	7.1	2890		-161					2	5,4	21.4	17.3	4.100
	13	2930	7.1			-143	6.8	6.0	6.7	100	2	5,4	17.3	13.16	4.140
	14	off	N/A	off	N/A	N/A	0.0	0.0	0.0	N/A	2	5,4	N/A	N/A	N/A
	15	2970	7.2	2910	7.1	-161	6.8	6.0	6.7	110	2	5,4	25.04	20.58	4.460
	16	2970	7.2			-147	6.8	6.1	6.8	110	2	5,4	20.58	16.04	4.54
Friday	17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	19	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

	Run	Gasoline Used (lbs)	Equivalent Diesel Used (lbs)	T/C Ratio (before gas is counted)	Comments
Wednesday	0	N/A	N/A	0.9364	
	1	2.400	2.347	0.9607	
	2	3.740	3.658	1.007	
	3	3.200	3.130	0.946	
	4	2.440	2.386	0.928	
	5	2.560	2.504	0.9605	
	6	3.680	3.599	0.9291	
Thursday	7	N/A	N/A	0.9449	
	8	2.960	2.895	0.9526	
	9	3.660	3.579	0.9376	
	10	3.640	3.560	0.9457	
	11	4.040	3.951	0.9103	
	12	4.100	4.010	0.9632	Starboard pressure hose popped off after run had ended
	13	4.140	4.049	0.9143	
	14	N/A	N/A	0.9414	Run at 57mph
	15	4.460	4.362	0.9321	Run at 57mph
	16	4.54	4.440	0.9258	Run at 62mph
Friday	17	N/A	N/A	0.928	Baseline, outlier
	18	N/A	N/A	0.9888	Baseline, outlier
	19	N/A	N/A	1.0582	Baseline, outlier
	20	N/A	N/A	0.9618	Baseline, good run
	21	N/A	N/A	0.9598	Baseline, good run
	22	N/A	N/A	0.9631	Baseline, good run

Figure 17. Testing Schedule: TAU Device

The passive devices were installed on a dry van-type trailer provided by CRST, and thus had to be baselined separately.

	Run	Configuration	T/C ratio	Comments
Mon	1	Baseline	1.0333	Good run
	2	Baseline	1.0404	Good run
	3	Baseline	1.0499	Good run
Tue	4	MFS Skirts	0.9988	Good run
	5	MFS Skirts	0.9886	Good run
	6	MFS Skirts	1.0265	Outlier
	7	MFS Skirts	1.0540	Outlier
	8	MFS Skirts	0.9872	Good run
Wed	9	MFS Skirts and TrailerTail	0.9474	Good run
	10	MFS Skirts and TrailerTail	0.9332	Winds too high for Smartway, good data
	11	MFS Skirts and TrailerTail	0.8295	Winds too high for Smartway, outlier
	12	MFS Skirts and TrailerTail	0.9327	Winds too high for Smartway, good data
	13	MFS Skirts and TrailerTail	0.9596	Winds too high for Smartway, outlier
	14	MFS Skirts and TrailerTail	0.9230	Winds too high for Smartway, good data
	15	MFS Skirts and closed TrailerTail	0.9681	Winds too high for Smartway
	16	MFS Skirts and closed TrailerTail with tandems pushed back	0.9691	Tandems placed at California legal position, winds too high for SmartWay
Thu	17	MFS Skirts and TrailerTail	0.9484	Good run
	18	MFS Skirts and TrailerTail	0.9440	Good run
	19	Trailertail	0.9767	Good run
	20	Trailertail	0.9702	Good run
	21	Trailertail	0.9963	Outlier
	22	Trailertail	0.9713	Good run
	23	Trailertail	1.0031	57mph
	24	Trailertail	1.0000	57mph
	25	Trailertail	0.9847	62mph

Figure 18. Testing Schedule: Passive Devices

Status of Technology

Results

What is apparent about the results is that AFC technology shows promise if the efficiency of the motor and blower package can be increased significantly. Given that the structural configuration of the full-scale AFC alpha prototypes designed were not necessarily fully optimized, there is potential for AFC technology to deliver over 5% at the rear of the trailer. The best-case track testing results were composed into Figure 19.

	Test Configuration	% Fuel Saved (Best Case)
Active	GTRI device, blower off	1.48
	GTRI device, blower on	0.19
	GTRI device, blower on, with input fuel counted	-8.78
	TAU device, blower off	1.81
	TAU device, blower on, best configuration	5.00
	TAU device, blower on, best configuration, with input fuel count	-3.76
Passive	TrailerTail only	6.58
	Transtex skirts only	4.77
	Full aero package, high winds	10.72
	Full aero package, calm winds	9.09

Figure 19. SAE Results: Best Case

The GTRI technology as it was designed for this test showed little drag-reduction. An odd trend was recorded during the testing of the GTRI device losing efficiency once the blower was activated. This effect was repeatable across all three runs. This effect may be due to a non-ideal flow velocity exiting the GTRI device, which causes an excessive amount of shear effect upon the air passing the rear of the trailer.

Some of the configurations of the TAU device tested did show significant drag reduction. The best configuration tested reduced the fuel consumption by 5.0% compared to the baseline (before accounting for the fuel used to power the blower).

The passive devices tested alongside the two active flow control devices were repeatedly observed to provide large fuel-savings results. The TrailerTail® alone improved the fuel economy by 6.6% and the full aero package (TrailerTail® with skirts) saved between 9.1% and 10.72% depending on wind conditions which created additional efficiency gains for skirts.

Conclusions

As noted for the TAU device, the plumbing and air compression mechanism were not optimized for this system beyond providing sufficient pressure and flowrate to operate the device. Thus, it is quite possible that the GTRI device would benefit greatly from a more optimized compressed-air system. Upon sharing the design data and testing results with Bob Englar of GTRI, it was decided that the remaining road testing would be forgone in lieu of further laboratory development and product design by GTRI. The design data and testing results collected from this study will be valuable to guide further GTRI product development.

Avi Seifert, the head researcher from Tel Aviv who was on-hand for the testing, identified some simple design changes that could increase the drag reduction. In particular, the supply side had some tubing design that was causing a significant pressure drop between the source of compressed air and the ejection ports, and some simple plumbing changes could sharply reduce the power input and increase the device's efficacy. Implementing these design changes and identifying a more efficient source of compressed air has potential to make the TAU technology more attractive. ATDynamics and TAU researchers agreed that TAU would pursue solutions to the challenges faced by the technology seen in ATDynamics full scale road tests prior to further road testing.

Commercialization

The objective of the project was to quickly bring laboratory concepts to full scale to understand their current performance as well as the technology's operational and design challenges. At the conclusion of this project, ATDynamics agreed with its project partners that the AFC technology would benefit from further laboratory development. Specifically, additional development work needed to be done on high efficiency motor and blower systems as well as further testing on SaOB mounting systems to enhance airflow control. Thus, ATDynamics concluded that the passive technology remained the most commercially viable option for rear drag reduction within the foreseeable future due to its fuel savings, durable materials, and simplicity of system architecture. The company, therefore, will continue to focus its commercial activities on the rapid market penetration of these passive technologies while continuing to evaluate active flow control concepts on an annual basis with research partners. ICAT funding was critical in advancing research in AFC technology and reaffirming ATDynamics ongoing focus to advance passive aerodynamic technologies.