ILLINOIS INSTITUTE OF TECHNOLOGY

MASTER OF ENGINEERING IN MECHANICAL AND AEROSCPACE ENGINEERING

END-OF-MASTERS PROJECT

VEHICLE CONSUMPTION MODELING IN PYTHON

Student: Alvarez Jauregui, Javier

Supervisor: Hall, Carrie

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1. ABSTRACT

Student: Javier Alvarez Jauregui

Project supervisor: Carrie Hall

Department: Mechanical, materials and aerospace engineering

Title of the Project: Vehicle consumption modeling in Python

Abstract: In an effort to make a continuous improvement to a Python code that estimates energy consumption for different vehicles, this project aims to refine the simulations for continuously variable transmission (CVT) vehicles. CVTs are of special interest since allows the engine to operate at constant revolutions per minute at different driving speeds. Results indicate that simulations got better after modifying the code to implement some improvements.

Keywords: energy consumption/driving cycle/continuously variable transmission/transmission efficiency

Título de Proyecto: Modelado de consumo de vehículos en Python

Resumen: En un esfuerzo por hacer una continua mejora a un código en Python que estima el consumo de energía para distintos vehículos, este proyecto tiene como objetivo refinar las simulaciones para vehículos de transmisión continua variable (CVT). Los CVTs son de especial interés ya que permiten que el motor opere a revoluciones por minuto constantes a disitintas velocidades de conducción. Los resultados indican que las simulaciones mejoraron después de modificar el código para implementar algunas mejoras.

Palabras clave: consumo de energía/ciclos de conducción/transmisión continua variable/eficiencia de transmisión

Proiektuaren izenburua: Ibilgailuen kontsumoaren eredua Pythonen

Laburpena: Ibilgailu desberdinetarako energia kontsumoa balioztatzen duen Python kode batean etengabeko hobekuntzak egiteko esfortzuan, proiektu honek transmisio aldagarri jarraituko (CVT) ibilgailuetarako simulazioak fintzea du helburu. CVTak interes bereziko ibilgailuak dira, motorrak bira minutu konstantea edukitzea ahalbidetzen baitute gidatze abiadura desberdinetan. Ondorioek adierazten dute simulazioak hobetu direla kodea aldatu eta gero hainbat hobekuntza sartzeko ahaleginean.

Hitz gakoak: energia kontsumoa/gidatze zikloa/transmisio aldagarri jarraitua/transmisio efizientzia

2. LIST OF ADDITIONAL MATERIAL

2.1. TABLES

2.2. FIGURES

2.3. ACRONYMS AND ABBREVIATIONS

CVT .... Continuously Variable Transmission

ANL ....Argonne National Laboratory

$F_{tractive}$ .... Tractive force needed by the vehicle

$F_{roadload}$ .... Roadload force acting on the vehicle

$F_{inertia}$ .... Inertia force acting on the vehicle

F_{aero} .... Aerodynamic force acting on the vehicle

F_{rf} .... Rolling resistance force acting on the front wheel

F_{rb} .... Rolling resistance force acting on the back wheel

rpm .... Revolutions per minute

NEDC .... New European Driving Cycle

UDDS .... Urban Dynamometer Driving Schedule

HWFET .... Highway Fuel Economy Driving Schedule

2.4. FORMULAS

3. INTRODUCTION

The following document presents the End-of Master's Project to which corresponds the research and development of a vehicle energy consumption model in Python.

The first part will provide a contextualization in the frame of reference that comprehends the study in question, stating the objectives established at the origin of the project as well as the scope that is set to reach once is fully completed. Moreover, the impact of the research in several fields, including the engineering and computer science ones, will be mentioned by listing and explaining the most important benefits that the project shows. The project stems from a need to give any vehicle user an accurate but relatively simple model to predict the energy consumption of their rides.

Later on, the driving cycles that are most commonly used will be analyzed, exposing both the main characteristics as well as the benefits and disadvantages for each of them. After this explanation is given, the current state of the art of the simulation will be exposed, commenting on the improvements to be made in this project and commenting on the future that lies ahead.

After having explained the elemental ideas for the project, the description of the followed methodology will be posed. For this, in first place, a general comment of the different simulations that were targeted will be commented. Due to the broad nature of the model, simulations were finally narrowed down to a model representative of continuously variable transmission (CVT). Furthermore, a detailed description of each task carried out in this research project will be given. The information will be included in a Gantt diagram.

After this, a briefing of the obtained results will be presented and discussed to understand the usefulness of a model capable of simulating energy consumption with just a few variables as input.

Finally, the conclusions drawn from this research will be presented. For a clear exposition of the results, outputs from the console and graphs will be included with the data obtained throughout the research project as well as the calculations used to achieve the aforementioned results.

4. CONTEXT

This project is carried out under the framework of a research study that affects the development of new models for energy consumption forecasting. The project focuses on coding a model that is simple enough for any user to interact with it and get an estimate of their vehicle's consumption. In this case, the project has taken place at Illinois Tech in the Department of Mechanical, Materials and Aerospace Engineering as part of a double master's program with the University of the Basque Country (UPV-EHU).

This time the venture has been accomplished under the supervision of Professor Carrie Hall and the collaboration of Professor Michael Duoba.

In this context, the project's premise is based on developing a Pyhton model that can calculate the energy consumption for any vehicle. As it will be seen, however, the project goes from a general and broad perspective, and it is later narrowed down to a specific type of vehicle. Hopefully, the knowledge obtained while narrowing it down and the conclusions drawn from the specific type of vehicle can be extrapolated back to the whole general perspective.

As mentioned, this project is in collaboration with Professor Michael Duoba which in fact he had previously started, and he provided a first basic Excel and Python file upon which we continued working on.

5. OBJECTIVES AND SCOPE OF THE PROJECT

This project can be considered open-ended. The main objective for the future is to have a model that can predict energy consumption for any vehicle. Therefore, energy consumption can mean consumption of any of the available sources of energy for vehicle propulsion, such as, diesel, gasoline, hybrids (fuel and electricity) or electricity for the newest technologies gaining popularity in the market.

Apart from the energy source the code must be able to predict consumption for any type of characteristics the vehicle might have, from different transmission types to different motor volumes or battery capacities. The purpose of this is that the user can define just some aspects of his or her vehicle and get an estimate.

In order to know whether the simulation was acceptable, during the development of the project well-established data for well-known vehicles models was retrieved from the Argonne National Laboratory (ANL). The analytical objective for the project at each step was to make sure that the energy consumption of the simulation matched the energy consumption given in the database.

The scope of the project reaches to a small extent in which mostly continuously variable transmission (CVT) models were analyzed. At the beginning of the project, all kinds of vehicles were analyzed in a first approach. Due to the different nature of the technologies of the different types of vehicles it was necessary to tackle them one by one. For this reason, CVTs were further analyzed as a whole and a model was constructed around the Nissan Altima. After getting good results for these two models, the code could be extrapolated to any other CVT model.

The next challenge for the upcoming researcher is to tackle another type of technology in hopes of creating a library of models that covers all technologies available.

6. BENEFITS OF THE PROJECT

If the research developed concludes with a positive outcome, that is, to predict energy consumption for any vehicle model, it will definitely imply a step forward in forecasting consumption and give the driver a better user experience.

On the contrary, if the evidence obtained after the process is not conclusive, it can still encourage other ways to make progress by analyzing which aspect of the project went wrong. Therefore, and in addition to the obvious benefit in engineering, several others can be distinguished, both direct and indirect.

A. Engineering improvements

The main and direct interest of the project is focused on the field of engineering. The understanding of the calculations needed to get a good estimate can lead to new improvements in mechanical parts in order to maximize energy and reduce energy consumption overall.

B. Computer science benefits

Although some models have been developed for some vehicle types, much research is still needed. To span every single vehicle model is a very ambitious objective, but little by little and as a joint effort the main purpose is to create a library as broad as possible between developers.

C. Technological improvements

Apart from introducing engineering improvements to reduce energy consumption to already existing technologies, the full project could open doors to explore new technologies in a very first approach and be able to discuss about their profitability and whether to follow developing them or letting them down.

D. Economic and social benefits

Related to engineering improvements comes an economic improvement. If less energy is needed for a certain trip, regardless of the energy source, the trip's cost is cut down. As a consequence, this is a positive aspect for the environment since less energy is needed from the source, no matter which source the vehicle uses.

7. STATE OF THE ART

7.1. FORCES ACTING ON A VEHICLE

It is really important to understand the different forces acting on a vehicle to be able to describe its dynamics. For this project, the main objective is to calculate the power at the wheels at each instant needed to move the vehicle. This power then translates to different types of energy consumption; gas, electricity, etc. Power can be defined as force times speed, the instantaneous power to propel a vehicle is then the tractive force times the speed at each instant. At the same time, the tractive force can be defined by Newton's 2nd law as the sum of the inertia forces and the roadload forces as seen in Formulae 1. In this case, the roadload forces that are interesting are the longitudinal forces acting on the vehicle as seen in Figure 1. In this section an explanation of the longitudinal forces is given, but it is worth mentioning that there are transversal and vertical forces acting on the vehicle as well, affecting the drivability and stability of the car.

$$\sum F = M \cdot a$$

$$F_{tractive} - F_{roadload} = m \frac{\partial V}{\partial t}$$

$$F_{tractive} = F_{inertia} + F_{roadload}$$

Recall: $Power = Force_{tractive} \cdot Speed$

$$\boxed{Power = (F_{inertia} + F_{roadload}) \cdot V}$$

Formulae 1. Definition of instantaneous power to propel a vehicle

The inertia force is the resistance of the vehicle to any change in its velocity. The roadload forces, in this case the longitudinal roadload forces are comprised by forces of three different natures.

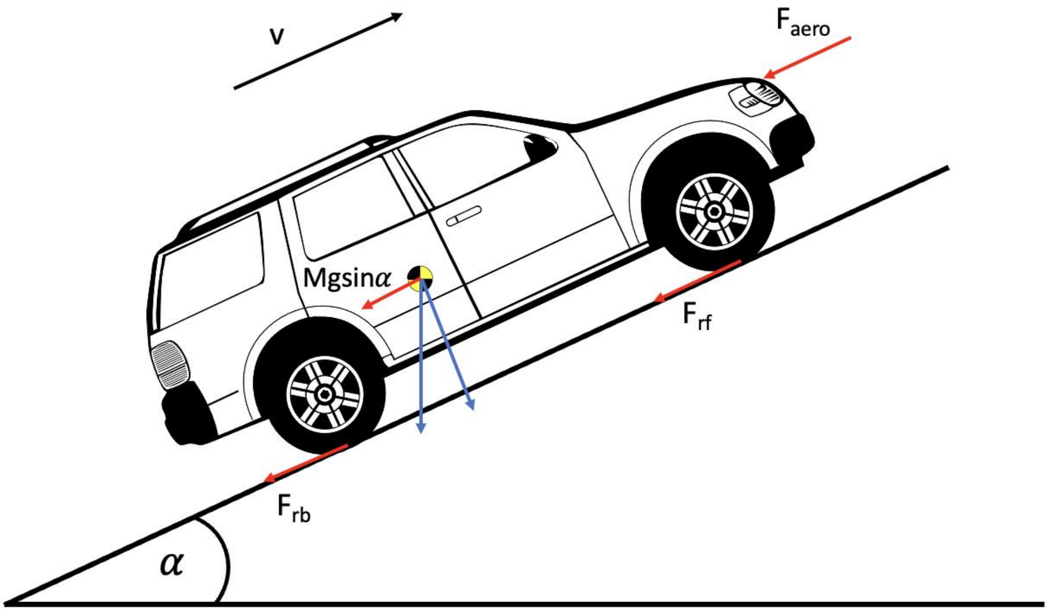

Figure 1. Longitudinal forces acting on a vehicle

The aerodynamic force F_{aero} is a force acting on the vehicle as it moves in a fluid like air. The variables that affect this car are the air density, the projected frontal area of the vehicle, the drag coefficient and the speed. The drag coefficient is different depending on the shape of the vehicle [1].

The rolling resistance F_r acts on the front and back wheels and it is proportional to the normal force at each wheel and the rolling resistance coefficient. The rolling resistance coefficient varies depending on the conditions of the surface the vehicle is moving on [1].

Finally, the longitudinal component corresponding to the weight of the vehicle is to be taken into account [1].

7.2. CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

A continuously variable transmission (CVT) is an automatic transmission that allows to change seamlessly through a continuous range of gear ratios in contrast to a manual transmission where the gear ratios are always fixed and there usually are 5 or 6.

In comparison to a traditional automatic transmission CVT vehicles don't have any gears at all and they rely on two cone-shaped pulleys to transfer power. By moving these conic pulleys, the diameter that the belt describes at the primary and secondary pulleys can be modified obtaining different gear ratios.

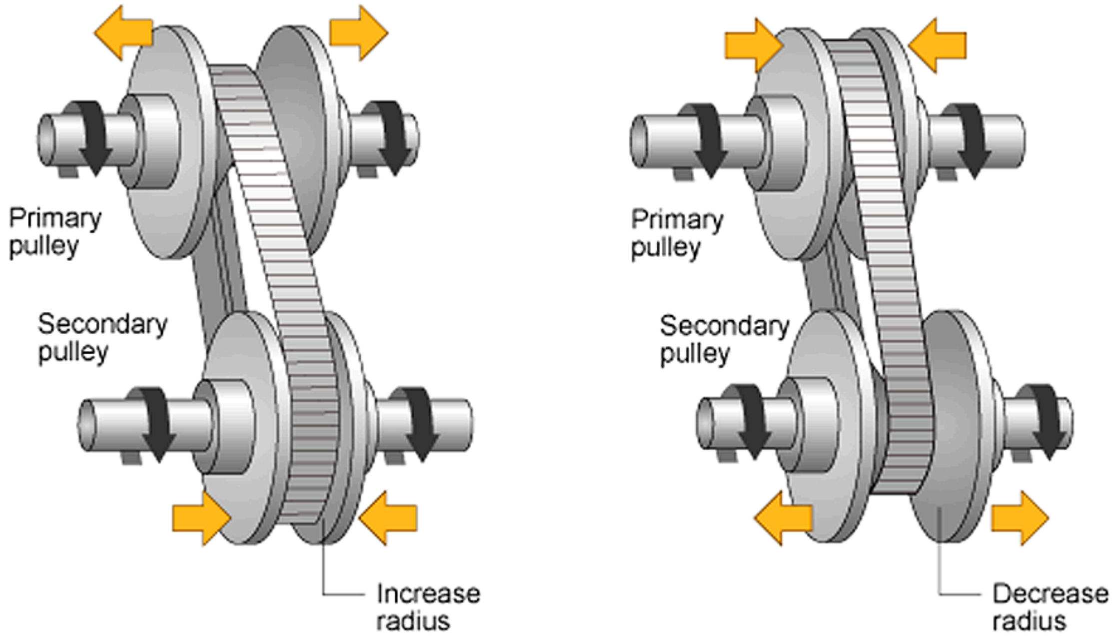

Figure 2. CVT diagram [2]

The flexibility of a CVT allows the engine to operate at constant revolutions per minute (rpm) while driving at different speeds. This comes with a direct benefit; the efficiency of the engine is always maximized therefore giving the best energy consumption. For this reason, CVTs were chosen to be further analyzed in this project.

7.3. DRIVING CYCLES

A driving cycle is a speed-time profile designed to represent a real-world driving pattern. Cycle length ranges from one or two minutes to 30 minutes or more. It is used to assess fuel consumption and pollutants emissions of a vehicle in a normalized wat, so that different vehicles can be compared. The driving cycle is carried out on a chassis dynamometer, where tailpipes emissions of the car are gathered and analyzed to assess the emission rates. There are two types of driving cycles, the modal cycles and the transient cycles. Modal cycles are a compilation of straight acceleration and constant speed periods and are not representative of a real driver behavior, for example European driving cycles (NEDC) as seen in Figure 3. Transient cycles involve many speed variations, typical of on-road driving conditions, such as the FTP-75 as seen in Figure 4. Cycle development efforts are challenged to mimic real-world behavior.

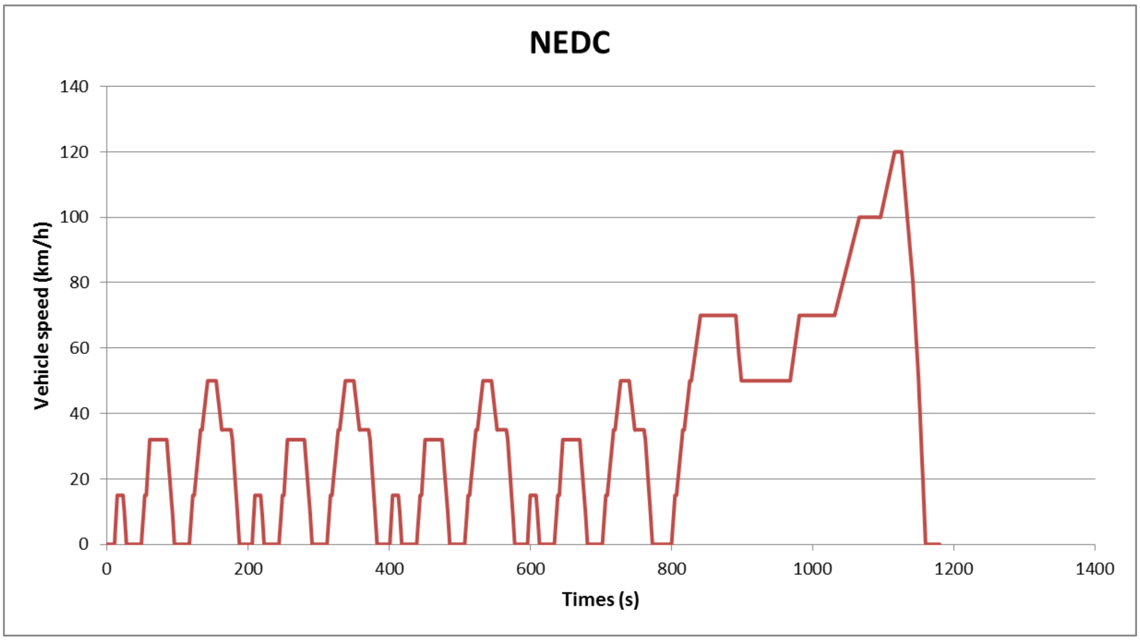

Figure 3. NEDC driving cycle [3]

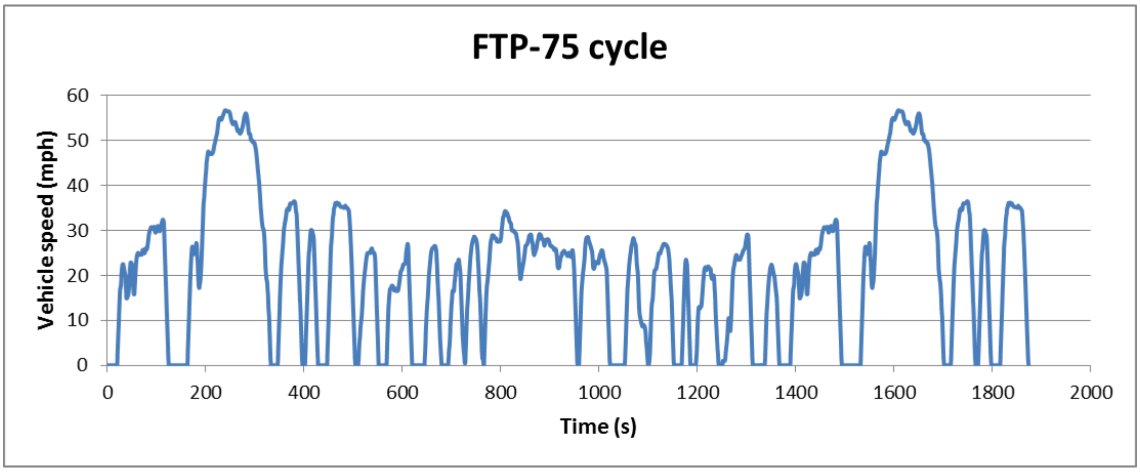

Figure 4. FTP-75 driving cycle [3]

Apart from the modal and transient classification, another classification can be made. Cycles can try to reproduce driving conditions in environments such as a city in which case the cycle is said to be urban, like the EPA Urban Dynamometer Driving Schedule (UDDS) as seen in Figure 5. In contrast to urban cycles, there are also highway cycles which reproduce longer times at higher speeds, for example the Highway Fuel Economy Driving Schedule (HWFET) as seen in Figure 6.

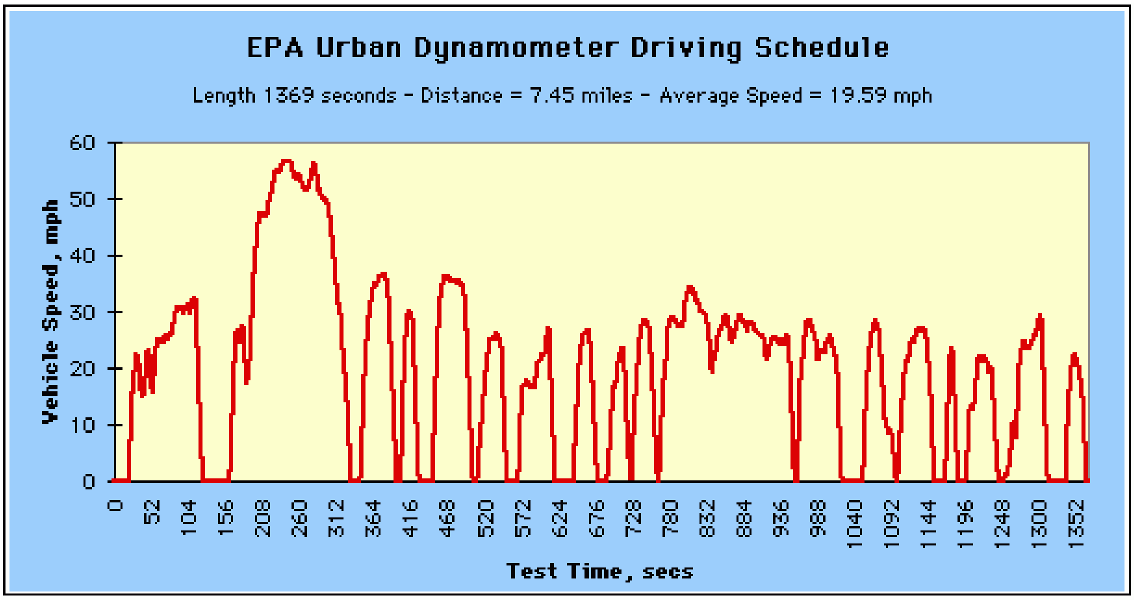

Figure 5. UDDS driving cycle [4]

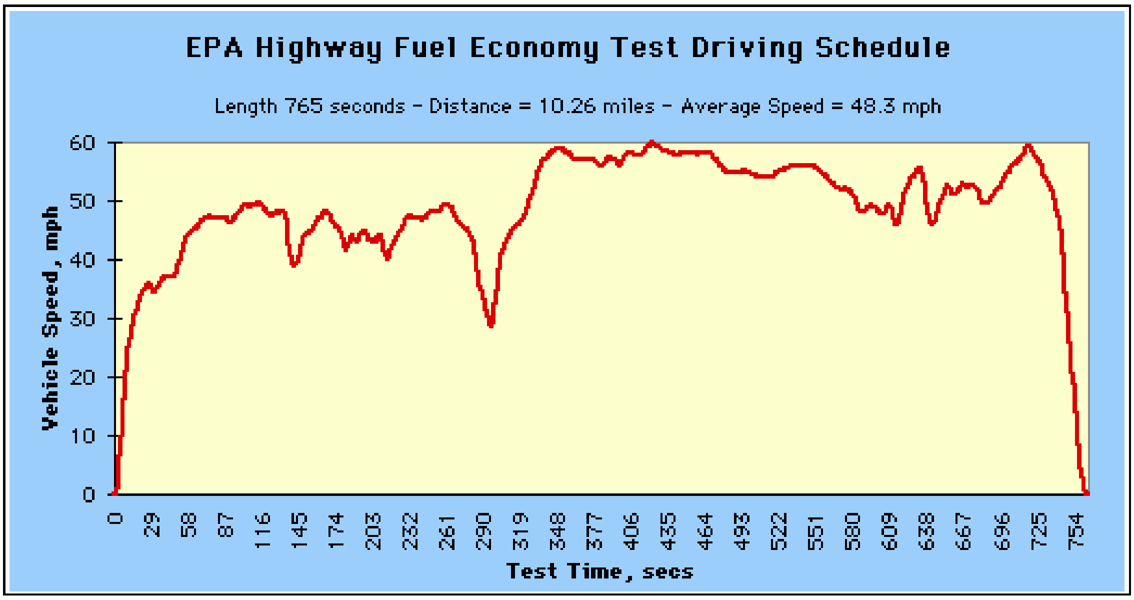

Figure 6. HWFET driving cycle [4]

7.4. ARGONNE NATIONAL LABORATORY

Argonne National Laboratory is a U.S. Department of Energy multidisciplinary science and engineering research center. It contains large data sets pertaining to this project, precisely it has a downloadable dynamometer database. In this database, for a certain vehicle one can obtain the main characteristics of the make and model, such as its weight, transmission type, engine's cylinder volume, etc. Apart from that and more importantly, it contains data that allows the calculation of the roadload force, $F_{roadload}$ mentioned in section 7.1. The calculation of this force is empirically modeled as a quadratic function of the speed of the form:

$$F_{roadload} = A + B \cdot V + C \cdot V^2$$

Formula 2. Roadload force empirical equation [5]

The datasets provide with coefficients A, B and C that along with the weight of the vehicle, allow for the calculation of the instantaneous power mentioned in section 7.1.

8. METHODOLOGY

8.1. PHASE DESCRIPTION AND TASKS

The project is expected to last up to 7 months, during which the next phases and tasks will be developed:

Phase I. Bibliographic research

An extensive initial research is carried out regarding articles involving vehicle propulsion, emissions measurement and driving cycles in order to get a broad and first knowledge of the matter.

Phase II. Inspection of the code

Since this project is the continuation of a larger one, it was necessary to inspect all the already existing code. There were two models to inspect, first an Excel file in which basic calculations were made to understand how the estimation was going to be obtained, and second Python files with the model upon which this project continued working on.

Task 2.1. Inspection of the Excel file:

Duoba-SimpleFull-HEVmodel-UDDS-Fall2015.xlsx

Task 2.2. Inspection of the Python files:

batchrunMODELiit_2021.py and *MODELiit_V0.py*

Phase III. Analyze aspects to improve

Since the objective was to improve the already existing code, it was needed to analyze in which aspects there was room for improvement. Moreover, the fundamental basis to run a simulation for a fuel vehicle or a hybrid vehicle is very different, so a decision had to be made regarding which vehicle type to improve. In this case, the fuel vehicle model was chosen, because the hybrid model one was still very poor.

Task 3.1. Create a file to see error for different vehicles: *compare.py*

Task 3.2. Filter out hybrids (vehicles presenting a 4^{th} bag in the cycle)

Phase IV. Simulations and interpretation of the results

From the results obtained in the previous phase, it was decided to try and improve CVT vehicles. The first aspect to improve was transmission efficiency, by creating a function dependent on speed. To check what else could be adding error to the simulation, plots of speed, fuel and simulated fuel were created. This would create a plot for every CVT vehicle, which made it difficult to analyze, so a specific model was chosen to further continue with the improvements, in this case, the Nissan Altima was chosen. To further improve the simulation of the Nissan Altima energy consumption, the input speed profile was simplified by inputting a steady-state speed profile. The output looked good, but it was noisy, so the last step was to filter out the noise introduced by the speed derivative.

Task 4.1. Create a transmission efficiency function dependent on speed for CVTs: *MODELiit_V1.py*

Task 4.2. Plot speed, fuel and simulated fuel: *MODELiit_V2.py*

Task 4.3. Work on the Nissan Altima: MODELiit_V3.py

Task 4.4. Input steady-state speed profile: *MODELiit_V4_SS.py*

Task 4.5. Filter out error introduced by speed derivative: *NissanSS_Filter.py* and *MODELiit_V4_SS_Filter.py*

Phase V. Writing the final document

8.2. GANTT DIAGRAM

Table 1 shows the tasks corresponding to each phase and the duration of each one. Those tasks are represented in the Gantt Diagram (see Figure 7).

According to the Gantt diagram in Figure 7, it is possible to identify as critical tasks the ones in the simulation and interpretation of the results, since they took the longest.

However, in this project all the tasks were cascading, meaning that one took place after another one, since it was a continuous improvement of an already existing model

Table 1. Task classification according to Gantt diagram

WBS	TASK NAME	DURATION	START	END
Phase I	Bibliographic research	4 weeks	18 Jan 21	14 Feb. 19
Phase II	Inspection of the code	2 weeks	15 Feb 21	28 Feb 21
Task 2.1	Excel file	1 week	15 Feb 21	21 Feb 21
Task 2.2	Python files	1 week	22 Feb 21	28 Feb 21
Phase III	Analyze aspects to improve	4 weeks	1 Mar 21	28 Mar 21
Task 3.1	compare.py	2 weeks	1 Mar 21	14 Mar 21
Task 3.2	Filter out hybrids	2 weeks	15 Mar 21	28 Mar 21
Phase IV	Simulations and interpretation	15 weeks	29 Mar 21	11 Jul 21
Task 4.1	MODELiit_V1.py	3 weeks	29 Mar 21	18 Apr 21
Task 4.2	MODELiit_V2.py	3 weeks	19 Apr 21	9 May 21
Task 4.3	MODELiit_V3.py	3 weeks	10 May 21	30 May 21
Task 4.4	MODELiit_V4.py	3 weeks	31 May 21	20 Jun 21
Task 4.5	NissanSS1.py	3 weeks	21 Jun 21	11 Jul 21
Phase V	Writing the final document	3 weeks	12 Jul 21	1 Aug 21

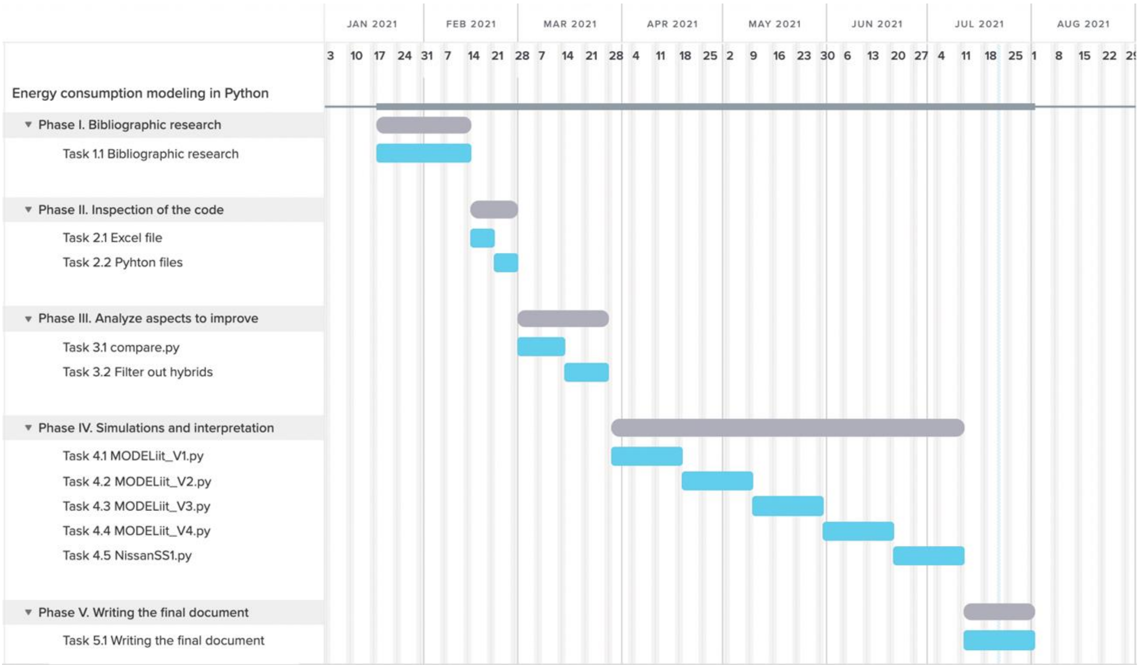

Figure 7. Gantt diagram

9. DESCRIPTION OF THE RESULTS

This section is focused on providing an explanation of the behavior of the simulations and the subsequent alterations done in the code to try and improve the results.

First, it was necessary to see where there was room for improvement. The already existing code was able to calculate an estimate of the energy consumption, but the main objective at all times was to get better estimates. It is necessary to mention, that gas and hybrid vehicles work very differently and as a consequence the calculations needed to get energy consumption estimates are very different too. The already existing code had a good estimation for fuel cars but didn't have a working code for hybrids. For this reason, the first thing to do was to filter out hybrid vehicles from getting run in the code. The way this was done was by figuring out that vehicles showing a 4th bag in their driving cycles were hybrid ones. After being able to just manage fuel vehicles, a new Python file was created to try and classify vehicle's error according to some of their characteristics, such as their transmission type or driving cycle. The new file is called *compare.py* and the output is shown in Figure 8.

```
javieralvarez@MacBook-Pro remodeliitbatchrunnotes_12feb2021_pptx % python3 compare.py
2880 number of vehicles with an acceptable error
70 number of vehicles with a non-acceptable error

Out of the vehicles with an acceptable error,
the average error of the simulation is 13.25828164006079 %
Out of the 2880 vehicles with an acceptable error 1312 have an error above the average

Out of the 1312 vehicles with an error above the average
107 have Automated Manual-Selectable transmission with an average error of 12.860025260028102
367 have Semi-Automatic transmission with an average error of 10.477328979947128
410 have Automatic transmission with an average error of 10.081512540700244
48 have Automated Manual transmission with an average error of 15.497886491348185
88 have Selectable Continuously Variable transmission with an average error of 12.975517360334315
39 have Manual transmission with an average error of 17.225380401496118
253 have Continuously Variable transmission with an average error of 11.455568985217583

Out of the 1312 vehicles with an error above the average
769 were analysed using the Highway Fuel Economy Test and
543 were analysed using the Federal Test Procedure.
```

Figure 8. compare.py output

As it can be seen, out of the 2950 vehicles in the database, 70 presented errors that affected the results and had to be discarded, since they were noise to the analysis. Furthermore, an average error of all the simulations was calculated and it was fixed as a threshold. The average error for the simulations was 13.3% and out of the 2800 vehicles with an acceptable error, 1312 had an error above the average. Later, these vehicles were classified according to their transmission type and driving cycle. It can be said that vehicles with manual transmission presented the biggest error and vehicles with automatic transmission presented the lowest error. What's more, vehicles using a highway driving cycle showed a larger error as well. It is necessary to say that up to this point, the files running the simulation were *batchrunMODELiit_2021.py* and *MODELiit_V0.py*.

After this analysis of the vehicle database, it was time to decide which aspect of the code was to be improved. It was decided that CVT vehicles were to be further analyzed and the next following task was to try and improve transmission efficiency. In a first approach, manual fixing was implemented, and it was obvious that the closer the efficiency to 1, the better results the simulation provided. However, that was far from reality and transmission efficiency was defined as a function of speed. This function was defined as a linear piece-wise function, and it can be seen in Figure 9.

```
def CVTtransEff(v):
    eff = 0
    if v <= 31.1:
        eff = 0.87
    elif 31.1 < v <= 37.7:
        eff = (0.16129*v + 81.98)/100
    elif 37.7 < v <= 43.5:
        eff = (0.2419*v + 78.9758)/100
    elif 43.5 < v <= 49.7:
        eff = (-0.080645*v + 93.008)/100
    elif 49.7 < v <= 74.56:
        eff = (0.080645*v + 85)/100
    elif 74.56 < v:
        eff = 0.91
    return(eff)
```

Figure 9. Transmission efficiency as a function of speed

To be able to implement such function, it was necessary whether the existing code would be able to take such function and the case was that it wasn't able. For this reason, another version of the file running the calculation had to be made. For this task, the Python files used were *CVTmodelHWYeff.py* and

CVTmodelURBANeff.py, depending on which driving cycle they were using, together with *MODELiit_V1.py*.

Figure 10 and Figure 11 show how the higher transmission efficiency was fixed, the better simulations were obtained. Nevertheless, as previously mentioned, that tweaking wasn't realistic and Figure 12 and Figure 13 show how if transmission efficiency was defined as a function of speed, simulations got better than the original ones, but not as good as fixing transmission efficiency directly at 0.955. However, for our purpose, the improvement that the transmission efficiency as a function of speed introduced was great.

Lastly, after sticking around to transmission efficiency as a function of speed, another type of transmission was to be analyzed, engine (indicated) efficiency. The original code had it fixed at 0.39 and it could be seen that if that figure went up to 0.4 or 0.42 the results were even better. However, this efficiency is usually given by the manufacturer and can't be modified towards the simulations, that's why the figure of 0.39 was untouched.

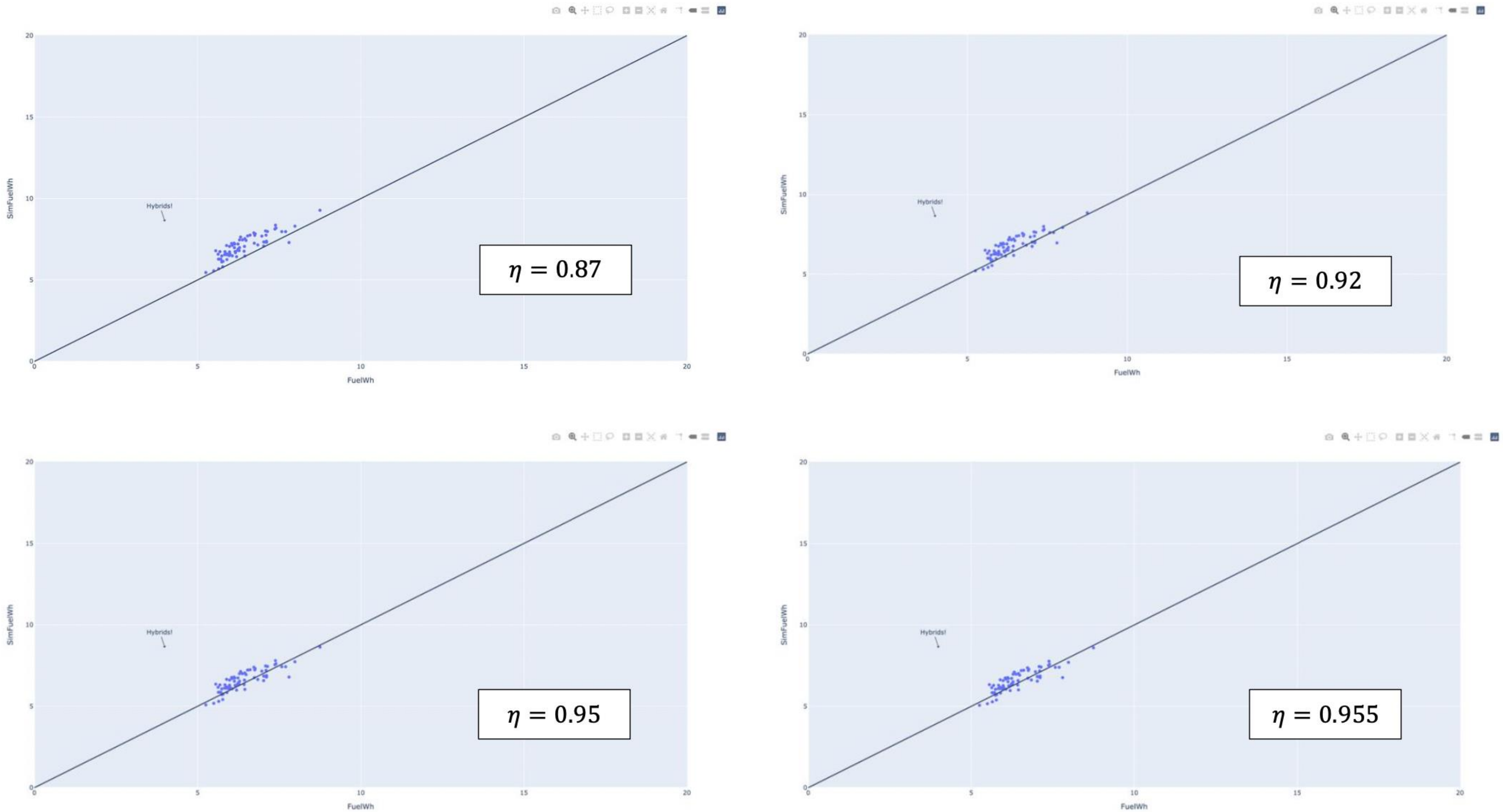

Figure 10. CVT HWY simulations with manual fixed transmission efficiency.

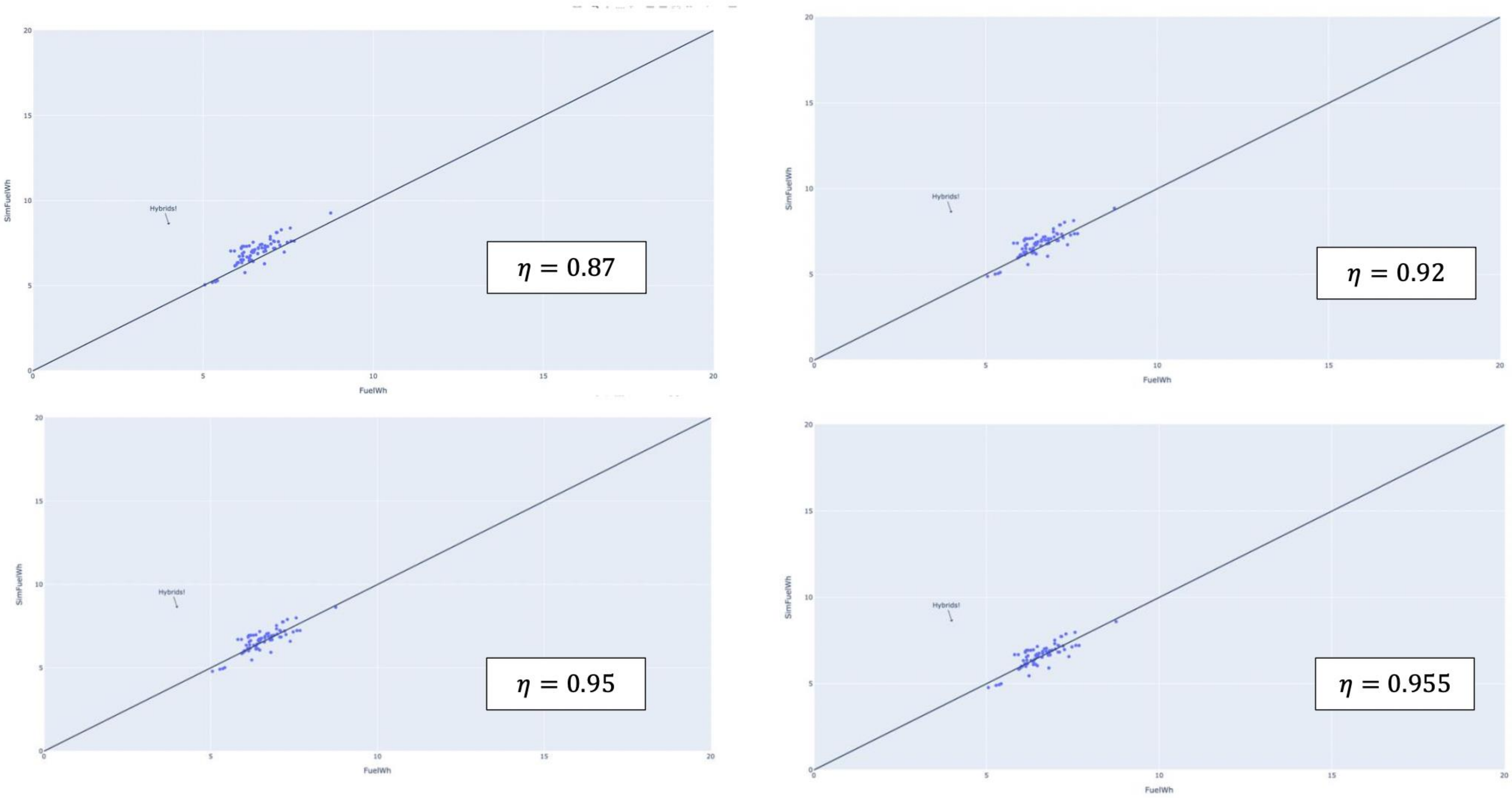

Figure 11. CVT URBAN simulations with manual fixed transmission efficiency.

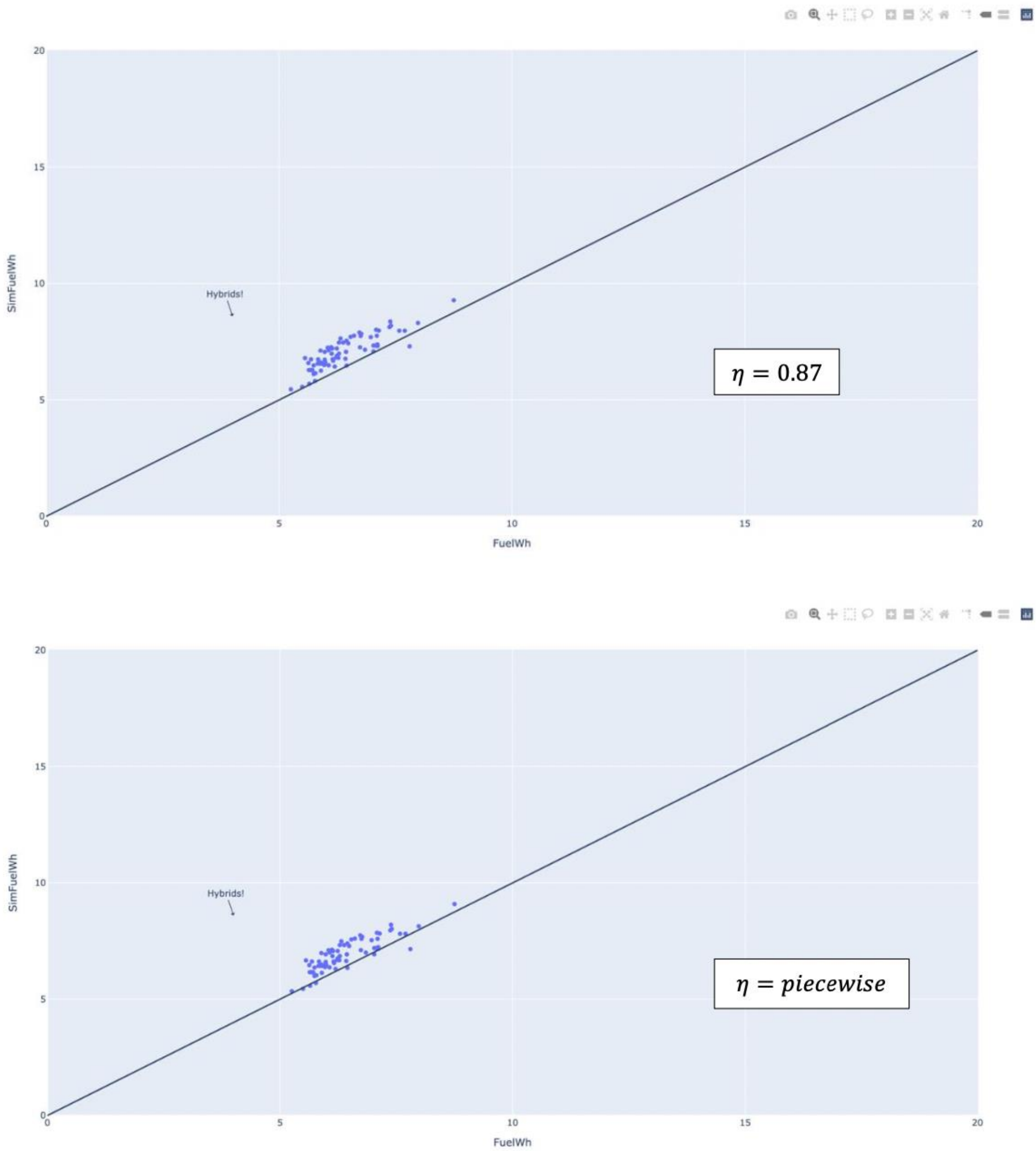

Figure 12. CVT HWY simulations with transmission efficiency as a function of speed.

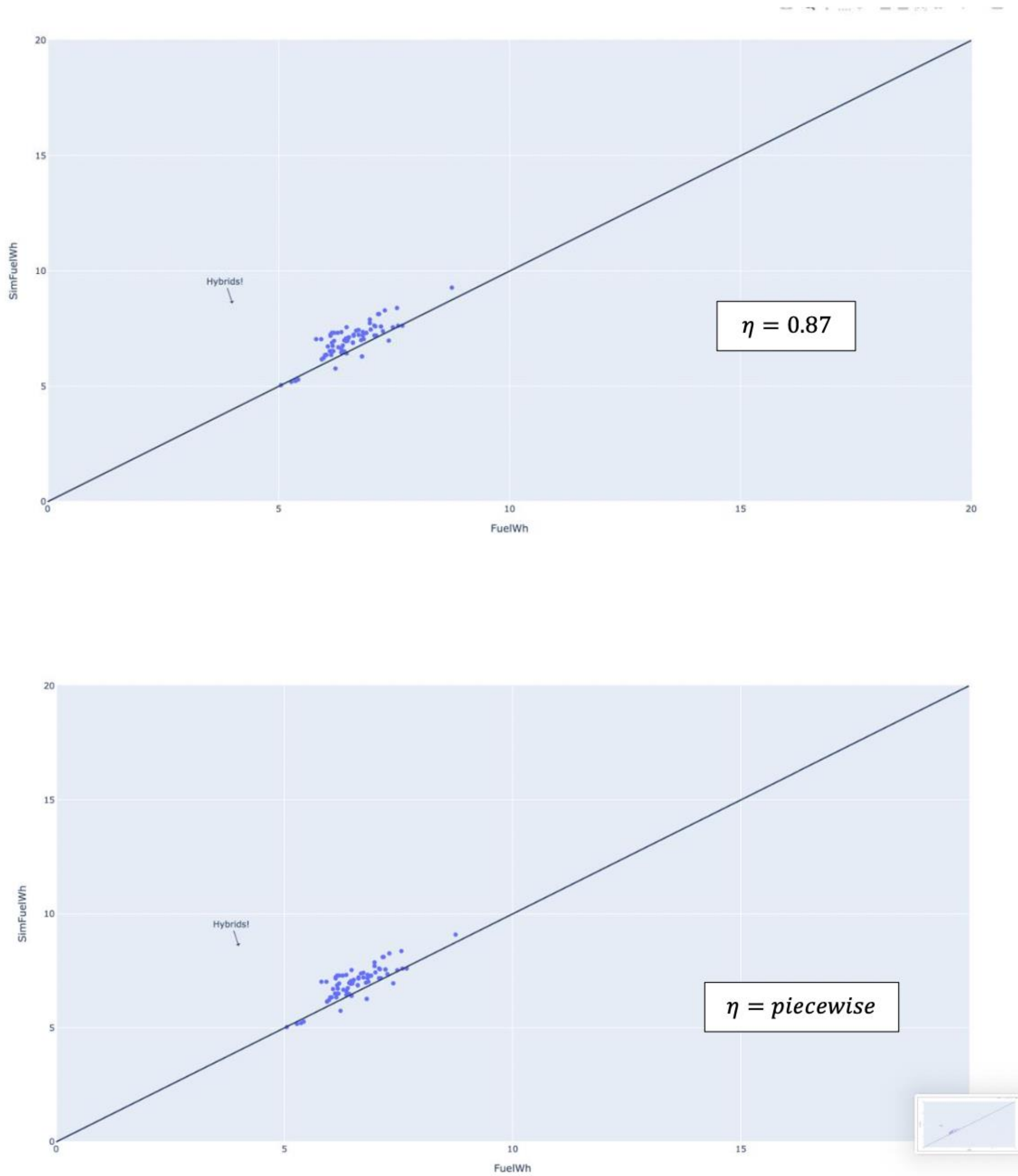

Figure 13. CVT URBAN simulations with transmission efficiency as a function of speed.

The following step was to reassess where to improve the code. The idea was to try and plot speed, fuel consumption and simulated fuel consumption. This was done using the files *CVTmodelHWYeff039.py* and *MODELiit_V2.py.* Keeping in mind that the CVT vehicle database had 75 different models in it, the code was outputting 75 different graphs, one for each model. This made it difficult to analyze and just one model had to be chosen to further continue with the analysis. For this reason, the Nissan Altima was chosen.

Once the Nissan Altima was decided to be the base of the simulations, the code was changed to just run the simulation on this model and plot this time the simulated fuel consumption against the fuel consumption from the bench. This plot was obtained with the files *NissanHWY.py* and *MODELiit_V3.py*. The output graph can be seen in Figure 14.

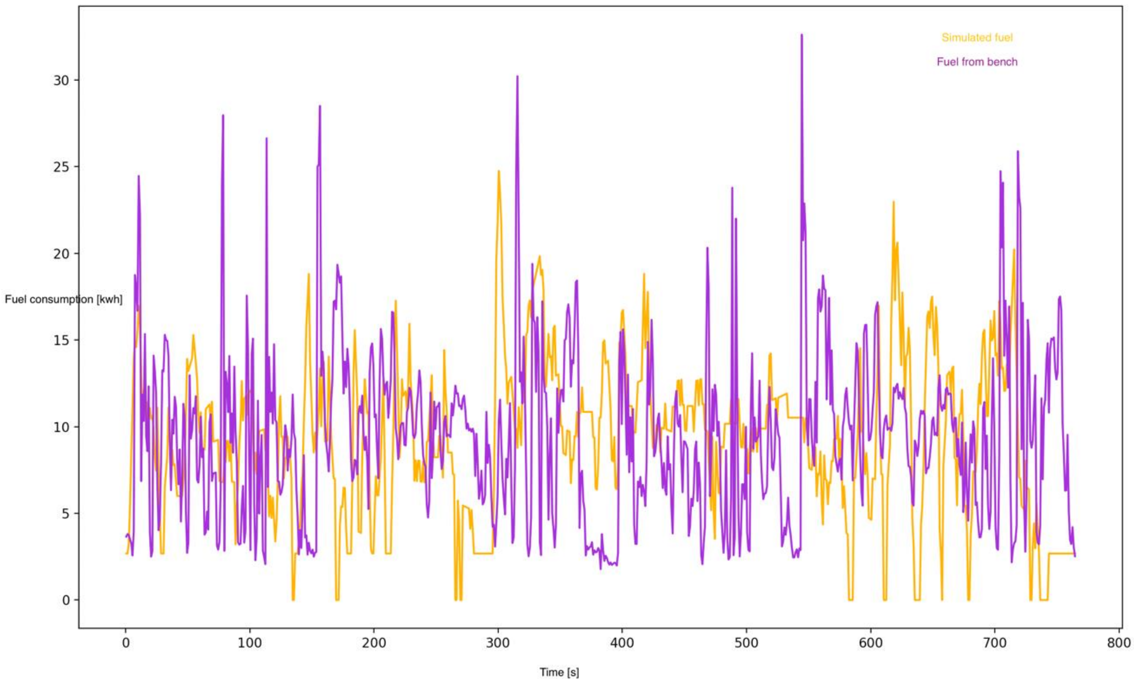

Figure 14. Simulated fuel vs fuel from the bench for the Nissan Altima in a HWY cycle

As it can be seen in the previous figure, both lines didn't match too good. Trying to figure out where the error could be coming from, a good approach to see where there could be sources of imprecision is to simplify the calculations. For this reason, instead of inputting a full highway driving cycle, a highway steady-state profile was used as an input, as it can be seen in Figure 15.

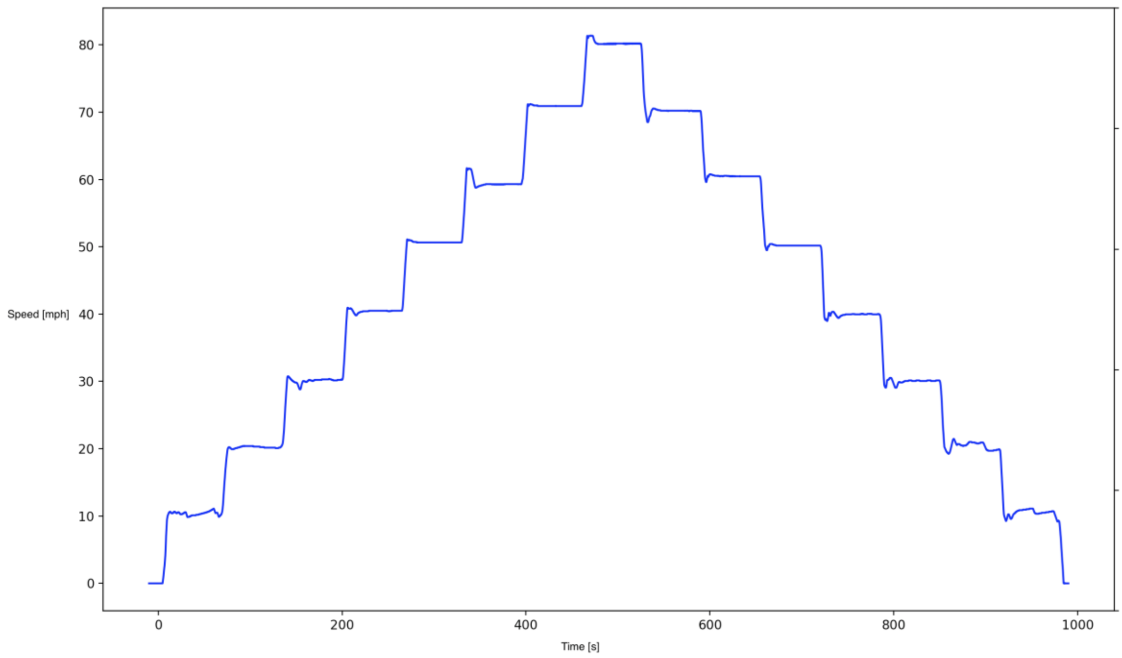

Figure 15. HWY steady-state speed profile

By changing the code to implement this speed profile, the files *NissanSS.py* and *MODELiit_V4_SS.py* were created. Once again, it was needed to check where the simulation wasn't matching the real fuel consumption, so both these parameters were plotted together again, resulting in Figure 16. This time, both lines matched much better but there was some sign that there was still some regard introducing noise into the simulation. In fact, the sharp fluctuations were coming from taking the derivative of the speed.

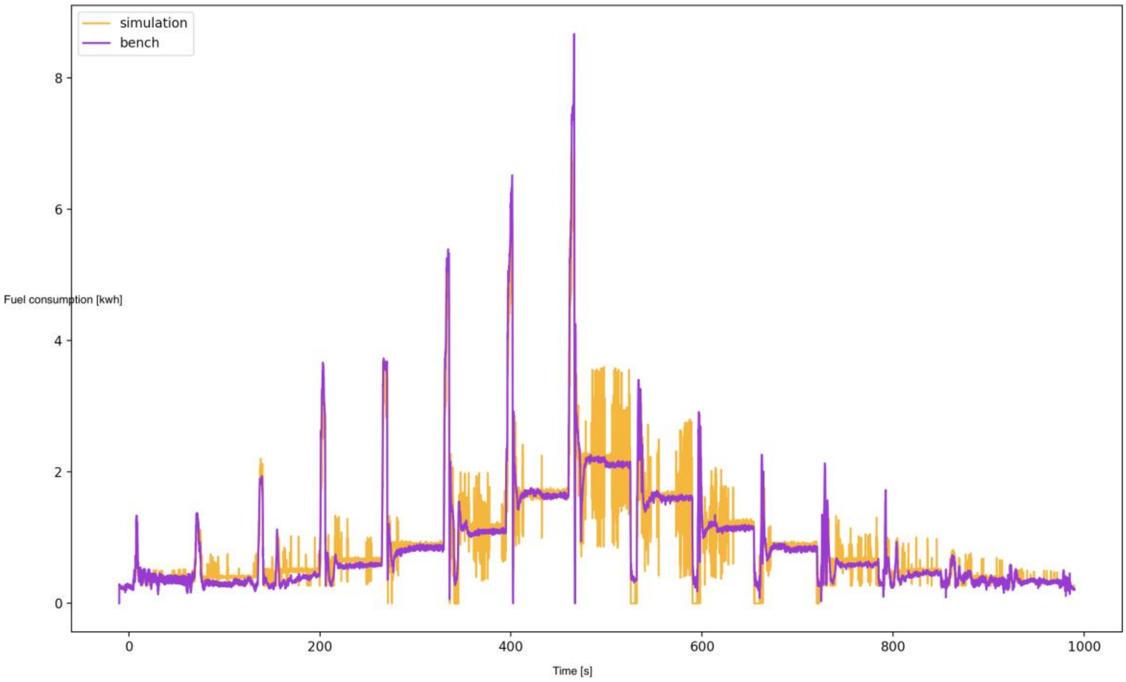

Figure 16. Simulated fuel vs fuel from the bench for the Nissan Altima in a HWY steady-state cycle

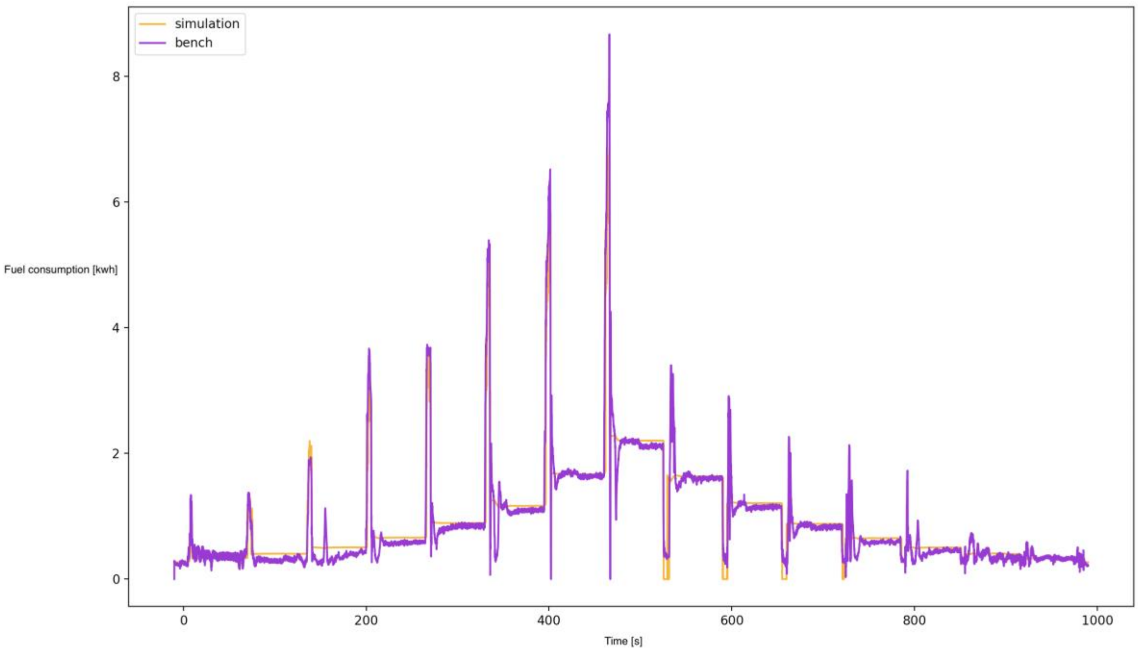

Figure 17. Simulated fuel vs fuel from the bench for the Nissan Altima in a HWY steady-state cycle with filter

The fluctuations from the signal were coming from the acceleration profile, so a filter was introduced to filter the noise in that signal. Such filter was introduced in the final files *NissanSS_Filter.py* and *MODELiit_V4_SS_Filter.py*. The output of the final code is shown in Figure 17. This time the fluctuations were erased with the filter and both signals looked much closer.

10. CONCLUSIONS

By the development of the project in question, simulations for the estimation of fuel consumption for CVT vehicles were refined. The code was altered to better reproduce the mechanical energy transfer by implementing a transmission efficiency function, instead of fixing it at a certain value. Moreover, this study allowed to better understand the calculations needed to get an estimation, and consequently to understand where calculation errors could lie.

This project paves the road to build a library to be able to simulate every type of vehicle and get a good energy consumption estimation. The development of pieces of code for other types of vehicles is left for the future, posing some different challenges for those vehicles that are not fuel powered. A possible next step would be to extrapolate the results of the Nissan Altima to every CVT model. In the database there were 75 CVT models, so this is proposed for the next researcher. Furthermore, another transmission type could be analyzed, such as the manual transmission since it presented the biggest error in the first analysis carried out for this project. Most likely, each gear ratio will require a different model in which efficiencies and other parameters will vary from one gear ratio to another.

In this way, the research not only answers to an engineering need, but also to a social one. The applications of this project could be a useful tool for future purposes in car software.

In conclusion, evidence seems to suggest that even if there is still a long way to go for having a full library with all vehicle models, the future that lies ahead appears to be good enough to give it a chance and make a joint effort to finish it.

11. REFERENCES

[1] C. Hall and M. Duoba, "MMAE 453: Advanced Automotive Powertrains".

[2] "Rapid Repair CVT," [Online]. Available: http://www.rapidrepairautocenter.com/cvt-transmissions-the-pros-the-cons/.

[3] «Car Engineer Driving Cycles,» [En línea]. Available: https://www.car-engineer.com/the-different-driving-cycles/.

[4] «EPA Driving Cycles,» [En línea]. Available: https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules.

[5] "Argonne National Laboratoty," [Online]. Available: anl.gov.