

Variable and Fixed Airflow for Vehicle Cooling

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ABSTRACT

This paper describes rationale for determining the apportionment of variable or 'shuttered' airflow and non-variable or static airflow through openings in the front of a vehicle as needed for vehicle cooling. Variable airflow can be achieved by means of a shutter system, which throttles airflow through the front end and into the Condenser, Radiator, and Fan Module, (CRFM). Shutters originated early in the history of the auto industry and acted as a thermostat [1]. They controlled airflow as opposed to coolant flow through the radiator. Two benefits that are realized today are aerodynamic and thermal gains, achieved by restricting unneeded cooling airflow. Other benefits exist and justify the use of shutters; however, there are also difficulties in both execution and practical use. This paper will focus on optimizing system performance and execution in terms of the two benefits of reduced aerodynamic drag and reduced mechanical drag through thermal control. For a device(s) to receive credit for improved drag and fuel economy, performance in the EPA Coast Down test must be improved. If the device(s) are open in the Coast Down test, then the benefit will not be reflected in the fuel economy label. If the device(s) are over-utilized to exploit possible gains on the Coast Down, then the resulting label value will be better than the real world gain. In other words, to have an optimized system, the measured fuel economy value must be derived in a manner consistent with typical consumer use. To that end, this paper will explore the determination of, as well as the difference between every day use and severe use, and how to best provide the consumer the means of using only the fuel required to cool the vehicle, given the operating conditions.

INTRODUCTION

As the importance of fuel economy in today's markets grows, so do the acceptable costs of fuel saving technologies. Technologies can come in the form of mass reduction techniques, improved management of energy transformation, recycling energy used, or aerodynamic and mechanical drag reduction. This paper will discuss front end cooling airflow shutters, which is an emerging technology that may increase in usage in the market given its cost vs. contribution to fuel economy. A significant benefit of shutters is one of aerodynamics, which is realized mostly at highway speeds. There are other energy saving related benefits as well, such as, improved management of elevated transmission and engine oil temperatures, and improved cold weather warm up time. The topic discussed in this paper is how an OEM can go about giving the customer the most benefit with the least cost and accurately describe, without overstating, the benefit. The effect of shutters on cooling airflow while the vehicle is moving forward can be seen by demonstration in Appendix 2). There is very little in the literature about shutters to specifically improve automobile fuel economy. Their modern use has mostly been on heavy duty trucks to reduce front end air flow in low ambient temperature conditions. Work has also been done to demonstrate the fuel economy benefit on heavy duty trucks using shutters. [4]

AERODYNAMIC AND MECHANICAL DRAG BENEFIT

Determination of the aerodynamic drag benefit, as well as the mechanical drag benefit, requires understanding the EPA Coast Down procedure SAE J2263 [2]. The Coast Down event captures the mechanical drag, as well as the aerodynamic drag forces acting on the vehicle, while coasting in neutral. The Coast Down plot shows, graphically, speed degradation vs. time of coast. Assuming no other losses that

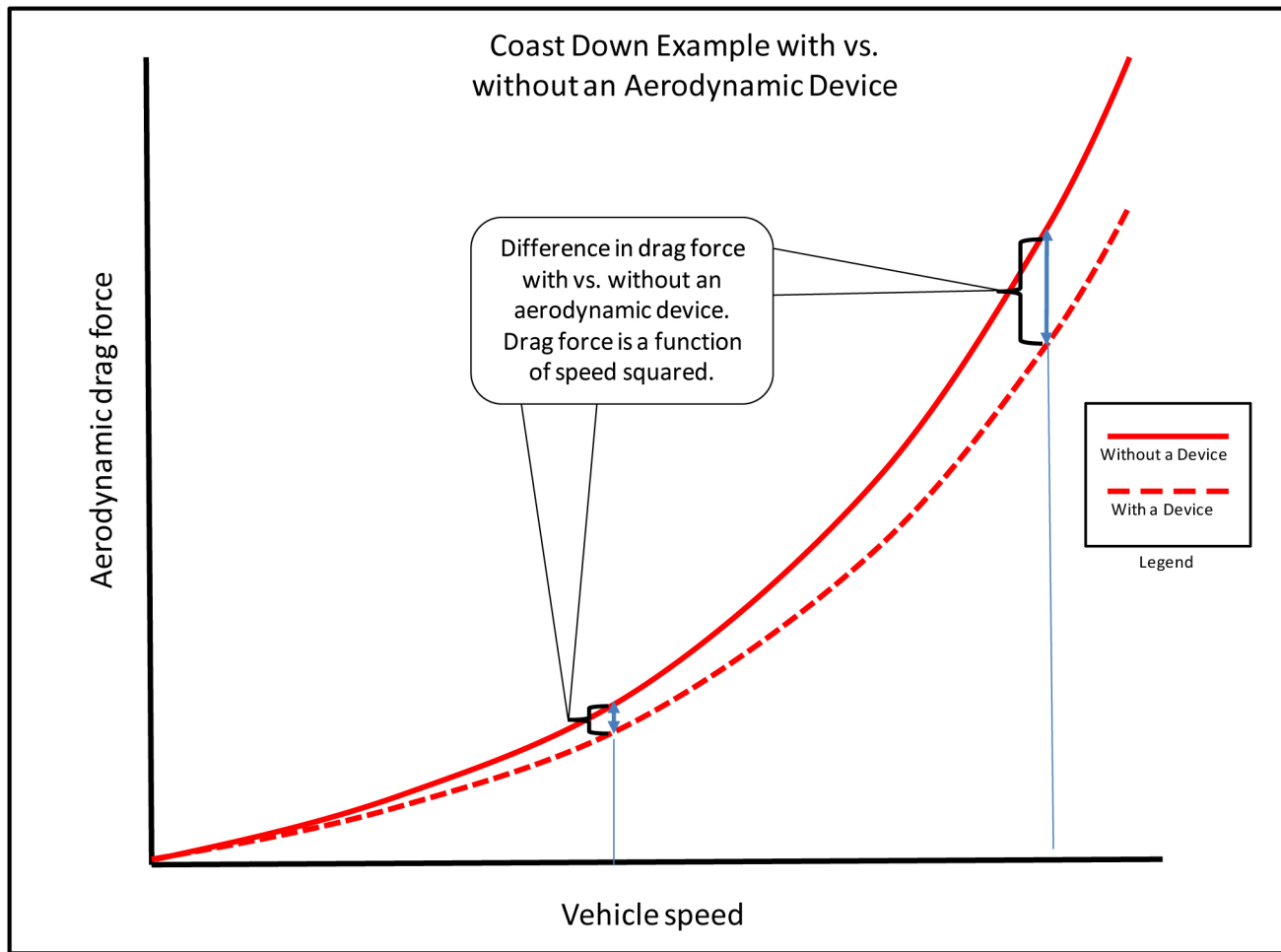


Figure 1. Vehicle Speed and Aerodynamic Drag Force in Coast Down

vary with the square of velocity, drag force can be calculated from the Coast Down plot. [Figure 1](#) shows a sample plot of vehicle speed vs. aerodynamic drag force during a Coast Down Test. The top, solid curve represents a baseline configuration, and the lower dotted curve represents the same vehicle with an added aerodynamic improvement. A similar graph could also reflect the effect of a device, or powertrain modification, which contributes to a mechanical drag improvement. As described later in this paper, shutters can contribute to both aerodynamic and mechanical drag performance improvements. In terms of the aerodynamic coefficient of drag, the 2011 Model Year Chevrolet Eco Cruze model, equipped with shutters, realizes an improvement of 0.009 for the automatic transmission model and 0.016 for the manual transmission model. These results were obtained in the General Motors Aerodynamic Laboratory. The results of the Coast Down are fed into the road load dynamometer profiles and the city and highway schedules are performed, which then determine the fuel consumption. Coasting from 120kph to 0kph in neutral is intended to gather the data needed to reflect the real world drag on a car that relates to real world usage. It is reasonable

to conclude that all ‘normal’ functions of the vehicle should be maintained according to expected use by the customer in the field.

The concept of ‘normal’ vehicle function during coast down is very applicable to Cooling Airflow Shutters, as there are conflicting motivations for throttling airflow during the Coast Down Event. Since cooling airflow through the grille and CRFM translates directly into aerodynamic drag, there is a motivation to block as much cooling airflow as practical. Conversely, to be in accordance with ‘normal vehicle function’ during the Coast Down, there is a motivation to provide, at least, the appropriate cooling airflow for the heat rejection needs of the vehicle in that condition.

There are three basic approaches with respect to the coast down procedure that can be taken when designing a cooling airflow shutter system. Each of these approaches will be referred to throughout the paper.

Approach 1) Fully Shuttered, Fully Restricted Airflow Path, (Restrict all cooling airflow with a fully shuttered airflow path from the start of the coast to the end of the coast).

- With this approach, the shutters can be commanded to close when the vehicle is in neutral and the accelerator is not being depressed. This approach will reap the maximum possible aerodynamic gain by completely blocking the front end cooling airflow through the grille(s). The disadvantage to this approach is when and how often will the consumer experience this condition. Even though the vehicle is coasting, the customer will rarely, if ever coast in neutral and there remains a need for heat rejection throughout the coast event. Certainly there are conditions and instances where coasting will occur in real world driving, however, there remains a need for some cooling airflow. Given this need, it is logical to conclude that restricting all cooling airflow during the coast event would interfere with 'normal vehicle function'. The result is lower drag force not reflective of real world use, which translates into a higher fuel economy label value that the customer may not experience. This is commonly referred to as a gap between measured fuel economy and real world fuel economy, which is undesirable and leads to customer complaints.

Approach 2) Fully Shuttered, Partially Restricted Airflow Path, (Partially restrict the cooling airflow with a fully shuttered airflow path and shutters in a partially open position allowing some ram [3] airflow).

- The cooling airflow needed by the vehicle during the coast event can be satisfied by partially opening the shutters. This could be achieved by a fully shuttered airflow path, (meaning all grille opening to be shuttered), that is partially open during the most or all of coast event. The disadvantage to this approach, is that the cost which is incurred for a shutter that covers the 'open' part of the airflow path, does not have any effect on the end result for the fuel economy determination. As far as the label FE, (Fuel Economy), value is concerned; there is no benefit to that portion of the device to be on the car. In addition, it assumes that there are significant opportunities to fully close during normal usage. There will be some infrequent conditions that would allow for the cooling airflow path to be fully closed, as well as some less infrequent conditions when shutters can be further partially restricted, however, the additional cost to fully shutter would begin to outweigh the benefit given in these 'off cycle' conditions, ('off cycle' conditions refer to fuel economy benefits that cannot be realized in the method defined by the EPA to determine fuel economy).

Approach 3) Partially Shuttered, Partially Restricted Airflow Path, (Partially restrict the cooling airflow with a partially shuttered airflow path. The shuttered portion of the path fully closed, and an open grille portion, without a shutter, allowing ram airflow).

- This Approach adheres to the intent of the coast down by ensuring that normal vehicle function and performance is maintained during the coast event. The shutters are taking advantage of the 'excess' cooling airflow, which is coarsely defined in the following section in [Figure 5](#)). To take maximum aerodynamic advantage of the shuttered airflow, the non-shuttered portion can be sized to meet the heat rejection needs throughout the coast event and for lightly loaded normal operation (EPA certification configuration). The remaining grille opening, which is shuttered, will therefore, tend to be automatically closed at the start and throughout the entire coast event. This condition is consistent with steady state operating speeds, with no grade or load, and no added weight from cargo or passengers, other than full fuel, air conditioning off, the front seat driver and passenger, per EPA certification requirements. The temperature is considered ambient, which is approximately 70-75F. Under this condition, the shutters remain closed and do not require cycling. The ram airflow that satisfies the vehicle cooling needs at highway speed and throughout the coast event can be the ram airflow that is delivered by the static, (opening without a shutter) grille opening. Refer to [Figure 2](#)), [Figure 3](#)), and [Figure 4](#)) below, as well as the following section. Satisfying cooling needs is defined as keeping engine coolant and under hood component temperatures in their acceptable ranges with a margin for typical air conditioning operation.

The shutter systems introduced by GM to date have been three vane systems with a single electromechanical actuator. The system cost per vehicle is easily justified by the fuel economy improvements they provide amortized by volume against the cost of compliance with the Corporate Average Fuel Economy regulations. The Craze shutter system adds approximately 1.3 Kg of mass per vehicle.

EVERYDAY AND SEVERE COOLING AIRFLOW NEEDS

The phrase 'Everyday Cooling Airflow Needs' cannot be defined universally. However, it is commonly recognized that vehicle cooling systems are designed with the intent of satisfying cooling airflow needs that are considered severe and not often seen by the consumer. In the description that follows, it shall be taken as a given that cooling airflow needs of a vehicle during the Coast Event reflect typical and commonly experienced cooling airflow needs in the real world. The Coast Event is a representation of "a" typical customer usage. There are many other conditions and situations, which the consumer experiences, that can be considered "normal". It should be recognized that future work can be done in this area to correlate cooling needs in the Coast Event with typical real world usage cooling needs, which can better define what can be considered 'excess' cooling airflow.

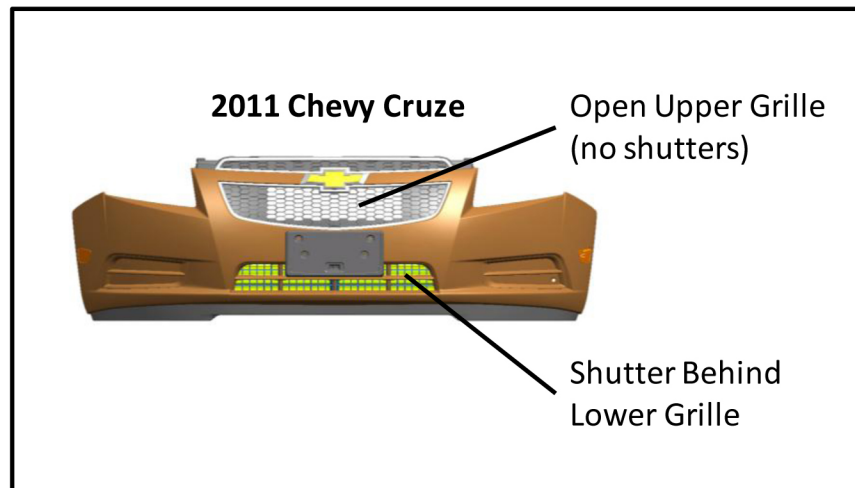


Figure 2. GM example of Approach 3) Partially Shuttered, Partially Restricted Airflow Path.

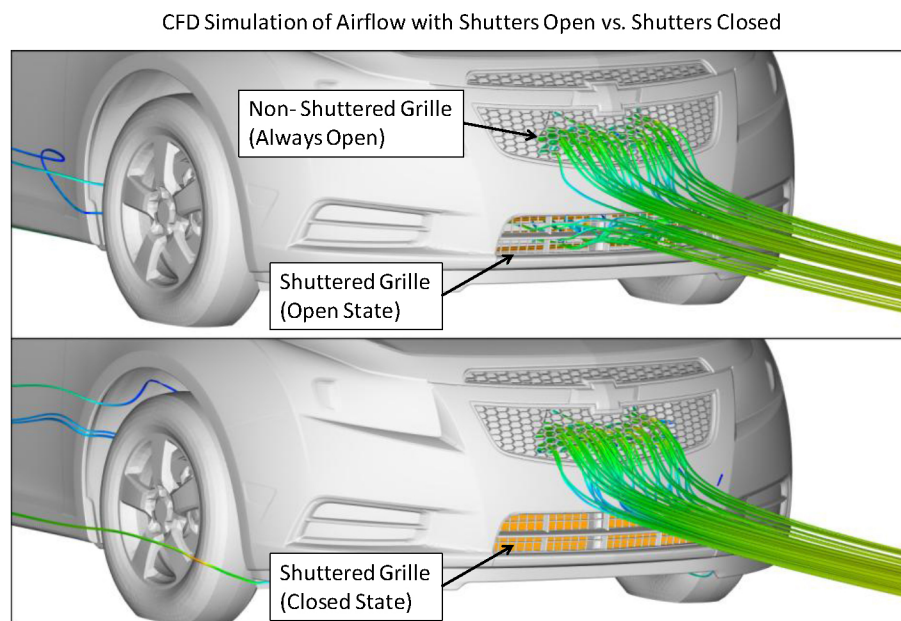


Figure 3. Effect of Shutters on Cooling Airflow

If the intention of the Coast Down event is to accurately capture the aerodynamic and mechanical drag characteristics of a vehicle while maintaining normal vehicle performance and function, then Approach 2) Fully Shuttered, Partially Restricted Airflow Path, and Approach 3) Partially Shuttered, Partially Restricted Airflow Path, would both fall within that intention. The advantages common between both 2) and 3) include: System behavior during the coast event is consistent with the conditions encountered at common highway speeds. Therefore the measured fuel economy, (FE), label value is more consistent with the FE value experienced by the consumer. An advantage that is specific to Approach 2) Fully Shuttered, Partially Restricted Airflow Path, is the ability to take advantage of certain off-cycle conditions where there

may be excess cooling airflow. This advantage comes with the cost of a fully shuttered airflow path. An advantage specific to Approach 3) Partially Shuttered, Partially Restricted Airflow Path, is the cost and complexity incurred by applying the device to the vehicle is completely taken advantage of in the coast event and therefore translated completely into the FE label value. The result of this approach is the most cost effective design. When compared to Approaches 1) and 2), Approach 3) provides the benefit with the least cost, complexity, mass, and other penalties incurred by adding additional content.

Having introduced rationale and methods of claiming benefits of variable airflow, as well as the topic of cooling airflow