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Auto Stop-Start Fuel Consumption Benefits

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Abstract

With increasingly stringent regulations mandating the improvement of vehicle fuel economy, automotive manufacturers face growing pressure to develop and implement technologies that improve overall system efficiency. One such technology is an automatic (auto) stop-start feature. Auto stop-start reduces idle time and reduces fuel use by temporarily shutting the engine off when the vehicle comes to a stop and automatically re-starting it when the brake is released or the accelerator is pressed. As mandated by the U.S. Congress, the U.S. Environmental Protection Agency (EPA) is required to keep the public informed about fuel saving practices. This is done, in partnership with the U.S. Department of Energy (DOE), through the fueleconomy.gov website. The “Fuel-Saving Technologies” and “Gas Mileage Tips” sections of the website are focused on helping the public make informed purchasing decisions and encouraging fuel-saving driving habits. In order to provide users with accurate information about the auto stop-start feature, experiments were conducted to determine its fuel economy effect. Four vehicles were tested both with and without the feature enabled under three test cycles: the Federal Test Procedure (FTP) city fuel economy test, the US06 high acceleration aggressive driving schedule that is often identified as the "Supplemental FTP" driving schedule, and the EPA New York City Cycle (NYCC). The results were compared to measure the fuel economy and consumption effects of using the auto stop-start feature. It was found that the fuel economy improvement varied significantly between drive cycles depending on the amount and percentage of idle time during the test. The largest fuel economy improvements were 7.27% and 26.4% for the FTP and NYCC, respectively.

Introduction

The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) and the U.S. Environmental Protection Agency (EPA) jointly maintain a fuel economy website (www.fueleconomy.gov) that helps fulfill their responsibility under the Energy Policy Act of 1992 [1] to provide accurate fuel economy information to consumers. The site provides EPA fuel economy ratings and annual fuel cost estimates for passenger cars and light trucks from 1984 to the present, information on alternative fuels, driving and vehicle maintenance tips, and other vehicle fuel-economy-related information. The Oak Ridge National Laboratory (ORNL) conducts studies to provide, validate, and improve these tips [2–11] as part of its effort to support DOE. The main reason for providing information to the public is to increase understanding of vehicle fuel economy issues and to assist consumers in making informed decisions related to vehicle fuel economy.

The pressure on automotive manufacturers to improve fuel economy continues with the latest revisions to the corporate average fuel economy (CAFE) standards being set forth in a May 2022 National Highway Traffic Safety Administration (NHTSA) Final Rulemaking. In it, NHTSA set standards that increase at a rate of 8 percent per year for model years 2024 and 2025, and increase 10 percent for model year 2026, for both passenger cars and light trucks [12].

This paper documents a study aimed specifically at evaluating the benefits of an automatic (auto) stop-start feature on non-hybrid-electric vehicles. This technology was first introduced in very select vehicles starting as early as the mid-1970s and became more common in the mid-2000s [13–15]. “Since [the advent of the] European emission standard Euro 5, more and more vehicles include a start-stop system, whatever the price level” [16]. The primary benefit of reducing idling, through the use of auto stop-start technology, is the reduced fuel usage and vehicular emissions of CO_2 [17].The overarching goal of these features is to eliminate unnecessary idling and the fuel penalty associated with it. This is easily done for all hybrid vehicles, since the vehicle does not rely on the internal combustion engine to launch the vehicle from a stop. The auto stop-start feature, in non-hybrid vehicles, is therefore emulating the behavior of a hybrid electric, in order to eliminate unnecessary idling. Additionally, the share of non-hybrid vehicles employing the technology has increased substantially since 2012. Figure 1 shows the share of non-hybrid cars and light trucks produced with auto stop-start for model years 2012 through 2021 [18]. Nearly 57 percent of all light trucks and 23 percent of cars produced in model year 2021 had auto stop-start. Light trucks include pickups, sport utility vehicles, and vans. Auto stop-start has become a widely used feature to reduce fuel consumption and CO_2 emissions, particularly in congested cities [19]. Significantly better fuel economy can be achieved when implementing the engine stop-start technology, especially during city driving conditions [20].

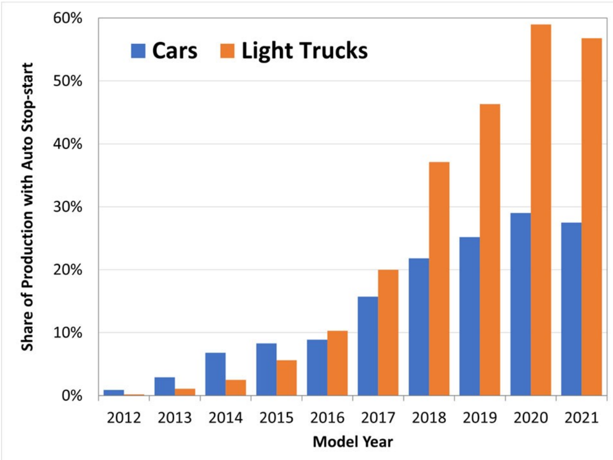

Figure 1. Market penetration of non-hybrid auto stop-start, model years 2012–2021

EXPERIMENTAL METHODS

VEHICLE TEST FACILITY

Vehicle testing was performed at the National Transportation Research Center (NTRC) vehicle research laboratory at ORNL. The laboratory features a Burke E. Porter 300 hp (224 kW) motor-in-the-middle, two-wheel drive, 48 in (1.219 m), single-roll, alternating current (AC) motoring chassis dynamometer. The dynamometer meets the requirements of the EPA Specifications for Large Roll Chassis Dynamometers. The road load generated by the dynamometer is nearly an exact approximation of what the vehicle experiences on the road, which consists of an internal drivetrain drag component, a tire rolling resistance component, and a wind resistance component. It might even be considered providential that this road load is conveniently represented by a quadratic equation: $A + Bv + Cv^2$, where v represents the vehicles velocity. The target A, B, and C coefficients, which represent the total load experienced by the vehicle's powertrain, are derived through an SAE procedure defined by J2263 [21] on the test track. The SAE procedure defined by J2264 [22] is used to determine the set A, B, and C coefficients for the dynamometer motor, such that the load from the dynamometer and the load internal to the vehicle combine to reproduce the total load for the vehicle's powertrain.

A 40 hp (30 kW) variable speed cooling fan (30,000 ft^3/min at 80 mph [850 m^3/min at 129 kph]) capable of maintaining wind speed proportional to wheel speed is used for vehicle tests. The fan outlet duct has a 25 x 25 in (0.635 x 0.635 m) opening. Additionally, the fan's pitch angle is adjustable, and it can be raised or lowered to properly blow directly into the front of the vehicle.

The laboratory is further equipped with an emissions bench that samples dilute exhaust from a constant volume sampling system (CVS or dilution tunnel), in Tedlar gas sampling bags, per the methods regulated by the EPA and described in the Code of Federal Regulations (CFR). The CVS is equipped with three critical flow venturis, allowing several discrete flow rates ranging from 200 to 1,050 ft^3/min (5.6 to 29.7 m^3/min). The CVS bag sampler is equipped with conventional California Analytical Instruments gas analyzers for measuring total hydrocarbons (THC), methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), and oxides of nitrogen (NO_X) concentrations. Additionally, the laboratory can also accommodate more advanced emissions instrumentation for particulate matter, ethanol, aldehyde, and other measurements. The ambient temperature in the test cell is controlled to 25°C±5°C (77°F±9°F). Fuel consumption measurements are made using an Emerson Micro Motion CMF010M Coriolis-effect flow and density meter. Measurements were made for both instantaneous and cumulative fuel consumption.

TEST VEHICLES

Four vehicles were tested to determine the fuel efficiency effect of auto stop-start features. The use of these particular vehicles was highly opportunistic. Each of the vehicles were selected based on either its availability from existing projects or a close collaborative relationship with the OEM, which could provide support in setting the vehicles into "dyno mode." Dyno mode allows the vehicle to operate in production intent when being tested on a single-axle dynamometer.

The first vehicle was a 2018 Chrysler Pacifica with a 3.6-liter V6 engine with 6,000 miles (9,656 km). The Pacifica had an equivalent test weight (ETW) of 4,750 pounds (2,155 kg) with the dynamometer set and target coefficients given in Table 1. The second vehicle was a 2017 Jeep Grand Cherokee with a 3.6-liter V6 engine with 44,000 miles (70,811 km) and rear-wheel drive. The Grand Cherokee had an ETW of 5,000 pounds (2,268 kg) with the dynamometer target and set coefficients given in Table 1. The third vehicle was a 2020 Ford Ranger with a 2.3-liter V6 engine with 19,000 miles (38,578 km). The Ranger had an ETW of 4,750 pounds (2,155 kg) with the dynamometer set and target coefficients given in Table 1. The fourth vehicle was a 2019 Toyota RAV4 with a 2.5-liter four-cylinder engine with 19,000 miles (38,578 km). The RAV4 had an ETW of 3,625 pounds (1,644 kg) with the dynamometer set and target coefficients given in Table 1.

Table 1. Dynamometer Target and Set Coefficients

	A (lb)	B (lb/mph)	C (lb/mph^2)	
2018 Pacifica 3.6L V6, 6000 mi 4750 lb ETW	27.15	0.2778	0.02345	Target
	9.14	0.084	0.02324	Set
2017 Jeep 3.6L V6, 44,000 mi 5000 lb ETW	46.11	-0.2283	0.03279	Target
	19.44	-0.4007	0.03270	Set
2020 Ranger 2.3L V6, 19,000 mi 4750 lb ETW	31.54	0.2932	0.03433	Target
	18.64	0.1475	0.03338	Set
2019 RAV4 2.5L I4, 19,000 mi 3625 lb ETW	24.47	0.2531	0.02189	Target
	6.96	0.1576	0.02214	Set

There are several factors that must be overcome to allow the auto stop-start feature to operate properly on the dynamometer. The easiest one to manage is the hood switch. The hood switch must be closed in order for the auto stop-start feature to operate. For these experiments, the hood switch was clamped closed all the time, which allowed the hood to be left open during the dynamometer testing.

This was desirable because it allowed the fuel lines to be routed to an external fuel flow meter.

There are also several safety features that will not normally operate on a two-wheel drive dynamometer (e.g., antilock braking, traction control, automatic emergency braking, and stability control). These safety features are disabled when the antilock braking system triggers a fault because it has detected the non-drive wheels being stationary. When these safety features are disabled, the auto stop-start feature will not operate. Fortunately, each automotive manufacturer includes a "dyno mode" in the powertrain control module [23] that disables these safety features for operation on a two-wheel drive dynamometer [24].

TEST PROCEDURE

Each vehicle was tested on the U.S. EPA's Federal Test Procedure (FTP) City Cycle and the US06 Supplemental Federal Test Procedure. The Ranger and RAV4 were also tested on the U.S. EPA's New York City Cycle (NYCC) [25].

The FTP, shown in Figure 2, represents typical city style driving with moderate acceleration rates and is used for emissions certification and fuel economy testing of light-duty vehicles in the United States [26]. The FTP cycle covers 11.04 miles (17.77 km) over a duration of 1,877 seconds with an average speed of 21 mph. The FTP includes 360 seconds of idling, which accounts for 19% of the FTP test.

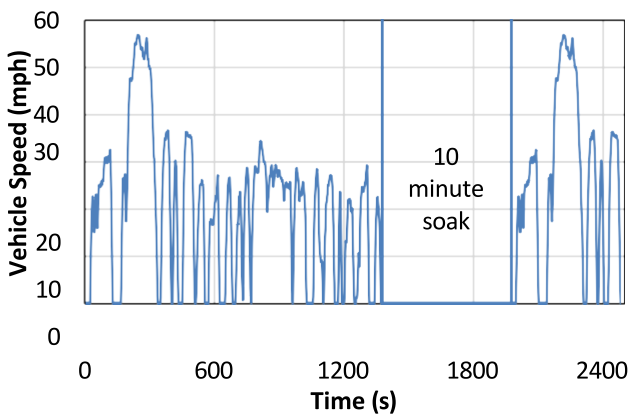

Figure 2. US EPA FTP Drive Cycle (speed vs. time)

The US06, shown in Figure 3, is a high-acceleration aggressive driving schedule giving a representation of aggressive, high-speed and/or high-acceleration driving behavior, rapid speed fluctuations, and driving behavior following startup [27]. The US06 covers 8.01 miles (12.89 km) over a duration of 596 seconds with an average speed of 48 mph. The US06 includes 40 seconds at idle, which accounts for 6.7% of the US06 test.

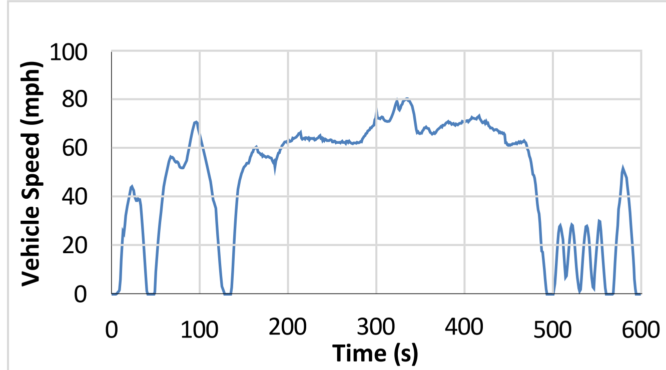

Figure 3. US EPA US06 Drive Cycle (speed vs. time)

The NYCC, shown in Figure 4, features low-speed stop-and-go traffic conditions. The test simulates low-speed urban driving with frequent stops [28]. The NYCC covers 1.18 miles (1.90 km) over a duration of 598 seconds with an average speed of 7 mph. The NYCC includes 226 seconds at idle, which accounts for 37.8% of the NYCC test.

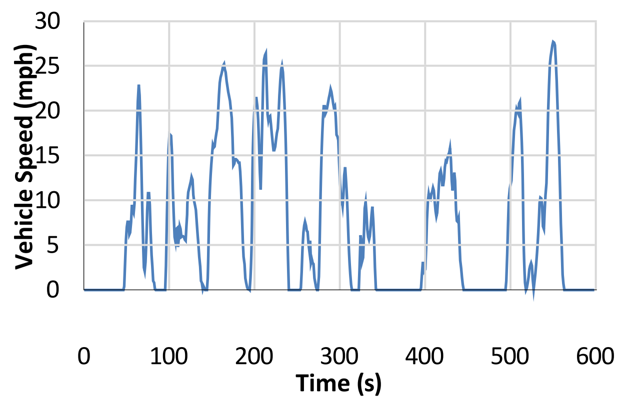

Figure 4. US EPA NYCC Drive Cycle (speed vs. time)

RESULTS

Results are presented in terms of both fuel economy (miles per gallon [mpg]) and fuel consumption (gallons per 100 miles). As with most unit standards, the US uses a different system than the rest of the world. However, converting between the two metrics can be accomplished by simply multiplying the reciprocal by a factor of 100.

When comparing the FTP test results with and without the auto stop-start feature activated, the Ranger showed the greatest fuel economy improvement (7.27%), and the RAV4 showed the least improvement (5.53%). Each test was run in triplicate, and the average results for all four vehicles can be seen in Table 2.

Table 2. FTP Results Comparing Vehicles Operating with and Without Auto Stop-Start (AS/S)

	FTP Fuel Economy [mpg]			FTP Fuel Consumption [gal/100 mi]		
	AS/S	no AS/S	% imp	AS/S	no AS/S	% imp
Pacifica	21.3	22.6	6.30%	4.7	4.4	5.93%
Jeep	22.2	23.5	5.97%	4.5	4.3	5.64%
Ranger	23.5	25.2	7.27%	4.3	4.0	6.78%
RAV4	35.0	37.0	5.53%	2.9	2.7	5.24%

For the US06, the fuel economy benefits were greatly reduced compared to the FTP. The largest benefit was seen with the Grand Cherokee at just under 1%. The RAV4 showed the least improvement at 0.42%. The results from all four vehicles can be seen in Table 3.

Table 3. US06 Results Comparing Vehicles Operating with and Without Auto Stop-Start (AS/S)

	US06 Fuel Economy [mpg]			US06 Fuel Consumption [gal/100 mi]		
	AS/S	no AS/S	% imp	AS/S	no AS/S	% imp
Pacifica	23.0	23.2	0.96%	4.4	4.3	0.95%
Jeep	21.0	21.2	0.99%	4.8	4.7	0.98%
Ranger	19.4	19.5	0.64%	5.2	5.1	0.63%
RAV4	30.2	30.4	0.42%	3.3	3.3	0.42%

The fuel economy benefits from the use of the auto stop-start feature on the NYCC were quite remarkable. For the Ranger, the fuel economy improvement exceeded 26%, which reinforces the impact of the idle time making up 37.8% of the NYCC test. Once again, the RAV4 had the lowest improvement in fuel economy, just under 22%. The results from both the Ranger and the RAV4 are shown in Table 4.

Table 4. NYCC Results Comparing with and Without Auto Stop-Start (AS/S)

	NYCC Fuel Economy [mpg]			NYCC Fuel Consumption [gal/100 mi]		
	AS/S	no AS/S	% imp	AS/S	no AS/S	% imp
Pacifica	–	–	–	–	–	–
Jeep	–	–	–	–	–	–
Ranger	11.8	14.9	26.4%	8.5	6.7	20.9%
RAV4	17.6	21.5	21.9%	5.7	4.7	18.0%

Summary/Conclusions

A total of four vehicles were tested to compare the fuel economy benefits of using an auto stop-start feature. The comparison was performed across three types of drive cycles with varying amounts of idle time. The cycles tested included the FTP, the US06, and the NYCC. This data is highly valuable to DOT and EPA to provide a referenceable study for the consumer fuel efficiency tips added to the fueleconomy.gov website.

The following key points were observed:

1. Fuel economy benefits varied significantly among drive cycles, depending on the amount and percentage of idle time during the test.
2. For the FTP cycle, the Ford Ranger showed the largest fuel economy improvement at 7.27%.
3. For the US06 cycle, the Jeep Grand Cherokee showed the largest fuel economy improvement at 0.99%.
4. For the NYCC, the Ford Ranger showed the largest fuel economy improvement at 26.4%.
5. Consumers with auto stop-start-equipped vehicles can save fuel and money by leaving the system engaged, particularly in congested settings where idling is common.

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Definitions/Abbreviations

AC	Alternating Current
auto	Automatic
°F	Degrees Fahrenheit
CAFE	Corporate Average Fuel Economy
CFR	Code of Federal Regulations
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CVS	Constant Volume Sampling
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
ETW	Equivalent Test Weight
ft	Foot/feet
FTP	Federal Test Procedure
hp	Horsepower
km	Kilometers
kph	Kilometers per hour
kW	Kilowatt
lb	Pounds
m	Meter
mi	Miles
min	Minute
mph	Miles per Hour
NHTSA	National Highway Traffic Safety Administration
NO_X	Oxides of Nitrogen
NTRC	National Transportation Research Center
NYCC	New York City Cycle
ORNL	Oak Ridge National Laboratory
THC	Total Hydrocarbons
US06 cycle	EPA high speed high acceleration supplemental FTP
VTO	Vehicle Technologies Office