Vehicle Front-End Active Aerodynamics

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Abstract
The objective of this project was to create a device, to be used as part of a total aerodynamic package, capable of actively modifying the downforce at the front of a high-end sports car to improve handling performance. This device works in conjunction with an existing active rear wing system designed by the sponsor, Aeromotions. The device developed for this project modifies downforce by actively controlling airflow through the vehicle’s front-lip vent openings via custom air valves. The efficacy of the initial concepts and final design were evaluated using extensive computational fluid dynamics (CFD) analysis. The custom air valves were designed with close attention to underbody space constraints, product reliability, and manufacturing costs. Market and patent research indicated that there are no similar products available.
The Need for Project

The developed device helps bring vehicle aerodynamics to an active level; downforce is continuously optimized for the situation. Racecar drivers and track enthusiasts push themselves and their vehicles to their absolute limits in an effort to lap the racetrack as fast as possible. In this extremely competitive world, innovation has continually led to new products which improve vehicle performance, allowing racers to get the edge on the competition. While vehicle suspension and engine management have evolved to into active systems, where settings adjust continuously to optimize performance as the car encounters different situations, aerodynamics has been left almost entirely static.

In the automotive industry, aerodynamics is the component of design that deals with the substantial forces generated as a vehicle moves through the air. Aerodynamic aids are devices designed to alter the air flow in a way that improves performance by modifying the downforce and/or drag. The project sponsor, Aeromotions, has designed an aftermarket rear wing system that actively adjusts based on settings in a control module which senses vehicle accelerations and speed. The developed front-end device ties in with the Aeromotions controller and rear wing to create a complete front and rear vehicle downforce optimization system.

The Design Project Objectives and Requirements

The front system must provide a meaningful lap-time reduction at a price that makes it a logical addition for rear wing customers or racers on a smaller budget.

Design Objectives

The project goal was to create a device, to be used as a total aerodynamic package, capable of actively modifying downforce at the front-end of a car to improve performance. This system will be installed on a Porsche GT3 RS. It needed to mount to the vehicle without modifying the cars non-wear components in an irreversible way. In addition, the appearance of the installed system needed to match the external body styling of the vehicle. This front system’s price to performance ratio must match that of Aeromotions higher priced rear system. This makes the front system a logical add-on to a rear system customer. It also allows racers with a smaller budget to have active aerodynamics at an entry-level price.

Design Requirements

This car’s lap times were reduced by 1.5 seconds at Virginia International Raceway (VIR) with the rear wing system installed. The
team’s goal is to reduce this lap time by an additional 0.5 seconds, or more, when the active front system is added. The actual performance benefit will be tested using a prototype system at VIR in May.

The system is projected to retail for around $2000. This matches the price to performance benefit ratio of Aeromotions rear-wing system. In order to achieve the minimum 35% profit margin, the product needs to be manufactured for under $1,300.

**Design Concepts Considered**

Two main concepts were considered to modify front-end downforce. The active splitter concept and active air valve concept would accomplish this task in very different ways.

**Active Splitter**

The first concept adjusts front-end downforce by equipping the vehicle with a splitter that actively controls its length. A splitter is a horizontal extension of the lower lip of a car that protrudes forward. A splitter provides a surface for the high pressure air in front of a vehicle to act on. Along with high-velocity, low-pressure air below the splitter, downward force is created. A well known racecar aerodynamic principal is that increasing a splitters length increases its downforce. This design concept exploits the principal in the most basic way.

The active splitter concept would have a splitter mounted to a slide assembly on the underside of the front-end. The benefit of this system is that large changes in downforce could be attained. However, the drawbacks include its size, weight, and complexity. This system required substantial design time, larger and more expensive components, and mechanical assemblies that would be prone to damage.

**Active Air Valves**

The second concept modifies downforce in a much simpler way, controlling airflow through vents in the vehicles front lip. This concept was inspired by racers who found that taping over the vents resulted in better traction. CFD simulations confirmed this effect, showing an increase in downforce of 10% with the vents closed. The simulations showed that closing the vents increased the size of the low-pressure zone at the front of the underbody.

In order to control airflow, small butterfly-style air valves were
mounted behind each front lip vent. The amount the vents are opened was determined by the Aeromotions controller, which also actuates the rear wing.

Recommended Design Concept

The active air valve concept is comprised of a compact air valve mounted behind the lip vent with a small section of splitter below. CFD simulations have proven the efficacy of this concept. The active air valve design concept was selected because it achieved a significant change in downforce from a much simpler, smaller and inexpensive package than the active splitter.

Design Description

There are three main components of the active air valve concept; the valve assembly, a duct that mates to the lip vent, and a static splitter or “splitlet”. This results in a product that is compact and simple to install. The actual cost is projected to be between $700 and $900, well under the $1,300 requirement.

Each valve assembly consists of a main housing, valve door, bearings and a servo. The housing features a custom profile flange designed to mate cleanly to the front lip vents via a custom silicone duct. This feature assists in maintaining the external styling of the vehicle and allows a less expensive 2D duct profile to be used. The cross sectional area of the valve closely matches the area of the lip vent to minimize losses. The housing protects the internal bearings, shafts and electronics from moisture and road debris. The servo was selected for its small size, high torque rating, and compatibility with Aeromotions existing controller.

The splitlets were added to magnify the change in downforce created by the active air valves. The profile of the splitlet was inspired by the factory body styling lines and aerodynamic splitter theory. The splitlet will see considerable wear-and-tear, thus it is an inexpensive ABS replaceable component.

Analytical Investigations

CFD simulations proved the efficacy of the active air valve concept. The software package used for pre-processing was ICEM-CFD and the solver was Fluent. Downforce increased by 10% when going from the valve-open to valve-closed condition. The image on the left shows the underside of the vehicle in both conditions. It can be seen that the low pressure zone is more pronounced in the closed condition, thus creating more downforce.

Further CFD studies demonstrated the benefits of adding splitlets
under the front lip. These splitlets are shown on the left in dark purple. When added, downforce increased 14.3% when going from the valve-open to valve-closed condition. An increase in absolute downforce was also an observed benefit. Compared to the no-splitlet simulations, downforce increased by 9.6% in the open-condition and 13.8% in the closed condition.

During the mechanical design of the valve assembly, finite element analysis (FEA) was performed using Abaqus. The force data collected from the CFD simulations was used as inputs for the model. The FEA models showed that the critical components in the system had a minimum factor of safety of over 3,000. The door and shaft assembly is shown to the lower left.

**Key Advantages of Recommended Concept**

*Lightweight* – Keeping race car parts lightweight is a top priority.

Each valve weighs only 2.25 lbs.

*Compact* – Early in the project, the underbody of the Porsche GT3 RS was mapped to create an envelope to design within. The active air valve concept fits within this envelope without altering the underbody.

*Inexpensive* – The active air valve concept falls well below the $1,300 cost requirement.

*Robust* – The active air valve concept has minimal moving parts, reducing possible failures. It is sealed to perform in harsh environments over long periods of time.

**Financial Issues**

Unit cost is approximately $700 per front system. These will be sold for $2000, representing 25% of the total cost of the full active-aerodynamics package. Pricing for this front system will be determined largely on the price to performance ratio of the rear system. The rear system sells for about $6,000 and was able to reduce the Porsche GT3 RS’s lap time by 1.5 seconds at VIR. The front system aims to reduce the lap time by an additional 0.5 seconds and would therefore be priced at roughly $2,000.
The product’s costs can be broken into the system’s three main components: the air valves, splitlets, and ducts. The air valve parts, including the servo, cost approximately $600. The splitlets cost about $50 if made from ABS plastic, however there will be an option for lightweight carbon fiber which would cost $200. The ducts require an initial setup charge of about $500 with a cost of about $20 per pair after that. Not including one-time costs such as tooling and fixturing, the total unit cost for a front system is $670.

**Recommended Improvements**

- **Track testing of the device will fine tune the design and provide information for the design of control logic.**

Track testing of the system will be required to fine tune the system to the handling characteristics of the Porsche GT3 RS. The most effective logic design is done through real-time experimentation and driver feedback on the track. Track testing will also indicate the actual torque required by the application. If the torque output of the current servo is overkill, a lower torque, cheaper servo can be substituted.