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FINAL REPORT

Methods to Increase Fuel Efficiency in Post-Production Automobiles

NITC-SS-737 ■ *April 2015*

*NITC is the U.S. Department of Transportation's national
university transportation center for livable communities.*



METHODS TO INCREASE FUEL EFFICIENCY IN POST-PRODUCTION AUTOMOBILES

Final Report

NITC-RR-737

by

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EXECUTIVE SUMMARY

Many arguments can be made for the need to reduce the consumption of fossil fuels in automotive transportation in the U.S. Most research in this area has focused on bringing new vehicles to market, including improved efficiency in vehicle design, hybrid-electric vehicles, full electric vehicles, and vehicles relying on alternative fuels.

However, much of the rolling stock in the U.S. and globally will continue to be used for many years. Since these vehicles contribute substantially to the consumption of petroleum fuels and will for the foreseeable future, there is potential for significant reduction in fuel consumption by improving the fuel efficiency of these vehicles. Any equipment or process to reduce fuel consumption must be cost effective or consumers who have the resources may purchase vehicles with emerging technologies, and those without will simply continue to drive vehicles at lower efficiency.

This research examines potential improvements in post-production vehicle fuel efficiency, and establishes a set of equipment and protocol for further research into fuel-efficiency improvements.

Fuel efficiency of post-production vehicles can be measurably improved by modifying the coding of the vehicle's electronic control unit (ECU) to manipulate the air/fuel ratio and spark the engine's ignition timing, resulting in increased fuel efficiency without a noticeable decrease in automobile performance. This low-cost modification, potentially applicable to most cars built in the 1980s and later, requires minimal investment by the vehicle operator, and fuel savings may offset that cost.

A 1994 Honda Civic DX sedan was modified to include a Hondata s300 tuning system, allowing the ignition timing and air-fuel ratio to be modified , which is otherwise not possible on this and similar vehicles. This allowed modification of both the standard fuel and the standard spark ignition maps used by the vehicle, resulting in a reduction in fuel consumption per mile driven.

Before modification, the vehicle was driven to establish its baseline fuel economy, an average of 34.0 MPG. The vehicle was then tuned to industry standard conditions, improving fuel economy marginally to 34.3 MPG. The vehicle was also tested for compliance with Oregon state emissions standards.

Vehicle horsepower and torque were measured using a dynamometer in an auto tuning and repair shop to ascertain the impact to system output of the experimental trials in altering the tuning maps. Using the Hondata, the vehicle was tuned to have a leaner air-fuel mixture, and then driven under conditions similar to those driven under the base tune. Implementing this lean fuel map alone resulted in an improvement in fuel economy of 2.5 MPG to 36.9 MPG. Combining the lean fuel map with a spark map that advanced the ignition timing further increased the average fuel economy to 40.1 MPG, with a maximum obtained fuel economy of 52.6 MPG under

near optimal highway driving conditions. Greater fuel economy improvements were seen in general under highway driving conditions than in stop-and-go or urban driving.

In these trials, the vehicle's performance was not noticeably affected. For example, this make and model of vehicle was shown under standard conditions to perform sub-optimally in climbing hills at high speed under standard conditions; the changes to the fuel and spark maps did not noticeably change this performance.

The tuning of the spark and fuel maps resulted in a decrease in carbon dioxide emissions from the vehicle, but an increase in carbon monoxide emissions. The relative benefit or harm of this outcome is not assessed in this study.

Though this study focused on a single vehicle, the results establish that improvements in fuel economy through changes to fuel and spark ignition maps are attainable without major modification to the vehicle or engine. This investigation also establishes a platform for additional study of modifications to vehicle operation which could further reduce fuel consumption without substantial reduction in performance.

This low-cost approach to improve the efficiency of existing vehicles could be promoted by auto repair and tuning shops that could potentially profit from performing these modifications, or by government or public service entities interested in reducing fossil fuel consumption.

1.0 INTRODUCTION

1.1 INTRODUCTION

This work shows that fuel efficiency of post-production vehicles can be measurably improved by modifying the coding of the vehicle's ECU to manipulate the air/fuel ratio and spark the engine's ignition timing, resulting in an increase in fuel efficiency without a noticeable decrease in automobile performance.

1.2 BACKGROUND AND PROBLEM STATEMENT

The fuel economy of post-production automobiles can be measurably and inexpensively improved. Fuel efficiency in consumer transportation is an issue which currently attracts a great deal of attention. While it is generally accepted that an increase in the overall fuel efficiency of vehicles in use would assist in the reduction of dependence on foreign oil, the mitigation of climate change, and other economic and environmental benefits, there are many possible avenues by which this goal may be accomplished.

The majority of attention to this issue has been focused on automobiles entering the marketplace, not to the vehicles already on the road today. Discounting a plethora of possible alternative fuel systems currently in production or development, there are many mechanical and physical variables which have an effect on the way the internal combustion engine, transmission and other components of a typical car or truck interact. These component interactions, coupled with the effects of the natural world on the vehicle in motion, have an impact on the thermodynamics of engine operation and observed fuel efficiency. Therefore, there are many avenues by which one may affect the fuel efficiency of a vehicle, with variance in the observed gains in fuel efficiency depending on the method utilized.

Cars and trucks already on the road have and will continue to have a tremendous impact on petroleum consumption in the U.S. While much focus has been placed upon the identification of completely novel technologies for the future of personal transportation worldwide, the majority of the U.S. and the world at large will rely upon petrol for personal transportation well into the future. Alternative fuel vehicles, electric vehicles and hybrid cars have all started to make an impact on the market, but their relative market share is and is projected to continue to be low. Furthermore, a large segment of the population is not readily able to purchase a new car and, therefore, such technology only becomes economically accessible years later on the secondary market. If a car is less expensive to operate for a consumer, it is less likely to be traded in for a newer model, which bears its own environmental impact as the retired vehicle may be "junked" and become part of the waste stream. The initial work discussed herein serves as the basis for further research into the largely scientifically uninvestigated field of consumers' ability to improve the fuel economy of their existing automobiles.

Private mechanics and enthusiasts undertake much of the investigation of modification and maintenance of used cars with little official academic documentation. Most knowledge is passed between automotive shops or between individuals by word of mouth or the Internet. Therefore, much of this received knowledge does not carry empirical evidence, which makes it difficult to implement with confidence or to apply to multiple makes and models. This is partly due to the fact that most car manufacturers use proprietary designs for engines and all other car components; there is likely more economic incentive to dedicating engineering efforts towards new vehicles than towards after-market improvements of cars already on the road. However, the fact that there is little academic research on the efficiency or improvement of post-production (used) vehicles points to the dearth of hard data on the subject. Furthermore, some third-party aftermarket parts manufacturers exaggerate the gains in power or fuel economy that their products provide as a selling tool, which further confounds the issue of reliability and significant gains relative to purchase price for the consumer.

This project sought to accomplish two goals. First, the investigation aimed to ascertain attainable fuel-efficiency gains from the reprogramming of vehicles equipped with early ECUs. Secondly, this research was aimed at establishing a platform upon which further empirical research on fuel efficiency and the modification of automobiles for such purposes may be conducted. Both the experiment and the modification of the vehicle itself were designed with these twin goals in mind.

1.2.1 Previous Research

Through the investigation of both academic and popular colloquial literature regarding fuel-efficiency optimization in automobiles detailed below, it was hypothesized that the original manufacturer's ECU coding for the test car (and presumably for most mass-produced automobiles) was not optimized for fuel efficiency. While there is a dearth of academic literature on this subject, there is a wealth of information gathered by amateurs and tradespeople and available on the Internet. This research seeks to bridge this gap in the academic literature and to develop the basis for a low-cost modification or series of modifications which may be performed on most conventional cars possessing ECUs (those made in the 1980s and later, generally). Such a method would allow for increased longevity of those cars already built through the extension of their effective lifetime of use, while also reducing the environmental impacts of normal operation which would otherwise go unmitigated. This investigation seeks to ascertain a method for utilizing only the minimum amount of gasoline required for engine operation without impacting performance. In addition, this method was tested in driving conditions meant to model general consumer driving patterns.

Although much attention is paid to the potential of alternative fuels, it is apparent that there is no agreed-upon replacement to gasoline and diesel fuels for the purpose of transportation in the near future. Automobiles which are at least partially driven by gasoline will be an integral aspect of the environmental and energy outlook in the near future. Therefore, investigation of the most efficient consumption of fossil fuels will be important for the seamless integration of alternative energy into transportation infrastructure and public consciousness. Following is a review of some

relevant literature on improvements to efficiency and reduction in consumption of petroleum-based fuels, excluding hybridization.

Unburned hydrocarbons (UHC) are a key source of air pollution emitted from internal combustion engines (Fulcher et al., 1996). They are seen in the emissions of internal combustion engines in the largest quantities during initial engine firing when fuel mixtures are richer, especially when the engine is cold-started. In all cases, UHC emissions decrease and then stabilize in the first few seconds of engine operation. Precise fuel-injection techniques, especially air-forced fuel injection, have been shown to assist in reducing the large amount of emitted UHC. This is due to more complete burning of the liquid fuel. When air-forced injection is utilized, the amount of UHC emitted is less than that seen in propane-burning internal combustion engines.

Recently it has also been shown that some UHC which exist in the upper portions of the intake ports of a typical internal combustion engine are heated and vaporized to some extent, and are burned after the initial combustion of the injected fuel-air mixture (Cowart, 2006). The intake port puddles are seen to normalize very quickly (~1 second) after engine start. The amount of vapor formed increases with the engine temperature.

There has also been work done to model the vapor/liquid equilibrium under engine running conditions (Cowart, 2003). This is a complex and dynamic system, requiring a temporal element to the changing gas and liquid phases of fuel during the high-pressure combustion situation seen in internal combustion engines. Gasoline and diesel display different vaporization characteristics. Gasoline displays a long lifespan for liquid droplets in combustion, as operation pressure and temperatures are both lower in gasoline internal combustion engines than that required for fuel vaporization. Diesel engines, on the other hand, operate at conditions which allow for vaporization to occur in the cylinder, causing fuel droplets to persist for a shorter period of time.

Saidur et al. (2012) investigated recent research in methods of exhaust heat recovery for internal combustion engines. In normal engines exhaust gasses account for a significant percentage of the fuel combustion energy, and are generally lost to the environment through the tail pipe. Therefore, it is a useful source to recover for additional electrical or mechanical energy, and certain methods may also assist in the reduction of emissions. Thermoelectric generation has recently been a popular area of research for exhaust recovery in automotive applications. Thermoelectric generators (TEG) have a variety of applications for the operation of a typical automobile. First, a TEG device may be used in place of the alternator, generating electricity from exhaust to recharge a typical car's battery. TEG may be mixed with other technologies, and is especially suitable for use in conjunction with hybrid vehicles, solar supplementation and the use of maximum power point tracker technology. Efficiency gains vary, but the advantage of TEG technology is that there are higher efficiency gains in higher temperature situations, which is useful for long-term use of an automobile. Additionally, six stroke cycle engines are also discussed. Rather than the typical four strokes seen in conventional engines, two additional strokes utilize the exhaust gas from the initial strokes with injected water for additional efficiency and a reduction in emissions. Rakine bottoming cycles are also investigated, which utilize a recirculating fluid and a heat exchanger to do additional mechanical work. Both Honda and BMW are recognized as automakers who have found a 10% gain in efficiency using such a

method. Rankine bottoming cycle technology could also be used in conjunction with TEG. Turbocharger technology allows engines to be downsized to produce a similar power output while also increasing fuel efficiency. However, a common issue for turbocharger use in this manner for automakers has been turbo lag at lower engine rpms, in which there is a stall in output power by the engine as the turbocharger “spools” to full power output. The investigators note that variable geometry turbines within the turbocharger can allow for the lower output of the engine exhaust at a lower rpm, and increase resistance through the turbine as output increases, reducing turbo lag. Two-stage turbo charging systems could also be utilized to reduce lag, with a small turbo for use in low-speed situations switching to a larger spool turbo as revolutions increase.

In an effort to pinpoint the benefits of efficiency technologies when used in internal combustion engine (ICE) applications, a review was conducted to gauge the efficiency gains of selected strategies and their use in conjunction, as well as their effect on emissions (Caton, 2012). High compression ratios, lean burning and a high level of exhaust gas recirculation (EGR) were among the strategies reviewed. Thermal efficiency showed a marked increase, moving from 37% low compression ratio (CR) and no additional technology, to 53.9% when high CR, lean burning, short burn duration and high exhaust gas recirculation (EGR) are all used in conjunction. This is due to the lowering of engine temperature during operation with these strategies. Additionally, when a higher CR, lean burn and shorter burn duration are used in conjunction, nitric oxide emission levels increase. However, when these technologies are used in conjunction with EGR, nitric oxide emissions are reduced to nearly zero, with typical engines producing close to 4,000 ppm nitric oxides in normal operating conditions. While a preferred method and technology for EGR and other efficiency technologies is not generally agreed upon, further research is warranted as the efficiency gains observed could prove to save a large amount of fuel and significantly reduce emissions due to transportation.

Laser ignition has proven to be a promising possible source of improved efficiency and reduced emissions for ICE cars (Morsy, 2012). While other technologies have investigated ways in which an engine can run on a leaner air-fuel mixture, this can cause issues in flame initiation, propagation and misfiring. Laser ignition can be used to alleviate these issues, in addition to providing its own increase in efficiency. In general, increasing the pressure inside the cylinder can lead to a direct increase in efficiency, as more power is provided from the same piston area, but a lean air-fuel mixture becomes difficult to ignite at higher pressures. Laser ignition creates ignition temperatures much higher than those seen in conventional spark-ignition, internal combustion engines. Therefore, its application in such engines could be instrumental in developing high-efficiency engines, allowing for multiple fuel capability, EGR, or even the use of alcohols or methane as fuel. A laser-induced spark is useful in that the amount of energy produced by the spark plug, as well as its duration and timing, can be controlled much more precisely than conventional plugs. Furthermore, the ignition location may be optimized with a laser spark plug and, as there is no associated material near the ignition’s location, there is significantly less wear induced on the part itself, increasing its theoretical useful lifetime. Laser ignition may also be used to create a multi-point ignition setup, which could also be utilized to increase burn efficiency. The same amount of energy input into a conventional electrical plug produces a larger spark volume in a laser plug. The reviewers focused on recent developments in laser ignition technology. Cavity ignition, in which the laser beam is directed into a reflective

conical cavity and allowed to concentrate to produce a spark, allows for the use of lower energy lasers and reduces the amount of laser energy lost to the surrounding gaseous medium before combustion, which can typically leach 30-70% of incident laser energy. The concentrative effect at the cone's apex, due to multiple laser reflections at the edges, allows for a conservation of all the energy input and a shorter combustion duration, as well as a higher maximum possible combustion pressure.

Morsy (2012) continues by discussing the use of laser ignition in a multi-point injection system. A multi-point system allows for a number of efficient modifications to be made to the engine and fuel system. First, a lean mixture of fuel may be employed, as such a system would compensate for the decrease in flame propagation in a lean fuel environment. Multi-point systems may be employed to increase thermal efficiency if the pistons are designed to reduce turbulence within them during firing. While increased turbulence is employed within conventional internal combustion engine design to accelerate fuel burning and mixing, it is also a contributor to the 25-30% fuel energy heat loss observed in the cylinder walls. Lastly, as a multi-point laser ignition system may be utilized to fire in a variety of patterns, even adaptively, such a system may also be employed to reduce other problems associated with lean mixture combustion such as cycle-to-cycle variation, misfire, pressure pulsation, partial or uneven burn, and early flame quenching. A two-point ignition setup is discussed in which the first ignition is accomplished through a spark ignition at a desired location, with a secondary event accomplished through the accumulation of the unused laser in a cavity for ignition. This was shown to reduce flame initiation time and total combustion time, especially in lower-pressure environments. Two-point systems utilizing two-cavity systems were also described, as well as a two-cavity ignition set up in which three-point ignition is accomplished through a focused laser beam, which additionally spark-ignites in the center of the chamber. Additionally, many of these multi-point systems achieve multiple ignition points through the use of a single pulse laser per cylinder, as opposed to needing a spark plug for each point of ignition, as in conventional applications.

An additional issue with the prospective use of laser spark plugs in conventional engines involves their durability in the field (Morsy, 2012). Many studies of laser ignition involve the use of open beam paths which utilize multiple lenses and mirrors to focus the laser. However, these would be impractical for use in a commercial implementation because such systems are susceptible to safety, thermal, vibrational and maintenance issues which cause misalignment. Additionally, the size of current laser systems prohibits their immediate attachment to the engine, and must be placed farther away in the engine bay. Flexible optical fibers, probably made of silica, and several hundred microns in diameter, are identified by the reviewers as promising for use in a consumer application. There is the possibility of a compact monolithic laser design which would not require a separate generation source, as the optical fibers would require, but it is yet to be made to endure the high temperature and vibrations which would assault such a plug in normal automotive use. Other compact laser designs have also recently been investigated. The National Energy Technology Laboratory has been active in research of compact laser designs, and it is possible that they could be developed to the point that such systems could be used to directly replace spark plugs in conventional engines. A four-cylinder Toyota engine is noted to have been tested with one laser plug against three typical spark plugs. Without optimization, the plug has an energy of only 2.3mJ, the smallest of any tested laser, and both fired the engine and kept it running without misfire while reducing ignition energy. The reviewers state that while

laser ignition could be immediately utilized in stationary applications, there are still a number of issues to be addressed in optimal design, especially for automotive applications. A monolithic laser, if developed to be suitably robust, could be a solution. Both a system involving optical fibers, or other compact designs, are currently highly susceptible to vibration and temperature, and this issue must be accounted for in an automotive application, as well as lowering the cost. Lastly, further research is required into the areas of laser delivery to an engine, in the form of a suitable laser window with suitable material properties, and an all-around lowering of cost, with the drastically longer lifespan possible in laser plugs taken into account. The high energy output of laser spark plugs may also be important in the ignition of less volatile fuels or fuel mixtures, presenting an opportunity for alternative fuel applications as well as providing a much more efficient mode of ignition, which may be utilized for even-burning scenarios.

As the distribution of the gaseous-liquid fuel mixture within the internal combustion engine has been identified as a key component in engine efficiency, the introduction of vaporized gasoline, as opposed to the liquid form, could allow for even larger gains in efficiency as the burn would be very lean but also quite even. However, as gasoline has a boiling point higher than those seen in normal operating conditions for injection, the gasoline would have to be preheated or otherwise vaporized from a liquid state prior to injection into the cylinders. Charles Pogue is known for his carburetor patents from the 1930s. The carburetor itself includes a heating surface over which the liquid gasoline and air are passed before being introduced into the engine (Pogue, 1935). While there is little substantiated evidence of his claim of nearly 200 miles to the gallon, using his carburetor design in an automobile of the era there have been a number of patents published afterwards which also attempt to introduce a more vaporous gasoline mixture into the engine (Bushnell et al., 2006; Geddes, 1984).

There is a large community of both amateur and professional automotive enthusiasts and technicians. A large subset of knowledge concerning older and used vehicles, especially that concerning methods of modification, is relegated to Internet discussion boards, forums and blogs. Therefore, much of this information is reported through experiential hearsay, without verifiable documentation or rigorous, standardized data recording. Additionally, those brick-and-mortar car repair shops which offer modification services are often reluctant to divulge methods or findings of modifications, as they serve as trade secrets and points of revenue. These conditions work in conjunction with the academic literature's bias towards new technologies, and have led to a dearth of academic evidence on the topic of modification of used vehicles to attain greater fuel efficiency. This study seeks to begin to bridge this gap, and to set the foundation for further empirical studies of efficiency in used cars.

2.0 APPROACH AND METHODOLOGY

2.1 RESEARCH METHODOLOGY

2.1.1 Experimental Setup

The small-scale project discussed herein is intended as a simple proof-of-concept for the basic protocol for producing fuel efficiency gains in a post-production automobile through the manipulation and adjustment of programmed fuel injection. This investigation tests the received wisdom found in the aftermarket community and among automobile enthusiasts and mechanics, which is information that is largely disseminated through magazines, Internet forums and as tradecraft. Additionally, this investigation establishes a baseline of both data and protocol for experimentation with post-production vehicles at the Oregon Institute of Technology. The test car was chosen and modified with the intent of establishing a useful platform for later modification and testing at the conclusion of this study. In addition, this study focused on obtaining improvements in fuel economy with the smallest amount of modification possible. This allowed for the study to accomplish its two goals: Determine a low-cost method for obtaining greater fuel economy, and establish a base upon which to investigate more complicated methods which, in turn, may also produce larger gains.

This section discusses the methodology for the basic tuning protocol testing, as well as the experimental structure and procedure. The characteristics of both the vehicle and the equipment utilized are discussed, as are the basics of aftermarket engine tuning. Experimental observations and results are also reported, along with preliminary analysis in this section.

2.1.1.1 Vehicle Characteristics

Because this study is intended to provide proof of concept, an exemplar vehicle was chosen. The characteristics required of the car were that it should be a popular (commonly used) vehicle, which is also commonly available on the resale market; it should be low cost; it must have a commonly available ECU tuning system; and it should operate at a high fuel efficiency.

A 1994 Honda Civic DX sedan was purchased for this study. A Honda Civic was chosen as the make and model utilized because it met the specifications for an example vehicle. First, the Hondata system appears to be one of the best known and most widely used ECU tuning systems on the market, as suggested by its widespread commercial availability and frequent mention in trade fora. It was developed for the 1992-1995 Honda Civic. Secondly, the fifth generation of Honda Civic was one of the most popular cars ever produced, and is ubiquitous in both modified car communities as well as a low-

cost, used car throughout the U.S.¹ Therefore, it can be reasonably taken to be a “typical” used car. Furthermore, this Civic is known to be a vehicle which returns high fuel efficiency, so any gains obtained from its already-efficient system could be taken to be reasonably applicable to other used vehicles with lower initial fuel economies. The specific vehicle obtained for this investigation was equipped with a manual transmission, which allowed for the ECU to be modified with a vehicle tuning system, described below. Additionally, the 1.5-liter, four-cylinder D15B7 engine was stock, unmodified mechanically, and had been recently refurbished and tuned up. This provided a reliable basis for tuning, as the engine and drivetrain could be taken as models of those generally found in similar examples of the vehicle 20 years after leaving the factory. Lastly, an inspection by a certified car repair shop confirmed that all mechanical systems were suitable for many more miles of use. For further confirmation, the car also passed Oregon Department of Environmental Quality (DEQ) voluntary vehicle emissions testing with minimal reported emissions (see Appendix A for a DEQ results summary).

2.1.1.2 General Summary of the Hondata s300 Tuning System

The availability of the Hondata s300 tuning system was a key factor in the decision to use a Honda Civic as the experimental vehicle in this study. This system consists of a microchip installed on the vehicle’s ECU. It includes within it a logic controller that directs the engine to obtain instructions from the s300, which is directly programmable as opposed to the controller installed within the OBD-1 P06 ECU.² The s300 system has been fine-tuned amongst the aftermarket community for some time and is well known by many higher-end car shops. The s300 chip includes a USB socket and allows for connection with a laptop computer and manipulation of the ECU programming through the Hondata software program. The program allows for real-time monitoring of engine performance, and provides three-dimensional graphs of both the fuel and ignition maps used by the ECU to control the fuel injectors and spark plugs based on engine temperature, revolutions per minute (rpms), and oxygen sensor readings, with the capacity for the incorporation of other inputs. The s300 may be used to control other modifications performed later, including examples such as an after-market turbocharger or a switch to an alternative fuel source.

2.1.1.3 Vehicle Operation

This study sought to investigate the effect of the ECU modification through a test-driving protocol which approximated “normal” driving. Therefore, the investigator’s day-to-day schedule and driving needs governed a large amount of the driving protocol used in this study. Driving conditions were mixed, with approximately 40% of miles driven in city conditions and 60% in highway conditions, with varying conditions where noted in Table 3.2.

¹ Between 1972 and 2006, over 16.5 million Honda Civics were sold among 8 generations (“How the Honda Civic got its groove back,” Joe Guy Collier, Detroit Free Press, May 15, 2006).

² OBD-1, or On-board Diagnostics-1, refers to the rudimentary diagnostic and programming system on this type of ECU. P06 is the specific model designation of ECU installed by Honda in the fifth generation Civics with the D15B7 engine.

Additionally, to gain a better understanding of particular aspects of the vehicle's operation, some test trips took place outside of normal day-to-day driving routes. Performance in hilly or mountainous regions and on the open highway were of particular concern and are discussed below. Weather conditions are noted where relevant to the interpretation of the results.

Other variables such as tire pressure, the weight carried by the vehicle, along with oil and other fluid levels were held approximately constant. Where relevant, details of the types of trips taken are discussed below, as well as the observed gas mileage and other engine performance characteristics based on driver observations.

2.1.1.4 Modifications

Engine modification was undertaken in a step-wise manner, building off each previous tuning session and professionally performed by PRE automotive tuning and repair shop in Portland, OR. PRE is well-known in the area for its tuning and modification of cars for personal use, as well as track and racing applications. Each step of the process was individually analyzed, while each step was also predicated based upon the one proceeding it. Furthermore, tuning was performed by a trained technician, Erich Uhlman at PRE. The Hondadata S300 system can be used to tune a vehicle without the assistance of a dynamometer, but "street tuning" as it is known was not deemed to be sufficiently exact for this study. Dynamometers are often utilized by auto tuning and repair shops to measure power output in the form of output power (measured in horsepower or kW) and torque (measured in N-m or lb-ft) throughout the rpm range of the vehicle tested. This experiment utilized dynamometer tuning to provide reliable power output information while also allowing for finer tuning of the air/fuel ratio through the modification of the ignition timing and fuel output (described further below), along with the expertise of an experienced technician. The use of a dynamometer also allowed for testing of parameters at variable engine speeds safely, which allowed for more exact tuning and a solid basis for later experimentation.

3.0 RESULTS AND FINDINGS

3.1 SUMMARY OF PRIMARY RESULTS

This chapter outlines the results of the fuel-efficiency protocol testing. Overall fuel efficiency results are outlined below in Table 3.1. The reported fuel efficiency of the vehicle increased in each stage of the experiment, with the largest increase occurring in the final stage of the experiment when the fuel leaning was coordinated with the ignition spark timing, which allowed for the higher levels of leaning than was possible when only reducing the fuel output. Overall average fuel efficiency increased by 6.07 mpg, and the maximum fuel efficiency experienced during highway driving increased by 13.02 mpg, suggesting that the protocol for fuel leaning is most effective in improving the top gear efficiency of used-vehicle engines.

Table 3.1: Fuel Efficiency Results for Each Experimental Stage

Stage	Miles Driven	Average Mpg	High Mpg	Low Mpg
Stock	259.85	34.00	39.54	28.47
Base Tune	1529.7	34.34	35.66	32.36
Lean Tune	1563.5	36.88	38.47	35.55
Lean+Spark	2106	40.07	52.56	33.85

3.1.1 Experimental Trials

A series of trials was conducted as a proof of concept of the ability of tuning to improve the overall fuel economy of the vehicle. These trials include baseline observations, a basic tune of the engine, a tune to lean the air/fuel ratio, and a tune that combined timing and leaning of the air/fuel ratio.

3.1.1.1 Baseline Observations

After the vehicle was obtained and inspected, it was driven for two tanks of fuel prior to the installation of the Hondata system. This was done to establish a baseline for the vehicle's driving characteristics for later comparison to the improvements. The vehicle was observed to be sluggish while ascending steep inclines in high gear, an issue commonly reported by reviewers with cars of this make, model and vintage due to their weight and relatively low stock horsepower and torque outputs. The engine noticeably lagged in response in these situations. This was likely a result of insufficient power or torque output by the engine, which caused the ECU to enrich the fuel injection, resulting in lag.

To establish a baseline for general commuter-type operation, the test vehicle was driven without modification for approximately two tanks of fuel. The first tank consisted of more city driving while the second tank consisted of more highway driving, returning 28.47 mpg on 7.73 gallons of fuel and 39.54 mpg on 7.83 gallons, respectively, which averaged to 34.00 mpg mixed driving over a total of 259.85 miles. This initial testing under varied driving conditions suggested a reasonable median recorded fuel efficiency.

3.1.1.2 Tune

PRE performed the installation of the Hondata s300 unit onto the ECU included by the manufacturer of the test vehicle on January 28, 2014. The installation of the s300 unit allowed for a basic dynamometer tuning of the vehicle to even out torque and horsepower curves, and increase overall power output under no-throttle and full-throttle conditions (see Appendix A, Fig. 1). The stock air/fuel ratio values under load were visible and are noted in this simulation. This tuning and optimization was also expected to result in an improved throttle response.

As expected, the improvement of output power by 6.3hp for a total of 108.3hp (see Appendix A, Fig. 1) resulted in an immediate increase in responsiveness and even power output during acceleration. Most noticeably, a plateau of engine response in second and third gears was eliminated, replaced by a gradual increase in power output. Lastly, the tuning noticeably improved the consistency of throttle and engine response. Lagging input response was no longer an issue.

Average gas mileage was calculated to be 34.34 mpg over 1529.70 miles (see Table 3.1).

3.1.1.3 Just Lean

The vehicle was tuned a second time at PRE on March 24, 2014. To perform this modification, a wideband oxygen sensor was fitted to the vehicle. This allowed for use of additional features of the Hondata software program for tuning. Originally, the vehicle was fitted stock with a narrowband oxygen sensor, which prevented the expansion of the air/fuel ratio. To lean the fuel use, the air/fuel ratio needed to be increased at all times while in operation, and the narrowband sensor was not capable of functioning in this range. Additionally, the application of the wideband sensor included the installation of an air/fuel ratio gauge on the dashboard of the test vehicle, which allowed the driver to observe the air/fuel ratio within the engine in real time. For this level of modification, focus was placed on the programming for the engine's fuel injection. Utilizing the power and torque bands set by the initial tune, the fuel map was leaned throughout the engine's rpm range. This was not performed uniformly throughout the fuel map, as would be traditionally performed manually or with a "street-tune" of the Hondata. Instead, each sector of the fuel map was leaned individually on the dynamometer to the point just before the knock sensor was tripped to attain the maximum allowable air/fuel ratio and lean burn without modification of the ignition timing. The knock sensor is triggered when the air-fuel mixture does not combust in the correct manner in response to ignition. This can cause ignition of the mixture in a manner which does not coincide with the movement of the piston as it increases pressure within the cylinder. The shockwaves

caused by this imbalance cause a characteristic pinging sound which may lead to engine damage if left unchecked. The knock sensor triggers when this reaction is beginning to occur, often before a knock is audible. The point of triggering is therefore the limit of the air/fuel ratio lean under which the engine tuned can operate.

After completion of the tuning, the engine's idle was observed to stabilize at an air/fuel ratio near 13.2:1 compared to stock values of closer to 12:1, running rich to prevent engine choke although there is some variance. During the vehicle's operation, the air/fuel ratio was observed to vary between 12:1 and 17:1. Air/fuel ratio values generally climbed as gearing increased, dipping during a gear change or during driving situations requiring heavy throttle input, as would generally be expected. There was a noticeable improvement in the consistency of engine idle as well, with little variation in idle speed during heavy traffic situations. Average gas mileage was calculated to be 36.88 mpg over 1563.5 miles (see Table 3.1).

3.1.1.4 *Timing plus Re-lean*

The vehicle was again tuned at PRE on June 2, 2014. This tuning session sought to further increase the engine's lean ratio through the advance of the ignition spark timing. Both the spark map and the fuel map were modified during this tuning session as the initial advance in spark led to the capacity for additional leaning of the fuel injection. Again, the spark advance and the fuel injection lean were pushed to the point at which further advance or lean, respectively, led to the triggering of the knock sensor.

After the modification's completion, the idle air/fuel ratio was observed to stabilize at a higher level of 14:1, compared to the 13.2 ratio observed in the previous tune. This suggested that the engine was successfully operating at leaner conditions, which implied more efficient operation and greater fuel efficiency.

Furthermore, the air/fuel ratio was observed to reach the maximum 18:1 limit measurable by the installed air/fuel ratio gauge. This did not occur in the previous tune, and further suggested that the leaning protocol was successfully pushing the engine's operating limit higher than was previously achieved.

3.1.1.4.1 *First Long Test Drive*

A number of specific trips were taken to test highway fuel economy specifically with the final tuning protocol. The first such highway trip was undertaken on June 22, 2014. The trip route generally consisted of southbound travel on I-5, turning west at Highway 20 where Highway 101 was travelled northbound, until turning off northeasterly on Highway 22 back to Portland. During this 259.10-mile test, operating speeds averaged approximately 55mph. While I-5 was largely open and flat, allowing for higher average speeds, highways 20, 101 and 22 were hilly with fewer lanes, lowering average speeds. A small amount of traffic was encountered on 101 and 22, but the vehicle spent no more than 15 minutes in such conditions. The maximum fuel efficiency observed in this experimental trial was 52.56 mpg. This fuel-efficiency value proved to be the highest recorded in this experiment,

and is 8.11 mpg higher than the next highest value for highway economy, discussed below. Further trials may give a more consistent value for highway fuel economy.

3.1.1.4.2 Second Long Test Drive

The second highway-only trip was undertaken on August 8, 2014. A similar route was utilized on a loop between Portland and the Pacific coast. However, on this occasion, Highway 26 was followed northwest from Portland until it met Highway 101, which was taken south to Highway 22, which was then travelled on a northeastern route back to Portland. The terrain and average speed differed in that a larger section of the drive was mountainous, and multiple traffic conditions were encountered. On this occasion, 257.8 miles were travelled and a fuel economy of 44.45 mpg was observed. This value was substantially lower than the previously recorded highway fuel economy value. There are a number of possible explanations for this 8.11 mpg discrepancy in fuel efficiency between these trials. It is possible that the differences in the routes taken were contributed to the difference in value. During the second trip, traffic was encountered on a hilly section of Highway 26 and again on Highway 22, which necessitated more use of lower gears than would normally be required. This time, over 45 minutes were spent in low-speed traffic conditions. The driver may otherwise have operated the vehicle differently. It is also possible that there was a significant difference in the gasoline used in either trial, which is discussed further below.

Average gas mileage for all driving under the Timing plus Re-lean scenario was calculated to be 40.07 mpg over 2106.0 miles (see Table 3.1), for a 6.07-mpg gain in efficiency from the stock condition. Discounting the high fuel-economy value from the first long trip, average fuel economy for the final tuning protocol was 38.29 mpg over 1846.9 miles. This result represented a 4.29-mpg increase in fuel efficiency over the 34.00-mpg average recorded before the test vehicle's initial modification.

The test vehicle was observed to perform well in traffic conditions, with three heavy traffic runs returning an average fuel efficiency of 35.04 mpg over 748.9 miles. This was also a 6.57-mpg increase from the 28.47-mpg mark recorded previous to the vehicle's modification. Higher-idle air/fuel ratio was probably the leading contributor to this, as a significant amount of time in city driving is spent with the vehicle stopped. But the lower gears also burned leaner, providing further benefits in stop-and-go situations as well as neighborhood driving.

3.1.1.5 Summary of Experimental Trials

After observing the test vehicle under baseline conditions, the car was tuned for improved performance in accordance with industry standards. Changes were made to fuel and spark maps in subsequent tune. Each tune resulted in improved fuel economy from the vehicle,

with the greatest improvement observed when spark timing was advanced and air/fuel ratio was furthest leaned.

Table 3.2: Summary of Results

Date	Miles	Fuel Used	Total Fuel Used	MPG	Notes
9-Jan	220.1	7.732	7.732	28.4661148	
16-Jan	309.75	7.834	7.834	39.5391882	
28-Jan					PRE s300
30-Jan	356.2	10.176	10.176	35.0039308	
11-Feb	303.7	9.383	9.383	32.3670468	
22-Feb		6.6			
3-Mar	446.8	6.41	13.01	34.3428132	
13-Mar		2			
18-Mar	423	9.86	11.86	35.6661046	
24-Mar					PRE s300
7-Apr		4.1			
11-Apr	479.2	9.38	13.48	35.5489614	
23-Apr	319.3	8.3	8.3	38.4698795	
12-May		2.6			
15-May	477.5	10.6	13.2	36.1742424	
2-Jun	287.5	7.7	7.7	37.3376623	PRE s300
11-Jun	293.8	7.4	7.4	39.7027027	
22-Jun	218.1	6.61	6.61	32.9954614	Traffic
22-Jun	259.1	4.93	4.93	52.5557809	Long
17-Jul	323.3	9.55	9.55	33.8534031	Traffic
16-Aug	315.4	7.47	7.47	42.2222222	
16-Aug	257.8	5.8	5.8	44.4482759	Long
20-Aug	231	6.33	6.33	36.492891	
21-Aug	207.5	5.42	5.42	38.2841328	Hills and traffic

3.2 ADDITIONAL AND UNEXPECTED FINDINGS

3.2.1 Hills

Despite the optimization of the power and torque bands through the initial dynamometer tune, hills were still an issue for the vehicle. On highways of steep enough grade, as little as 6-7%, the test vehicle was unable to accelerate while in fifth gear. On occasion, the vehicle would begin to slow and would require a downshift into fourth gear to continue the ascent. In these situations, the ECU would often input more fuel to prevent the engine from bogging, which would create a richer air/fuel ratio, and would therefore cause a reduction in fuel efficiency. The tuning did

assist in performance in this area over the stock programming, but the issue was not resolved. This is largely due to the relatively small size and output of the engine, and is therefore difficult to compensate for.

3.2.2 “Sweet Spot”

As stated above, there were points in the course of highway driving which resulted in the maximum lean air/fuel ratio observed during vehicle operation with the Timing plus Re-lean test. There was no tachometer installed standardly in the test vehicle and none was added for this research, so engine rpms relative to air/fuel ratio are unknown. However, this condition was replicable on the open highway when the vehicle was permitted to cruise at an average of approximately 65 mph with minimal throttle input. The air/fuel ratio would often exceed 17:1 in this situation, sometimes reaching or exceeding the 18:1 limit of the air/fuel ratio gauge itself. However, this condition was difficult to maintain at highway speeds without a form of onboard automated cruise control, as anything which caused the driver to vary throttle input would invariably cause the air/fuel ratio to decrease. If this maximal lean environment of engine operation could be maintained longer, there could be larger observed gains in fuel efficiency.

3.2.3 Gearing

No effort was made by the test driver to modify his driving habits during the course of the experiment. This was done to ensure that the data obtained in this investigation was consistent throughout the modification protocol. Therefore, shifting of the transmission was performed as the operator was accustomed to through the extensive personal use of a fifth-generation Honda Civic, by sound and feel, without the use of a tachometer. A subject of further research, discussed below, may be one of the usage of gearing for fuel efficiency with this protocol.

3.2.4 DEQ Results

The final DEQ test confirmed that the modifications performed on the test vehicle resulted in an increase in CO₂ emissions but a decrease in CO emissions (see Appendix A, Figure 7). Just as when tested before the modification was performed, these values were both well below the legal emissions threshold established by the DEQ. It should be noted that DEQ’s testing does not include NO_x and SO_x emissions in its standard testing protocol. Therefore, it is recommended that Oregon Tech acquire more advanced testing equipment to be used in-house for subsequent vehicle emissions and efficiency studies. This is discussed further in the Future Research section detailed below.

3.2.5 Spark Plugs

The same set of NGK spark plugs were used for the experiment’s entirety. After the completion of all test driving, the spark plugs were removed. The electrodes were inspected for corrosion or discoloration. White discoloration of the electrode is often a sign of an engine which burns too leanly and other conditions. The electrodes of the spark plugs used in this experiment showed little differentiation from the clean factory condition. However, it was noted that oil was present in at least one of the spark plug tubes, which implied that the engine had been operating without

fully sealed lower tube gaskets. While such a leak did not hinder engine performance in a noticeable manner, it does imply that greater fuel efficiency values are attainable if this issue is repaired in the future.

3.2.6 Changes in Performance Output During Modification

The vehicle was initially tuned to a maximum of 108.3hp. The leaning protocol performed thereafter did result in a reduction in horsepower, but only to 104.3hp, and the performance was still increased overall from the stock output of 102hp.

3.2.7 Regional Characteristics

While there may be some regional variation in the extent of air/fuel ratio leaning available when tuning a vehicle, tunes will most likely be transferrable amongst various localities. However, there may be some limitations to this, which have yet to be fully investigated. It is most likely that tunes must be carefully applied to vehicles in higher elevations, but it is unknown if lower oxygen content would lead to a higher or lower air/fuel ratio limit or if such a change would result in a net difference in fuel efficiency.

3.2.8 Summary of Results and Findings

A series of experimental trials involving changes to the air/fuel ratio and ignition timing, as controlled by fuel and spark maps programmed in the ECU, were conducted. The results show that measurable gains in fuel economy could be obtained, especially when combining changes to both air/fuel ratio and ignition timing. The vehicle's performance depended upon driving conditions, with inclines being problematic for this make and model – a problem not substantially improved by the re-mapping and tuning that were a part of this research. Constant speed, as that delivered by automatic cruise control, allowed for the greatest improvements in fuel efficiency, which is consistent with expectations of automobiles in general. Similarly, less fuel economy was observed in high traffic conditions, but this does not appear to be disproportional to analogous decreases found in stock automobiles of the same make and model.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL CONCLUSIONS

Overall, this investigation produced a successful first experiment. The hypothesis that the vehicle's tuning would produce a measurable gain in fuel efficiency, measured through gas mileage, was confirmed by this study. Importantly, this gain in fuel efficiency was achieved without major modification to the automobile, making specific vehicle tuning protocols a potentially inexpensive way to achieve these fuel savings.

Furthermore, the secondary goal of the establishment of a base for further research at Oregon Tech was also accomplished. With this secondary goal in mind, the test vehicle itself is still very much a work in progress and is intended as such. In this way, the vehicle can be utilized as a teaching tool, research platform, and as a demonstration of the education provided by the university. As this avenue of scientific investigation involves the integration of mechanical and electrical engineering, as well as control systems, this investigator is confident that there are more demonstrable gains in fuel efficiency which are attainable for later researchers. Further research could be quite elucidating as the relatively simple experiment performed here returned nearly an 18% gain in overall fuel efficiency. More precise measurements of the variables involved will also be critical in the further optimization of the modification efforts on the test vehicle.

The modification that was performed on the test vehicle in this investigation may also have some marketable value in itself. The simplicity of this leaning strategy suggests that a qualified auto repair shop, equipped with a dynamometer and tuning capabilities, would be able to offer the modification as a service, with a reasonable expectation of profit to the repair shop and cost savings to the consumer. Once the first vehicle of any given generation of any make or model is successfully tuned, any other local vehicle of that make and model would be modifiable with a simple download of the previously developed tune. This would allow the auto shop to take a loss on the cost of the first vehicle, expecting a profit on every car of the same make and model while also offering the service at a competitive price point. General tuning of a vehicle is an often overlooked method of attaining efficient engine operation, but few such businesses market tuning services separate from modification services seeking gains in horsepower or torque. With the overall rising cost of fossil fuels, these services could become quite popular if more of an effort is made to educate consumers about its advantages.

4.2 RECOMMENDATIONS FOR IMPLEMENTATION AND TECHNOLOGY TRANSFER

4.2.1 Research Opportunities

The Honda s300 utilized in this study allows for the control of a variety of possible modifications to further increase vehicle fuel efficiency. This grant provided by OTREC is the basis for many possible projects for car modification. The test car purchased in this study through the grant is intended for use by Oregon Tech to assist in the development of research in renewable energy and fuel efficiency in automobiles and other forms of transportation. The section below highlights a variety of possible research areas which may be undertaken, using the test vehicle platform developed by this investigation. Some may be performed individually, and possible methods for the coordination of multiple modification efforts are discussed. Other test vehicles may also be utilized to perform many of these experiments.

4.2.2 Commercial Potential

The potential savings in consumer energy expenditures, petroleum consumption and emissions reductions are tremendous if this low-cost methodology of improving fuel economy in post-production automobiles is widely implemented. In order to realize these savings, however, mechanics must recognize that these changes can be easily implemented in many shops, with some experimentation by the shops themselves on optimal fuel and spark maps for their regions and the types of cars in which they specialize. Consumers must also be educated in the potential value of these tuning services and must recognize that a small investment must be made up front to realize potentially substantial fuel savings. Consumers may be unwilling to invest in the older, less efficient cars that could benefit most from this modification, as a car with low resale value may seem “not worth” even a small outlay of capital: If you don’t know how much longer the car will last, how do you know you’ll see a positive return on the investment?

Auto manufacturers will have little incentive to participate in outreach on how to optimize the use of their post-production vehicles. Since advertising is one of the main avenues for the education of consumers on automotive issues, other outreach mechanisms must be explored.

Automotive repair and service shops may potentially be reached through the Internet in the fora and blogs where much received automotive wisdom is currently exchanged. Directed efforts by government agencies may be necessary to reach consumers, however. Tuning modification could be promoted, for example, as a means of meeting automotive environmental quality standards by state motor vehicle departments or environmental testing facilities.

4.3 RELEVANCE TO USDOT OBJECTIVES AND PRIORITIES

This project is particularly relevant to USDOT objectives and priorities in that it addresses the issue of increasing fuel efficiency in older used automobiles, which make up the majority of vehicles driven in the U.S. Many efforts to curtail carbon emissions focus on the development of

new technologies to replace the use of fossil fuels. However, many of these efforts require years of additional research and development to be viable in the national marketplace. This project seeks instead to develop methods to reduce the impact of currently operable vehicles on the environment, as a stop-gap effort in preparation for divestment from fossil fuels in the more distant future.

5.0 REFERENCES

R.B. Bushnell, A. Dean, D.R. Lewis, "System for Improving Fuel Utilization," U.S. Patent 7631637. June 1, 2006.

J.A. Caton, "The thermodynamic characteristics of high efficiency, internal-combustion engines," *Energy Conversion and Management*, vol. 58, pp.84-93, June 2012.

J.S. Cowart. "The Formation of a Combustible Mixture During the First Cycle of Cranking and Startup in a Port-Fuel-Injected Spark-Ignition Engine". *Journal of Engineering for Gas Turbines and Power*. no. 125, vol. 2, pp. 402-11, 2003.

J.S. Cowart. "Post-Combustion In-Cylinder Vaporization During Cranking and Startup in a Port-Fuel-Injected Spark Ignition Engine". *Journal of Engineering for Gas Turbines & Power*. vol. 2, 2006.

Fulcher, S. K., B. F. Gajdeczko, P. G. Felton, and F. V. Bracco. "The Effects of Fuel Atomization, Vaporization, and Mixing on the Cold-Start UHC Emissions of a Contemporary S.I. Engine with Intake-Manifold Injection". *S.A.E. Transactions*. no. 104, vol. 3, pp. 2345. 1996.

H.L. Geddes, R. Beckstead, "Vapor Fuel System for Internal Combustion Engines." U.S. Patent 4458653, 1984.

M.H. Morsy. Review and recent developments of laser ignition for internal combustion engines applications. *Renewable and Sustainable Energy Reviews*, no.7, vol. 16, pp. 4849-4875. 2012.

C.N. Pogue, "Carburetor," U.S. Patent 2026798. September 27, 1935.

R. Saidur, M. Rezaei, W.K. Muzammil, M.H. Hassan, S. Paria, M. Hasanuzzaman, "Technologies to recover exhaust heat from internal combustion engines," *Renewable and Sustainable Energy Reviews*, no. 8, vol. 16, October 2012.

APPENDIX A
DETAILS OF DATA

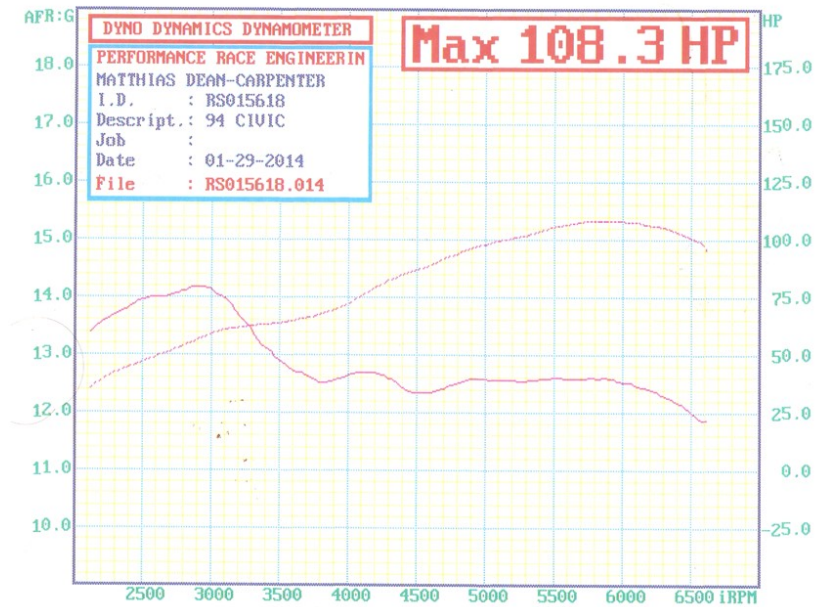


FIG. 1: First Dynamometer Tuning Session 1/29/14. Horsepower and AFR Output.

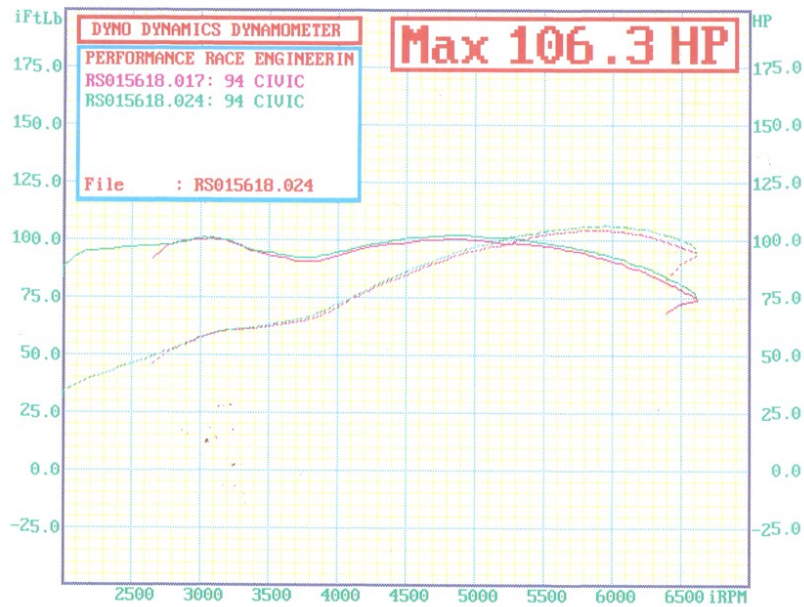


FIG. 2: Second Dynamometer Tuning Session 3/24/14. Horsepower and Torque (ftLb) Output.

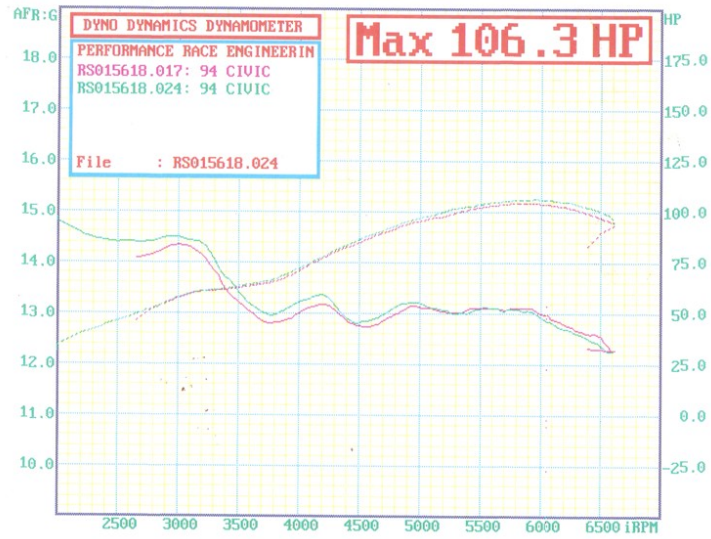


FIG. 3: Second Dynamometer Tuning Session 3/24/14. Horsepower and AFR Output.

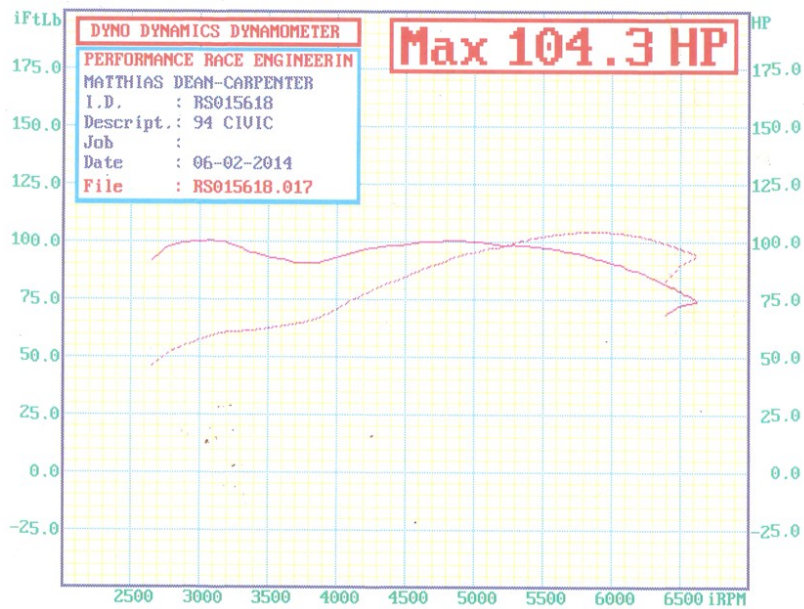


FIG. 4: Third Dynamometer Tuning Session 6/2/14. Horsepower and Torque (ftLb) Output.

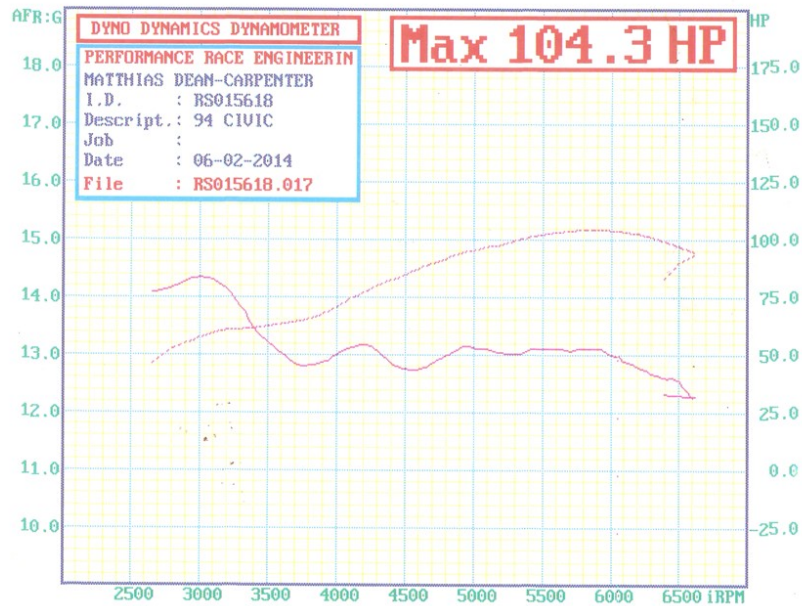


FIG. 5: Third Dynamometer Tuning Session 6/2/14. Horsepower and AFR Output.

OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY
 DEQ
VEHICLE INSPECTION PROGRAM

Overall Result - Voluntary

Station Information
 DATE: 03/27/14 9:14:21 AM TEST # 1
 STATION: HQ LAURE # UNIT: 0340421 INSPECTOR: Kulec

Vehicle Information

VIN: JH4E084100018018	Cylinders: 4	Hybrid: No
Year: 2004	Body Type: 10	Fuel: G
Vehicle Year: 04	Transmission: M	Weight: 2700.00 lbs
Vehicle Make: Honda	Displacement: 1.8	Class: C
Vehicle Model: Civic	Class: P	DEQ Catalytic: Yes
	Color: 100.000	

TAILPIPE EMISSION TEST RESULTS - Pass

Readings:	HC STD	CO STD	CO-CO2	HC	CO	CO2
1st Run:	223	1	0	36	0.000	13.3
2nd Run:	223	1	0	NA	NA	NA
1st Run: (If Applicable)	223	1	0	NA	NA	NA
2nd Run: (If Applicable)	223	1	0	NA	NA	NA

Smoke Test: Pass
 Visual Inspection: Pass
 Fuel Cap: Present
 Catalytic Converter: Present

FIG. 6: First DEQ Voluntary Testing Session 1/22/14. HC, CO and CO₂ Outputs.



OREGON DEPARTMENT OF ENVIRONMENTAL QUALITY
VEHICLE INSPECTION PROGRAM

Overall Result -Voluntary

Station Information

DATE: 8/20/2014 11:42:52 AM TEST #: 1
STATION: 943 LANE: 3 UNIT: OR040302 INSPECTOR: Dan

Vehicle Information

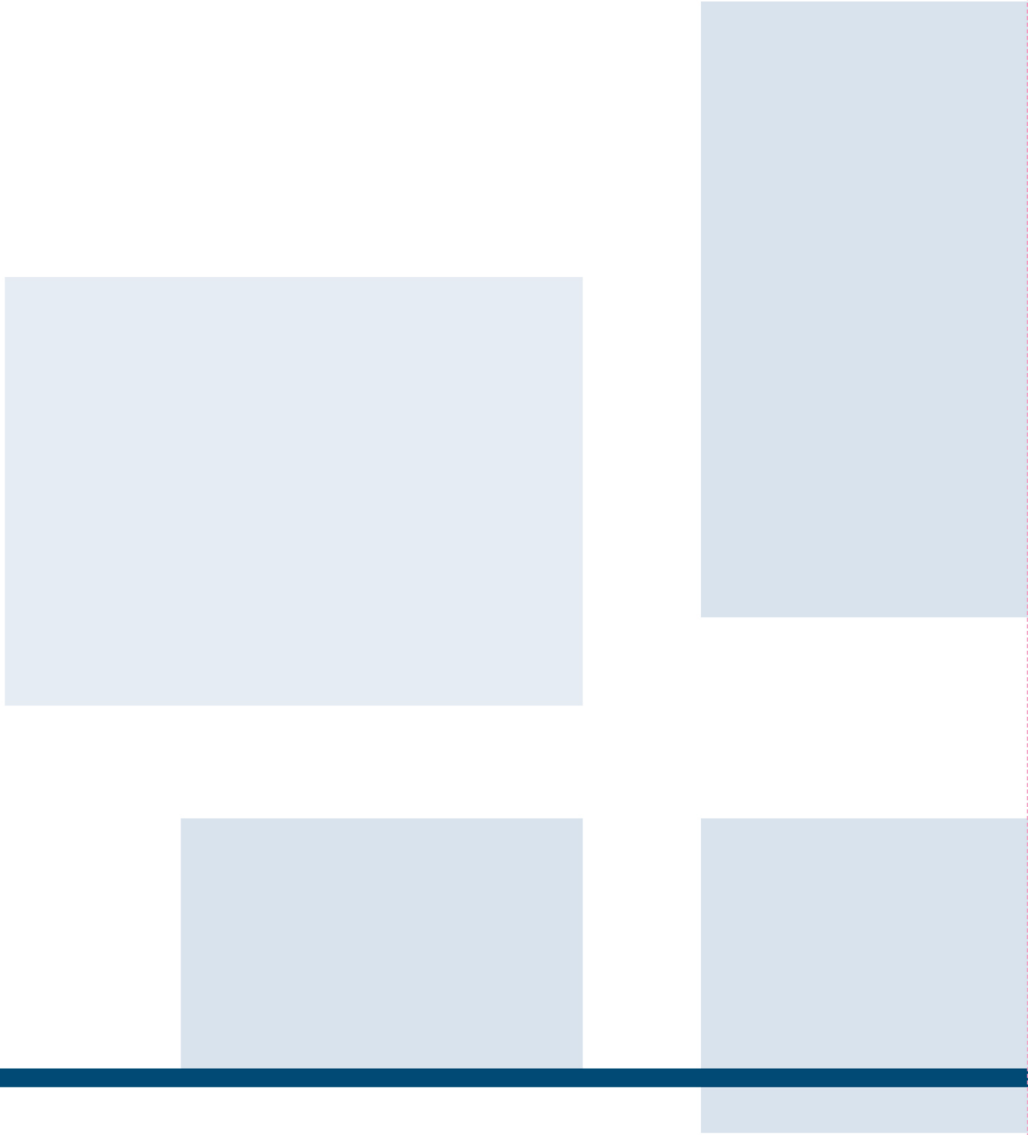
VIN: JHMFG8541RS015618	Cylinders: 4	Hybrid: No
Plate: E281790	Body Type: 10	Fuel: G
Vehicle Year: 1994	Transmission: M	Weight Class: 0 to 6000 lbs
Vehicle Make: Honda	Displacement: 1.5	OEM Catalyist: Yes
Vehicle Model: Civic	Class: P	
	Odom: 173,000	

TAILPIPE EMISSION TEST RESULTS - Pass

	HC STD	CO STD	CO+CO2	HC	CO	CO2
Readings:						
Idle Results:	220	1	6	13	0.0128	12
2nd Idle:	220	1	6	NA	NA	NA
Dual Fuel: (If Applicable)						
Idle Results:	220	1	6	NA	NA	NA
2nd Idle:	220	1	6	NA	NA	NA

Smoke Test: Pass
Visual Inspection: Pass
Fuel Cap: Present
Catalytic Converter: Present

FIG. 7: Second DEQ Voluntary Testing Session 8/20/14. HC, CO and CO₂ Outputs.



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