Automotive
Control
Solutions

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February 21st, 2005

Mr. Lakshman One
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 440 Project Functional Specification for the AF Optimizer

Dear Mr. One:

Please find the attached document, *Automotive Control Solutions' AF Optimizer –Functional Specification*, which outlines our project for ENSC 440. The included document contains all of the functional requirements of the AF Optimizer, as determined by the design team. The ACS team is currently well into the prototype development stage of the AF Optimizer, a low-cost, flexible air/fuel controller.

The purpose of this document is to specify exact requirements to be met by the AF Optimizer. These include environment requirements such as temperature and humidity, as well as requirements of the packaging and user interface. These requirements will met or exceeded at the prototype stage, with further design optimization before the final product is created. Together, these specifications will define the system's overall functionality, including end-user's application requirements.

Automotive Control Solutions is a company that is interested in providing electronic performance solutions for car enthusiasts. ACS is comprised of intelligent individuals who are in their concluding year of engineering science at Simon Fraser University; Alex Gutica, Brian Nelson, and Russell Potter. If you have any concerns with this project proposal, please feel free to contact us at acs-ensc440@sfu.ca.

Sincerely,

Russell Potter
President and CTO
Automotive Control Solutions

Enclosure: Automotive Control Solutions' AF Optimizer –Functional Specification

Automotive Control Solutions'
AF Optimizer
Functional Specification

Version 1.0 (January 2005)

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Executive Summary

This document outlines, in further detail, the functional requirements of the AF Optimizer project. This product fills a unique and expansive niche [1] in the after-market automobile part industry. The AF Optimizer will give users the ability to inexpensively install/uninstall an air-flow recalibration unit, with the result being consistent and accurate control of the air/fuel mixture. Current competitors, including A'PEXi, offer similar functionality to the AF Optimizer, at a premium price. The here-contained specifications will be comparable to competitors' products, satisfying more than the basic needs of our customer.

The project itself is comprised of two stages: the prototype stage and the production ready stage. The prototype will posses the following features:

1. Ability to track and modify the airflow sensor signal.
2. Programmable settings via buttons and a display
3. Ability to monitor other car data (battery voltage, RPM etc)

The final product will include prototype features, as well as:

1. A compact and professional package
2. A backlit multi-line display
3. A user manual

The prototype design and construction will be complete by the end of March, 2005.

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1 Introduction

The AF Optimizer product is intended to appeal to a wide variety of amateur auto enthusiasts. Once the product is designed and completed to specification, it will perform at or above the expectations of customers who are looking to optimize their air/fuel control. The product is currently in the design phase. The first milestone, the prototype, will be completed by the end of March, 2005. After that time, the design cycle will be integrated again to account for all those requirements intended for the final product.

1.1 Scope

This document outlines the AF Optimizer's technical requirements and specifications. From these specifications, we will design the product effectively to meet or exceed them. The requirements will all be quantifiable, and will not include any aspect of design specifications. This document will outline *what* the product does, and *what* conditions it will work under. This document will not outline any details as to *how* the AF Optimizer will perform these tasks and meet these requirements.

1.2 Intended Audience

Design engineers will use this document to create design specifications for the components that make up the AF Optimizer.

Entrepreneurial engineers will use this document to generate sources of funding for the prototype development and the initial production cycles.

Managerial staff will use this document to verify that our finished product has met all the intended specifications.

Potential customers of our company will use this document to inform themselves of all the functional features of our product.

1.3 Objectives

The objective of this document is to introduce and lay out all the functional specifications for the AF Optimizer. Each requirement will be given a designation in the format of: **{RNNy}**. The **NN** will be an identification number, which will be assigned in sequential order. As stated previously, our product will be set into two design stages: a prototype stage and a final product stage. The **y** will be a suffix designating the stage for each requirement. Those requirements given an "**a**" will be fundamental to the product, and will be met by both stages of the product. The "**b**" designation implies that the requirement will only be necessary in the prototype stage. Finally, a "**c**" designates that the requirement will only be functional in the final product stage.

Example:

{R38a} The airflow sensor must either be a manifold air pressure (MAP), or a vane airflow (VAF) sensor type.

This is requirement "**R38**", and it will be met by both product stages, as seen by the "**a**" suffix. The description clearly defines the requirement itself.

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2 System Requirements

2.1 System Overview

The AF Optimizer is an electronic controller that will be used as a tool to optimize a vehicle's air-fuel ratios. By giving the automotive enthusiast the ability to have a customized recalibration of their vehicle's airflow sensor, their vehicle can be made to run more efficiently with either increased horsepower output or increased fuel efficiency. We give the automotive enthusiast the capacity to easily and reliably recalibrate the air-fuel ratios throughout the mid and upper portions of their RPM range and at different throttle positions. The strict requirements with respect to the system's functionality will be discussed below.

{R01a} The AF Optimizer must be integrated into a vehicles wiring and interact with only the existing sensors and ECU.

{R02b} The AF Optimizer shall be installed and fit to perform in 4-cylinder vehicles.

{R03c} The AF Optimizer shall be fit to perform in vehicles with 4, 6, or 8 cylinders.

{R04a} The AF Optimizer must not distort in any way (signal must not be changed more than 2% from the unmonitored signal) the sensor signals that are being monitored, such as engine RPM and throttle position.

{R05a} The AF Optimizer must be able to output the car's airflow signal within 2% when the unit is operational and the airflow signal is left at stock calibration levels.

{R06a} The AF Optimizer must completely interrupt the vehicle's airflow sensor to allow it to perform a recalibration.

{R07c} The entire system must not disrupt any of the ECU's operations (must not throw any engine error codes) when the system is professionally tuned.

{R08a} The airflow sensor's value can be modified by ±25% limited by the 0-5 DC Volt operational range of the airflow sensor.

{R09a} The AF Optimizer will not interfere with the inherent feedback as introduced with increased air speed as the vehicles travelling speed increases.

{R10c} The AF Optimizer will have two modes of operation: a "calibration-on" mode and a "calibration-off" mode, where the signal of the airflow meter will be modified by a user-defined factor only when the "calibration-on" mode is chosen.

This system as described through the requirements listed above can be seen in Figure 2.1 below.

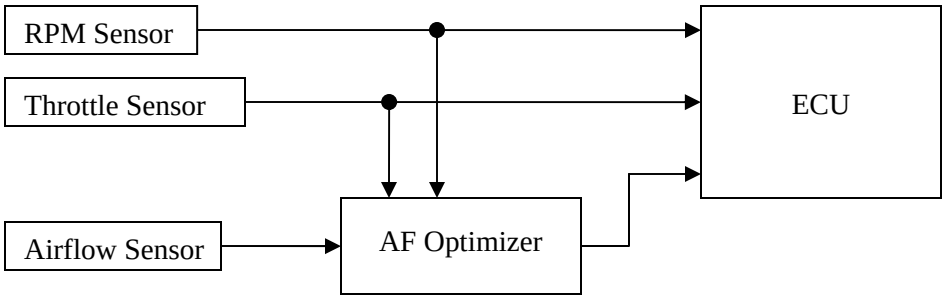

Figure 2.1 – Component and System Layout

2.2 Recalibration Requirements

As our system, the AF Optimizer, is allowing car enthusiasts to recalibrate their vehicle's airflow sensor, there are requirements of the recalibration system in order to provide the user with a comprehensive calibration system. This system must be robust so as to not disturb the operational nature of the vehicle, as described in requirement **R07c** above. The following requirements will be used to sufficiently provide the user with a system that will give flexibility and reliability to the recalibration system of the AF Optimizer.

{R11a} The airflow sensor recalibration function must not be a constant function, but rather a function of two variables, dependent on the engine speed and throttle position.

{R12a} The airflow sensor's recalibration factors must be able to be changed or altered as many times as desired or as required by the user.

{R13a} The recalibration factors shall only be changed by the user while the vehicle's motor is not running but ignition is on, and these changes will then take effect when the motor of the car is running.

{R14a} Recalibration factors should vary from 100% by ±25% in 1% increments.

2.2.1 Engine Speed Recalibration Requirements

The following requirements are specific to the AF Optimizer's function of recalibrating the airflow sensor based on the engine speed.

{R15a} The recalibration factors that are a function of engine RPM will have a resolution of 250 RPM, and range from 2000 RPM to 8750 RPM.

{R16a} The AF Optimizer will choose a point between the specified recalibration factors for all engine speeds between the user-defined points to prevent discontinuities.

The interpolation between the varying RPM values in our AF Optimizer will function like that seen in Figure 2.2a below, where the function is continuous. Figure 2.2b shows a system functioning with no interpolation between the recalibration factors. A system in which no interpolation is done will introduce unnecessary discontinuities. As one can see, the recalibration factors in the two systems are identical at the designate RPM calibration points; however, the

interpolation eliminates the discontinuities as seen in a stepwise function. The graphs show the normalized airflow signal, which is the re-calibration factor.

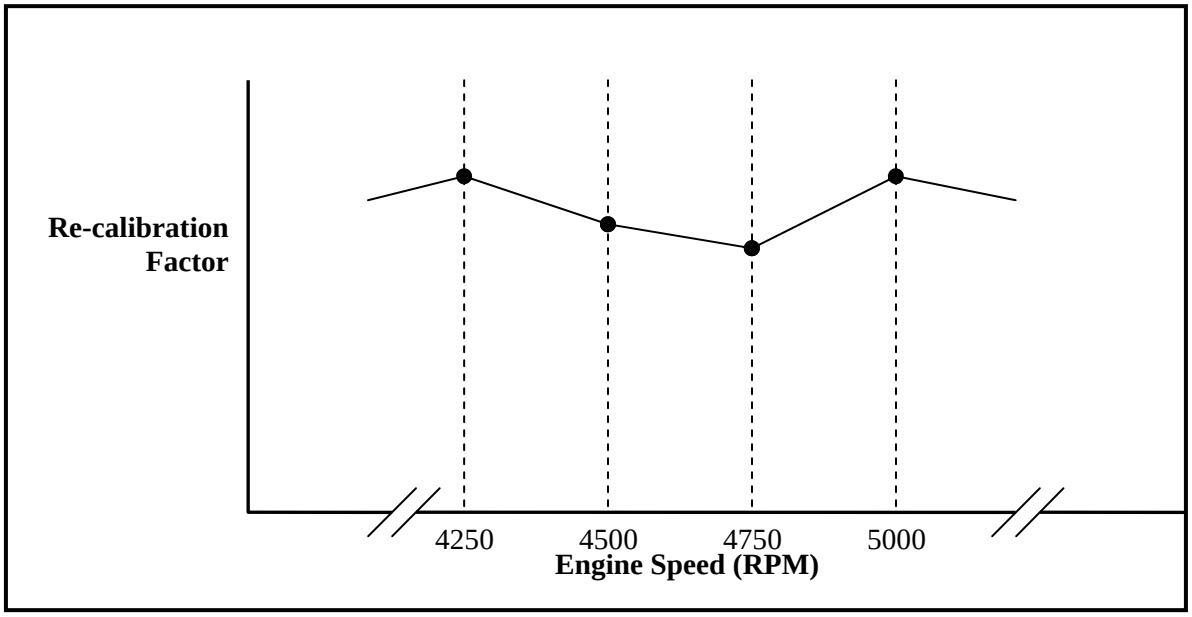

Figure 2.2a – Interpolated Re-calibration Factors as a Function of RPM

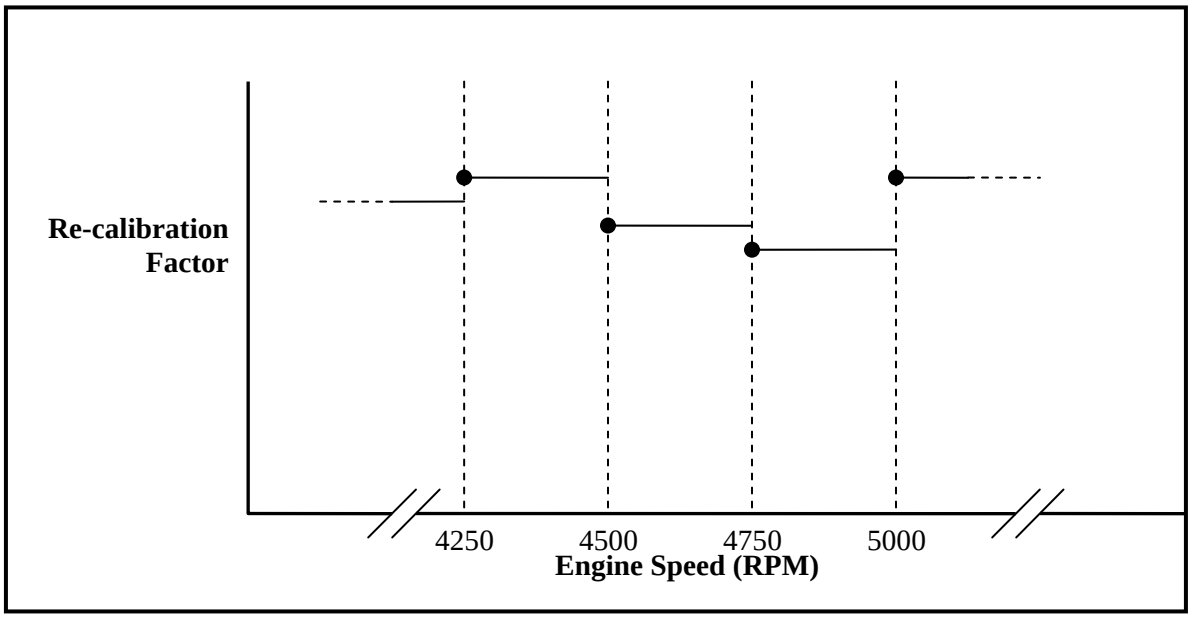

Figure 2.2b – Non-interpolated Re-calibration Factors as a Function of RPM

{R17a} For engine speeds below 2000 RPM, the AF Optimizer will function transparently, allowing the original airflow sensor signal to pass through un-calibrated within ±2%.

{R18a} For engine speeds above 8750 RPM, the AF Optimizer will use the low throttle and high throttle recalibration factors set for 8750 RPM.

2.2.2 Throttle Position Recalibration Requirements

In order to allow the user to tune their vehicle for fuel efficiency and output performance, the AF Optimizer will base its recalibration on a variable other than engine RPM: throttle position.

{R19a} There will be two sets of calibration factors to allow for the throttle position dependence; a high throttle calibration and a low throttle calibration.

{R20a} The low throttle calibration factors will be used when the driver's applied throttle is less than the user-specified low-throttle threshold percentage.

{R21a} The high throttle calibration factors will be used when the driver's applied throttle is more than the user-specified high-throttle threshold percentage.

{R22a} For the applied throttle between the two thresholds, the AF Optimizer will choose a point between the two calibration values.

{R23a} The user can choose any throttle percentage threshold points between 0% and 100% where the high throttle threshold is always at least 5% higher than the low throttle threshold to prevent discontinuities.

{R24a} The user is able to make changes to the throttle threshold percentages as desired while the vehicle motor is off and ignition is on, and these changes will take effect when the motor is running.

This interpolating functionality based on throttle position is shown in Figure 2.3 below.

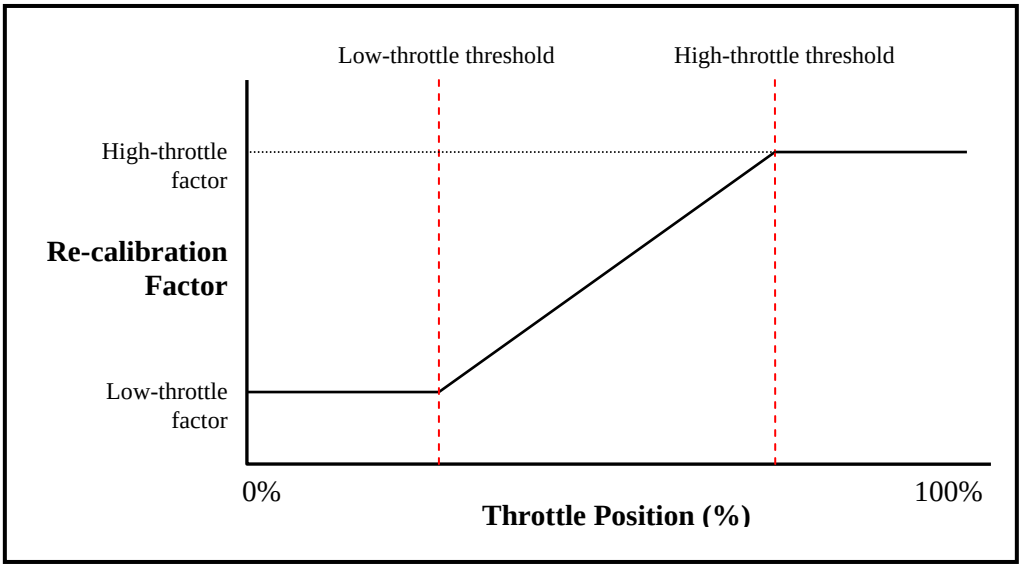

Figure 2.3 – Interpolated Re-calibration Factors as a Function of Throttle Position

One can see that the recalibration factors are a function of two distinct and independent variables. The recalibration factors will function to allow the tuning of a car's air-fuel ratios, thus it is of

utmost importance that these factors be implemented in a transparent fashion using interpolation to prevent unwanted discontinuities.

2.3 Physical Requirements

The requirements for size, weight, etc. are based on preliminary comparison of the standard of other automotive products on the market.

{R25a} The unit shall be fully enclosed (except ventilation) for testing the prototype in a vehicle.

{R26c} The unit shall be smaller than 5" x 3"x 2", excluding wiring.

{R27a} The unit shall be weigh no more than 681g (1.5lbs), excluding wiring.

{R28c) The interior of the AF Optimizer will have access to adequate cooling to keep the internal temperature from exceeding rated maximums, as discussed in Section 2.4 below.

{R29c} The unit will have two mounting points from which to fasten it to a vehicle/dashboard.

{R30a} The unit shall be constructed so that the back is removable, and the front has the display and buttons on it.

2.4 Environmental Requirements

The AF Optimizer unit will have to perform under all environmental conditions experienced inside the passenger cabin of a typical vehicle. The following temperature, humidity, shock and vibration specifications ensure that the unit will safely and reliably operate under all such conditions.

{R31b} The unit shall operate within performance tolerances for an ambient temperature range of 0 ^{0}C to 40 ^{0}C.

{R32c} The production unit will operate within performance tolerances for an ambient temperature range of -40 ^{0}C to 85 ^{0}C.

{R33a} The unit shall tolerate humidity ranges from 0 - 80%.

{R34a} Under normal operation, the temperature of the product case shall not exceed 30 ^{0}C, or 5 ^{0}C above ambient temperature, whichever is higher.

{R35a} The unit shall be able to withstand an operating and non-operating shock of up to 40G.

{R36a} The unit shall be able to withstand constant vibration at a frequency of 10Hz with amplitude of displacement of 1cm.

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2.5 Sensor Input Requirements

The Air-Fuel Optimizer is a vehicle air sensor re-calibration unit that has as inputs several of the vehicles existing sensors. These sensors are the airflow sensor, the throttle position sensor, the tachometer input signal, the oxygen sensor, as well as a direct input from the vehicle's battery. The airflow, tachometer and the throttle position sensors are required for the fundamental calculations of the calibration factors. The oxygen sensor and the vehicle's battery voltage are auxiliary inputs to the unit solely used for monitoring purposes.

{R37a} The unit must work with a vehicle equipped with a Bosch Jetronic electronically controlled fuel injection system that is implemented using the pre-OBD or OBDI engine computer management standards.

{R38a} The unit must work with the airflow sensor being either be a manifold air pressure (MAP), or a vane airflow (VAF) sensor type.

{R39a} The input from the airflow sensor must be an analog voltage signal with a range between 0 and 5 DC Volts.

{R40a} The input from the throttle position sensor must be an analog voltage signal with a range between 0 and 5 DC Volts.

{R41a} The input from the tachometer signal must be a digital square wave voltage signal with a voltage level swing larger than 5 DC Volts peak to peak.

{R42a} The input from the oxygen sensor must is an analog voltage signal between 0 and 1 DC Volts.

{R43a} The input from the battery supply must always be less than 20 DC Volts.

{R44a} The airflow, throttle position, tachometer, and oxygen sensors must all be available as inputs to the car's electronic control unit, (ECU).

2.6 ECU Output Requirements

The following requirements specify how the unit is to interact with the car's ECU. The performance of the AF Optimizer will depend on the characteristics of the ECU's input, such as input resistance, R_L, (higher is better) and the input capacitance, C_L.

{R45a} The product will output over a range of 0.01 to 4.99V with minimum resolution of 20mV ±10mV.

{R46a} The output will settle to its desired value in under 20 us.

{R47a} The product will maintain all output characteristics for $R_L > 1\ k\Omega$, $C_L < 100pF$.

2.7 Reliability & Serviceability

The AF Optimizer will be designed to perform reliably for a reasonable length of time (5 years or more). In the event of a part failure due to manufacturing defect, or customer misuse, major components of the AF Optimizer will be designed to be serviceable. In other words, functional units that malfunction will be replaceable/repairable, without having to replace the entire unit.

2.7.1 Durability

The Final product will be subjected to typical durability tests to ensure it will be exceed the expected level of durability for a product of its type. These include,

{R48c} The final product will perform normally after being dropped 10 times from a height of one metre. The landing surface will be smooth cement.

{R49c} The final product will perform normally after being cycled through its entire allowable ambient temperature range, while in operation, 100 times.

{R50a} The product will perform under continuous use for a period of up to 3 days without incident, and if a failure does occur after that period of time, it must be corrected by resetting the power to the unit.

{R51c} The MTBF (Mean Time Between Failure) should exceed 50,000 hours (around 6 years of continuous, 24 hour per day use).

{R52c} The product will come with a limited 2 year warranty.

2.7.2 Serviceability

The final product will also be serviceable, while still protecting the intellectual property contained in it. Servicing will be done by ACS in the event of a warranty or non-warranty product return.

{R53c} Key components such as the display module, the PCB, connectors, and the case should be replaceable using standard tools.

{R54c} The Firmware code shall be locked to prevent reverse-engineering by customers or competitors.

2.8 Safety

As with any electronics device, safety will be considered at all stages of product development. As laid out in the standards section, 2.9, the final product will comply with various standards for safety and performance as well.

{R55a} The product casing will not have any sharp edges, or corners, with a minimum fillet radius of 1mm.

{R56a} The product will require tools to uninstall or open, preventing children from opening or removing it.

{R57c} The production unit will include a hardware failsafe circuit in the event of failure of the microcontroller.

{R58c} The production unit will meet all North American Safety standards (see “Standards” below).

2.9 Standards

When the final product is being developed, it will comply with the various applicable North American consumer electronics standards. Consumers expect this level of compliance, and we also wish to ensure safe and compatible operation of the AF Optimizer.

{R59c} The AF Optimizer will be UL, CSA and CE approved for domestic use. [2] [3] [4]

{R60c} It will follow EN 50082-1:1997, and EN 55011:1991/CISPR 11:1992 +A2:1992 (Group 1, Class A) – RE/CE relating to electromagnetic compatibility. [4]

{R61c} It will follow the CSA C22.2 No 1010.1-92 safety specification, IEC 1010-1:1990+A1:1992+A2:1995, and UL 3111-1 [3]

3 User Interface

The user interface will provide the users of our product with a means to recalibrate their vehicle's airflow sensor.

This display will provide the user with the necessary information to adjust the airflow calibration in each of the desired tuning points across the vehicle's entire RPM range.

The user interface, in its entirety, will consist of a display screen, on which information will be relayed to the user, and navigation buttons to allow the user to scroll through the various user menus and input the airflow calibration factors.

Both the display module and the navigation buttons have physical and operational requirements that must be met in order to provide the users with the most comprehensive user interface solution.

{R62a} The user interface shall have a visual display to provide information visually to the user.

{R63a} The user interface shall have a means of input, momentary push buttons, so as to allow the user to communicate as desired with the AF Optimizer.

{R64a} The user interface must allow the user to interact with the AF Optimizer in order to change the airflow sensors recalibration factors while the car's engine is not running.

{R65a} The user interface should display real-time monitoring information to the user while the vehicle is running.

3.1 Visual Display

The display is the main feedback of the system with its users. Without a means of display, this electronic controller will not be able to provide the needed information to the user with regards to its use. Since the final product is to be used inside a car, the visual display must prove to have an acceptable level of operation in this specific environment.

{R66a} The visual display shall provide the user with sensor monitoring information either graphically or numerically.

{R67c} The visual display must be mounted to the front of the AF Optimizer casing without means of detachment.

{R68a} The display must provide visible characters or graphical information to the user at all times when the controller is in operation.

{R69a} The display must either be back-lit or have characters that are internally lit, in order to provide the best viewing at all times of the day.

{R70a} The display must be viewable at all angles in order to allow the driver to easily view the information provided by the display wherever the display may be mounted.

{R71c} The display should be able to provide variable brightness.

{R72a} The display must display characters or graphics of appropriate size so that users are able to clearly read the display from 1 metre away.

{R73a} The display must have more than 2 lines of display in order to display all the monitoring information to the user as well as to allow the user to easily view eight calibration factors at once.

{R74a} The display must be able to put at least 15 ASCII characters per line of display in order to allow the user to easily view eight calibration factors at once.

{R75a} The shift light display will provide the user with sequential graphical notification as the vehicle approaches a user-defined RPM point.

3.2 User Input

The user interface will consist of a display, having functional requirements as previously stated, and user input by way of momentary push buttons. These push buttons will allow the user to navigate through the menus, allowing him/her to successfully input recalibration factors to the AF Optimizer. The following functional requirements are specifically aimed toward these user interface input push buttons.

{R76c} The push buttons will be located on the front of the AF Optimizer casing, as stated in requirement **R30a**, to allow the user to operate the unit while it is installed in a vehicle.

{R77a} The AF Optimizer shall have 5 pushbuttons to allow for easy navigation without redundancy.

{R78a} The push buttons will allow for navigation in the following ways: Right, Left, Up, Down.

{R79a} The push buttons will be of appropriate size to fit with the display un-crowded on the front of the case, minimum spacing of 15mm between the centre of each button.

{R80c} An individual push button shall be no larger than 1 cm^2.

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4 Documentation/Support

The intended customer of the AF Optimizer is the enthusiast that uses professional services to modify their car in any way, or the do-it-yourself mechanic. Because both will result in the product being installed by a skilled person, the installation instructions will be written as a traditional automotive installation guide. The following requirements will be made for the user manual:

{R81a} The company website will contain user-manuals, Frequently Asked Questions, and product information.

{R82b} The prototype will have a short (below 10 page), English only user-manual with information pertinent to the product developers and testers.

{R83c} The production user manual will contain step-wise installation instructions written for a skilled mechanic, not a lay-person.

{R84c} The production user manual will explicitly define compatible vehicles and incompatible vehicles.

{R85c} The production user manual will be offered in English, French, Japanese, and Spanish.

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5 Product Verification Plan

As the product nears completion of each stage, an iterative product verification plan be executed. This will ensure that before the final product is being designed, the prototype product met or exceed all requirements contained in this document applicable to the prototype (those requirements with the suffix "**a**" or "**b**"). Once it can be shown that all are satisfied, engineering decisions will be made to bring the product to a mass-producible stage. Once all new functions have been incorporated into the final product, it too will be tested rigorously to ensure it meets all requirements contained in this document that are applicable to the final product (those requirements with the suffix "**a**" or "**c**").

Product Verification Plan:

1) Complete design and construction of prototype, built to specification
2) Verify the prototype satisfies all applicable requirements. If it fails one or more, go back to 1), or under exceptional circumstances, modify the requirement
3) Begin designing the production unit to meet functional requirements "a" and "c'
4) Verify the final production product sample meets ALL applicable requirements. If it fails, return to step 3), or under exceptional circumstances, modify the requirements.
5) Prepare a production plan for the product, begin manufacturing
6) Using a select number of requirements from this document, as well as a "hot" test (allow each manufactured unit to operate normally for a period of time in a test jig) to verify each product meets requirements. If a unit fails, return to 4) or 5), to investigate how the problem/defect occurred.

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6 Conclusion

ACS is poised to attack a massive multi-billion dollar aftermarket automotive parts market [5]. The world of aftermarket parts is youthful by nature, and consumers are demanding quality upgrades with solid engineering design for competitive prices. The AF Optimizer will satisfy all these demands, and will find its way into the dashboards of many enthusiasts. The benefits of the product will make it an easy sale: it can be used to create custom fuel maps; the cost will be a fraction of our competitors; the display provides a usable interface with useful feedback; and it will be a non-invasive install.

This document will be a reference for engineers, customers, distributors, and management alike. Not only does it define the functional specifications to which AF Optimizer will be designed, but in writing it the design team has given themselves an early focus and end-target for this exciting product. Doing so will result in a product engineered to a high standard of quality, functionality, safety, and value in a short period of time. Also, implied in the collection of requirements is the foundation of a product verification plan for the prototype, final product design, and final product manufacture.

Our team members have experience in both the engineering realm and the world of automotive. The project will demand a combination of hardware and software development, as well as a novel integration into a test vehicle. With thorough testing and precise programming, this unit will have proven reliability through its robust design. The aspirations and extensive skill of the ACS team will ensure that this product comes to fruition in a timely manner and within the projected budget.

Car enthusiasts will be able to use our product, through professional tuning, to realize a better performing car. Whether it is a car producing more power, or a car with better fuel economy, this unit will prove its versatility and ease of use to the $29 billion market [5], while maintaining itself at an affordable price point for all consumers.

7 Referenced Documents

[1] Proposal for ACS AF Optimizer. The Automotive Control Solutions Team.

[2] CSA International. 2005. Canadian Standards Association. 9 Feb 2005. <http://www.csa-international.org/manufacturers_distributors>.

[3] UL StandardsInfoNet. 2005. Underwriters Laboratory Inc. 9 Feb. 2005 <http://ulstandardsinfonet.ul.com>.

[4] Ramie, Jerry. July/August 2001. EMC Testing and Design: The Impact of Emerging European Standards. 9 Feb. 2005 < http://www.ce-mag.com/archive/01/07/ramie.html>.

[5] Schoenbachler, Mike. November 2004. 2004 SEMA Show an International Industry Sensation. 23 Jan. 2004 <http://www.semashow.com/content/?id=31812>.