RANGE EXTENDER FOR THE RENAULT FLUENCE Z.E.
Choice of the engine and design of the structural support.

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Abstract

Electric cars have appeared as an alternative to the big pollution caused by internal combustion engine cars. However, electric cars as the Renault Fluence Z.E. are not very sold in the market because of their small range of autonomy. To make this car an attractive option, it is necessary to add a range extender that extends its autonomy. This range extender is based in the addition of a small internal combustion engine to be attached only when the electric autonomy cannot fulfill the trip. A range extender is chosen by means of a comparison between different electric engines sold in the market. By means of a classification tree, the different places of the car where to mount it are compared and the most appropriate is chosen. By using Solidworks, a structure to support the engine and attach it to the car is designed. The result is a Range Extender device to mount in the hitch hook of the Renault Fluence Z.E. that provides an autonomy of around 665 km. This supposes a good solution for the owner of the Renault Fluence Z.E. who needs to cover trips of more than 180 km, the electric autonomy of this car.
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1 INTRODUCTION

1.1 Background
Along the years, automobile industry has used the same technology as means of propulsion for the vehicle, but developing new improvements. It was in 1885 when Karl Benz patented the first vehicle with an Internal Combustion Engine (ICE) (Danielson, 2008). The main fuel source for the ICE is petrol, a derivate from oil. It was the best choice thanks to its high heat of combustion, portability and easy storage (The classic times, 2008). The purpose of fuel is to let free calorific energy that can be transformed into another kind of energy. The users employ it to generate heat that is transformed into kinetic energy (Brame, 1920). Due to the problems that started appearing from the consumption of fuel for the internal combustion engines, it was necessary to look for a new more sustainable fuel. The main problems derived from the consumption of petrol are the massive consumption of oil and the problems derived from it. A graph of the oil consumption until 2005 can be seen in Figure 1.

![World Oil Consumption, 1950–2004](Image)

Figure 1. Graph of oil consumption. (Worldwatch Institute, 2005)

During the last years, new alternative fuels have appeared. The research has obtained other alternatives to gasoline as biofuel, alcohol fuels or hydrogen. Nevertheless, all these alternatives still have several problems as the unsustainable biofuel production or the difficulty to store the hydrogen.

The electricity is one of the alternatives that are becoming more useful in the recent years as source of energy for the propulsion of an automobile.
Nowadays, electric cars are a reality and are taken as a possible alternative to cars with fuel engines. Although these cars have many advantages, they have a problem for their improvement: their batteries. Electric car batteries are not still developed enough to equalize the capacity to store energy of gasoline. Due to the problems derived from the use of batteries in cars plus the price difference between them, a combination of both resources (electric and fuel engine) is the best solution for now, the hybrid cars. Nevertheless, this system implies to carry one fuel engine that is switched off most of the time. This fact produces the need to look for a solution that allows the user of an electric car to mount the fuel engine only when needed. In the recent years, some solutions of electric vehicles with detachable systems to extend the range of autonomy have appeared in the market. However, these solutions usually consist on a trailer to be mounted in the back of the car, which causes a bad aesthetic impression. It would be interesting to develop a device to be mounted in the back of the car in a manner that it did not use an extra pair of wheels.

1.2 Problem

The batteries are the part of the electrical vehicle motion system that stores the electricity. They are based on reversible chemical reactions. The batteries issues are the following:

- Prices are high in comparison with the prices of fuel storage system; this raises the prices of electric vehicles. For example, the electric version of the Renault Fluence costs 25800€ while the fuel version is available from 14000€. (Renault Company, 2010). In spite of the big price difference between electric cars and fuel engine cars, the recharge of a fully electric car is much cheaper than the recharge of a fuel engine car. This would represent a save of money after a determined time of usage. (Noya, 2012)

- Charging time is long, while refilling the fuel tank only takes a few minutes. The charging time depends on the system that the costumer chooses, but the average recharge takes about six hours. (García, Autoblog, 2011).

- The batteries occupy a lot of space and, generally, are very heavy. For example in the Renault Fluence Z.E. the weight of the complete electric system is 410 kg, while the fuel engine system weights around 200 kg excluding the fuel in the
tank. (Arruz & Calle, 2011). The addition of a Range Extender would add more weight to the electric car but that would improve the autonomy over twice, at the expense of the extra weight.

- The batteries have a very low density of energy in comparison with the fossil fuels. It means that a huge volume of batteries is needed to equalize the energy stored in a small volume of gasoline. (Irurzun & García Rosillo, 2009)

The main problem is, therefore, the low autonomy of fully electric cars. This problem is caused by the low density of energy of the batteries that exist nowadays. The German company Bosch says that it is necessary to increase three times the power-weight relation of the current batteries and reduce their cost a 66 percent for the electric vehicles to be a good alternative to the fuel engine cars. (Boullosa, 2009). Current research is focusing on the development of a more efficient type of batteries.

Although all these problems are disadvantages to commercialize them, electric vehicles present a good alternative to the pollution created by fuel engine cars. To make the electric vehicles more attractive in the market, a combination between electric and fuel engines is being searched in order to extend the range of them. This gives another kind of vehicle that is appearing on the market, hybrid vehicles. Nowadays, a great majority of cars have an internal combustion engine. So, in order to reduce the big amount of fuel engine cars, the new electric cars have to achieve similar ranges of autonomy as the current fuel engine cars. Here is where the hybrid cars play an important role. (Juan Carlos Chicón, 2006)

Fully electric cars have a very limited autonomy in case the driver wants to make a long trip, as in case of the Renault Fluence Z.E. whose autonomy is around 180 km. Just a nine percent of vehicles never exceed 100 miles driving in a day (Pearre, 2010).

This is the reason why it is necessary to look for an alternative that makes the Renault Fluence Z.E. able to cover more than 180 km in case the owner needs it, but not losing the advantage of being a fully electric car for short trips in which the electric capacity is enough to cover the travel. The owner refers for example to a mid-class person who normally uses the car for going to work but in weekends wants to make long trips with the family. Another point to take into account is that in long trips, the space of the trunk
is necessary, because in these kinds of trips, the passengers usually carry their luggage with them.

At the present time, one can find several solutions in the market to extend the range of an electric vehicle. They are usually based in a small trailer mounted in the back of the car, which increases notably the length of the vehicle and adds an extra pair of wheels to it. Nevertheless, there is not any solution that does not require the use of an extra pair of wheels. The development of a system to be mounted on the hitch hook with no extra supporting point would constitute a much more aesthetic and efficient solution, due to the fact that there would not be friction losses produced by the extra wheels; this would also suppose an alternative to the massive consumption of oil and, therefore, to the pollution created by the huge emissions of exhaust gases in fuel engine cars.

The problem of a Range Extender design has been solved before. Most of the solutions consist on adding a fuel engine or a hydrogen cell under the bonnet. Some other solutions consist on a fuel engine mounted in a small trailer. However, a solution that consists on the mounting of the Range Extender system on the hitch hook has not been developed previously because it needs a structure that resist the whole weight of the Range Extender system. There is a system to attach a tray to the hitch hook, the towbox, described in Chapter 1.6.9, but it is not strong enough to hold the Range Extender. This system is going to be improved using better materials. The safety aspect of this solution is related to the addition of the license plate in the design of the system, the addition of two small red lights to improve its visibility and also the incorporation of a safety wire in case of accident for the system not to be dangerous. The ethical aspects related to the development of this new system are the reduction of consumption of fuel in comparison with a fuel engine car, the reduction of pollution and the search of a good noise level and the social aspects are related to the facilitation for the owner of a Renault Fluence Z.E. to be able to make long trips The development of this solution will be accomplished by adding already existing products in the market, i.e. a combination of products already developed by different companies.

The time available for the development of this project is 74 days. The work is to be accomplished by two students. The working time for each week is 40 hours per student. During this time, a suitable fuel engine for this car will be chosen, as well as the main parts of the supporting and attaching system will be designed. This process is expected
to be accomplished in the available time. The diagram of the expected tasks to reach can be seen in Figure 2.

![Gantt diagram](image)

**Figure 2.** Gantt diagram.

### 1.3 Goal

The goal of this thesis is to design a Range Extender for the Renault Fluence Z.E. in order to provide this car an autonomy of at least 500 km, as the current hybrid cars in the market, these data are explained in Chapter 1.6.3. The design includes the choice of an already existing fuel engine and the design of a supporting structure for the engine.

The social aspect to fulfill is the increase of the autonomy of the Renault Fluence Z.E. It is important to realize that for the EVs to become a solution to the CO\(_2\) emissions, the electricity used to recharge them has to come from renewable energies. This supposes an ethical aspect. Aspects as the signaling lights, the cover case and the security wire in case of accident are to be designed in order to fulfill the safety and human factors. All this process consists in changing the Renault Fluence Z.E. from a fully electric car into an EREV (Extended Range Electric Vehicle) in a way that the final system consists on an external device that can be removable and mounted in a way that avoids the extra consumption produced by the friction/contact with the road. The device must use the less amount of material and the cheapest materials in order to be sustainable developed.
1.4 Purpose
The Renault Fluence Z.E.’s autonomy needs to be improved to help the electric car be a good choice between it and the fuel option and because it supposes a solution when the owner needs to make a trip longer than 180 km, its electric autonomy. Furthermore, the possibility of carrying out long trips makes the Renault Fluence Z.E. a good option to be bought and, therefore, an alternative to the big amount of CO₂ emissions of the current fuel engine cars. However, the use of the electric car supposes an alternative to the CO₂ emissions of the fuel engine cars if the electricity used to recharge its batteries comes from renewable energies.

1.5 Method
This thesis is based on the need to develop a system to extend the autonomy of the Renault Fluence Z.E. The different steps to develop this system are explained below:

An approach to the current situation is made in Chapter 1.1. Namely, the electric car history is described in order to situate the reader in context in Chapter 1.6.1. The different electric car types are defined and a closer look to current hybrid cars is taken, focusing later on EREVs in Chapters 1.6.2 and 1.6.3. The investigation is focused later on the Renault Fluence Z.E. and its main features are described in Chapter 1.6.4. Furthermore, in Chapters 1.6.5 and 1.6.6 a study of autonomy will be developed in order to know the requirements for the auxiliary engine to be used as well as a study of the ways of recharging of this car.

After, a study between different engines sold in the market is carried out in Chapter 2.2 and the most powerful, because of the low time to charge the batteries that it takes, is the chosen one. In accordance to this problem, some calculations are developed to know if the chosen engine is a valid option for the current problem.

Once the engine is chosen, by means of a classification tree, explained in Chapter 1.6.10, its position related to the car will be decided in Chapter 2.3 and the not feasible options of the position of the engine will be discarded. Later, by means of pros and cons related to the modifications of the center of mass and the air resistance of every concept, the most appropriate position will be chosen.

A study of the current systems that exist to attach a device to the car will be carried out.
The features that the attaching system needs to join together with the hitch hook are studied in Chapter 2.4. Then, a prototype that fulfills these requirements will be developed by means of brainstorming, explained at Chapter 1.6.11, and searching for similarities with already existing products (Chapter 1.6.9).

When the attaching system is designed (Chapter 2.4.1), the structure to support the system engine plus tank will be chosen by deciding among different concepts. These concepts will be developed by means of brainstorming in Chapter 2.5.1, with the premises of developing structures with at least three contact points with the cover case that encloses the engine and the fuel tank. The final choice will be accomplished by means of a comparison based in the less use of material.

Afterwards, in Chapter 2.5.4 a stress test of the solution reached will be carried out in order to know if this is really a valid solution. This process will be accomplished with Solidworks.

Further, the approximate exterior design will be carried out in Chapter 2.6 by doing a 3D model taking into consideration all the requirements that it must fulfill, as the signaling, cooling, exhaust and the protection against external agents as rain or stones.

Finally, an evaluation of the results obtained from the analysis of the solution will be discussed in Chapter 3, the conclusions will be explained in Chapter 5 and a collection of possible further work will be established in Chapter 6.

1.6 Literature review

1.6.1 History
Porsche developed the first hybrid electric vehicle one century ago (1901) as shown in Figure 3, but then the gasoline was more rentable that the electricity and the prices of a car with an ICE were the half that the Electric Vehicles (EVs) (The classic times, 2008). It has not been until nowadays that taking the alternative of EVs has become really necessary, due to the massive consumption of fossil combustibles and the problems derived from it.
Several studies have revealed that the oil can decrease its production in a near future. One of these studies is the Hubbert Peak’s Theory, which stipulates that the oil extraction is going to decrease at the same rhythm as it has been growing, due to the limitation factor of the required energy to extract it (Deffeyes, 2001). Furthermore, the exploitation of the oil is creating an environmental impact that is higher with the time. The environmental problem of oil consumption is the emission of CO$_2$, molecule produced in any combustion.

This CO$_2$ produced goes to the atmosphere and it is one of the most important contributors to the global warming. In Figure 4, the higher consumption of petroleum and the increase of CO$_2$ emissions in the last years and the uptrend in the next 8 years can be seen:
These emissions are due to the factors of Figure 5. The first factor that causes these emissions is electricity and heat, and it is referred to the systems that use fossil combustibles for the production of these goods. Transport is the second factor of emissions, and it is referred to all means of transportation that use fossil combustibles and, therefore, the object of this project:
Realizing that this was an increasing problem, governments tried to set up more and more restrictive laws in order to force the automobile companies to manufacture vehicles that emit a less amount of CO\(_2\) (European Parlament, 2007). People also have been taking care of this growing problem, and that is why other alternatives have been searched, such as EVs.

A clarifying example of a government restrictive law is the European normative about emissions. The European normative about emissions is a body of requisites that regulates the acceptable limits for the emissions combustion gases of the new vehicles sold in the countries of the European Union. At the present time, emissions of NO\(_x\), HC, CO and particles are regulated for the majority of vehicles, including cars, trucks, trains and all the transports. The normative that establishes the legal amount of these emissions receives the name of Euro x, in which the x denotes the current version of normative. Now, the current normative is Euro 5, although Euro 6 values are already purposed. CO\(_2\) emissions are regulated in a different manner. Nowadays, there is a regulation stipulated by the European Union in which the average emissions of all the fleet of a company cannot exceed a specific amount. That is one very important reason why a number of brands are developing EVs among their models. (European Parlament, 2007).

**1.6.2 Electric cars**

An electric engine is a machine that transforms electrical energy into mechanical energy through electromagnetic relations. Other electric engines are used in the opposite way, to change mechanical energy into electrical energy working as generators (PC in Control, 2008). Nowadays, EVs are not very common and, at least for the time being, too expensive to become an interesting alternative.

Gradually, we are seeing how car companies are adding EVs on their lines. These cars have many benefits including a complete reduction of urban air pollution and dependence on oil. On the other hand, adoption of EVs has a huge problem, the batteries.

To correct the problem of the low autonomy that the electric cars present, companies are developing more and more another type of cars: hybrid vehicles. Hybrid vehicles use two energy sources for their propulsion. One based on an electric engine and the other
based on an ICE. (Juan Carlos Chicón Dominguez, 2006) Some of the advantages of hybrid electric vehicles come from the electric movement inception, like:

- Regenerative braking, that allows to employ the energy generated in the braking to recharge the batteries.
- Smaller ICE than in a fuel car. This lets reduce the vehicle weight as much as possible, decreasing the frictional losses.
- A huge decrease of the fuel consumption. Around fifty percent of a normal consumption.
- Fewer emissions.
- Change to alternative fuels, reducing the dependence of fossil fuels.

1.6.3 **Configuration types for hybrid cars**
There are 2 main configurations on hybrid cars, parallel configuration, shown in Figure 6, and serial configuration, shown in Figure 7. Some cars have a system that combines both configurations in a way that the engine can change its position in the schedule to work with the most favorable system.

![Figure 6. Parallel configuration detail. (Bagatelle-Black, 2007)](image)

The main feature of parallel configuration of hybrid cars is that the internal combustion engine has direct mechanic transmission with the wheels, as the electric engine. Both can work at the same time or alternate between them, working the ICE when the electrical engine has depleted the batteries or even when an extra power is needed. This
configuration has the advantage to be able to supply more power to the car due to the fact that both engines can work together.

![Diagram of serial configuration](image)

**Figure 7. Serial configuration detail. (Bagatelle-Black, 2007)**

Serial configuration hybrid cars have also been named as Extended Range Electric Vehicles (EREVs). These cars also have two engines, but only the electric one is connected directly to the drive train, so the car is driven by electric traction. It has its ICE connected to a generator in order to recharge the battery pack when the car is being driven. A serial hybrid car has several advantages: it is less complex than a parallel configuration car, the engine can be placed anywhere because a mechanical transmission with the wheels is not necessary and the engine works very efficiently because it works inconstant rpm. Serial configuration hybrid cars contain:

- An electric engine, i.e., the wheels are only moved by electric traction.
- An ICE used as a generator to recharge the batteries.
- A generator connected with the internal combustion engine to form a generator set.
- Batteries to save the electrical energy.
- Regenerative brakes. To save potential energy losses within the friction brakes and transform this energy to electrical energy that can be used for the electrical engine.
- A plug in order to be attached to the electric power supply system to recharge the batteries.
Normally, a fully electric car has around 90 km of autonomy; some examples are the Renault Twizy with 100 km of range (Renault Company, 2012) or the Reva, the bestseller electric automobile until 2009, with 80 km of range (Boxwell, 2011). There are some exceptions such as the Volvo electric car or Tesla Roadster. They can be driven about 400 km before recharging (Tesla Motors, 2012). A resume of the autonomies of different car types can be seen in Table 1.

<table>
<thead>
<tr>
<th>Car model</th>
<th>Car type</th>
<th>Autonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla Roadster</td>
<td>Fully electric</td>
<td>400 km</td>
</tr>
<tr>
<td>Renault Fluence Z.E.</td>
<td>Fully electric</td>
<td>180 km</td>
</tr>
<tr>
<td>Opel Ampera</td>
<td>Serial Hybrid</td>
<td>500 km</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>Parallel Hybrid</td>
<td>1200 km</td>
</tr>
</tbody>
</table>

Table 1. Autonomy in electric cars.

1.6.4 **Renault Fluence Z.E. (Technical specifications)**

The car selected in this thesis to become an EREV is the Renault Fluence Z.E. showed in Figure 8, the electric version of the Renault Fluence. It is an EV with a pluggable battery. According to Renault website, its maximum speed is 135 km/h and it has a range of autonomy of 180 km according to the New European Drive Cycle (NEDC). The lithium ion battery is located behind the back seats. The weight of the system of batteries is 250 kg and it has an energy capacity of 22 kWh at 400 V. The car can be charged in a home plug by means of an adapter, but it is necessary to buy a specific adapter (Renault Company, 2010). The electric engine has a power of 70 kW (95 hp) and it weighs 160 kg.

Figure 8. Renault Fluence Z.E. (Renault Company, 2010)
1.6.5 **Autonomy of the Renault Fluence Z.E**

The medium autonomy of the electric engine of the Renault Fluence Z.E. is 180 km, and the battery capacity is 22 kWh. The autonomy is calculated with a method named “New European Drive Cycle” (Costas, Motorpasión, 2011). This method consists of a test in which a vehicle with between 3,000 and 15,000 km is placed in a room with a temperature between 20ºC and 30ºC, with the engine shut off for at least six hours. No air resistance or inclination of the road is considered in this test. The test is divided into two parts: urban and open road parts. The complete process is a route of 11 kilometers and 7 meters. Once all these conditions are accomplished, it is time to do the test:

Here are the steps of the test in urban zone:

1. The car is switched on and it remains 40 seconds motionless.

2. It is leaded to 15 km/h and then, it is stopped.

3. After waiting 50 seconds, it is leaded to 35 km/h and then, it is stopped.

4. After waiting another 50 seconds, it is leaded to 50 km/h, then decelerated to 27 km/h and stopped.

All these steps will be repeated four times.

Here are the steps of the test in open road zone:

1. The car is leaded from 0 to 70 km/h and maintained one minute at that speed. Then it is decelerated to 50 km/h and maintained one minute. Accelerated to 70 km/h again and maintained one more minute. Just after that minute, it is accelerated to 100 km/h and maintained a few seconds.

2. It is accelerated to 120 km/h for a few seconds and then stopped.

A complete graphic of the test can be seen in Figure 9:
Besides the NEDC autonomy test, another more realistic test has been developed, namely, a test that involved road and city driving and in which several people had driven, so the random factors had been eliminated (García, Autoblog, 2011). The data obtained from this test reveals a medium consumption of 11.3 kWh/100 km. This test has been developed in a route of 60 km in the city. However, in the same webpage another test has been developed with the Kangoo Z.E., another electric model of the Renault. This test involved rough accelerations and more unfavorable conditions for the autonomy of the batteries and showed a consumption of 19 kWh/100 km. (García, Autoblog, 2011).

1.6.6 Ways of charging
For the Renault Fluence Z.E., there are two ways of charging (Renault Company, 2010).

- Slow charging method: Connecting the car to the regular electrical supply (220V, 16A, ~3200W). Taking into account that the battery capacity is 22kWh:

\[ 22kWh = 3.2kW \times x \]

\[ x = 6.875h \]

This result is around 6.875 hours of charge.

- Fast charging method: Connecting the car to a special charging station that provides high power. This can only be done in some countries that are implementing this kind of service. (22kW, 60 min).
1.6.7 **Connection with the batteries**
The Renault Fluence Z.E. uses a connection wire developed by the company EV Plug Alliance. This connection has the following features (Ricaud, 2010):

- 5 pines.
- Monophasic connection with the adaptor.
- 250V/32A/22kW Max

In Figure 10 the plug of the Renault Fluence Z.E used to charge the battery can be seen, the 5 pines of the connector can be appreciated. One of the big pines is for phase, another one is the neutral and the remaining is the earth protection. The two small pines are made for communication.

![Figure 10. Renault connection plug. (cochespia.net, 2010)](image)

The general scheme of the engine of the Renault Fluence Z.E. in Figure 11:
It is made of several parts whose functions are the exposed below:

- **Interconnection box**: All the flux of energy has to pass through this component.

- **Charger**: It is the part in charge of sending the electric energy from the wire at 220 V to the batteries at 400 V to charge them.

- **Electronic power unit / Converter**: Converts the electrical power into three phase electricity in order to make it able to work with the engine.

- **Engine/reducer**: Uses the electrical energy from the batteries to produce movement.

While the charge is being in process, the scheme is as shown in Figure 12:
The car is plugged to the electrical supplier; electricity goes through the charger and changes to 400V. It goes through the interconnection box and charges the batteries.

1.6.8 Models of electric generators

**HONDA ECM-10**

From Honda, it is easy to find several electrical generators. The one chosen for this project, due to the fact that it is the one most powerful, is the Honda ECM-10. Technical specifications and details can be seen in Appendix 1 (Honda, 2012).

Furthermore, attending to the constructor’s specifications, and related to our needs, it is known that constant power supply: 7 kW.

**TAIGÜER XX8500LE**

From Taigüer, the most powerful electric generator of gasoline is Taigüer XX8500LE.

Its constant power supply: 6 kW. A detail can be seen in Appendix 1 (Taigüer, 2012).

**TAIGÜER ICV840E**

This engine is from Taigüer as well, it is a diesel engine with a displacement of 836 cc. Its autonomy is able to reach the 8 hours with a deposit of 25 liters. It works at 3000 rpm constantly and it also has electric start. It weighs 200 kg and its dimensions are: 870x780x830 mm. (Taigüer, 2012). It has a constant power supply of 8kW.

**MAHLE RANGE EXTENDER**
Mahle GmbH is one of the 30 largest automotive suppliers worldwide. This company has developed an engine to work specifically as a Range Extender for EVs. This is the Mahle Range Extender. After contacting the company via e-mail, detailed information about this extender and its technical specifications were obtained. (Warth, Bassett, Hall, Korte, & Mahr, 2011). This engine is shown in Figure 13:

![Mahle engine](image)

Figure 13. Mahle engine. (Warth, Bassett, Hall, Korte, & Mahr, 2011)

This engine has a displacement of 900 cm$^3$. It is an in-line 2-cylinder, 4-stroke, gasoline engine. It is destined to work at 4000 rpm, producing a maximum power of 30 kW. Its dimensions are 327x416x481 mm and its weight is 70 kg (fuel tank not included). Adding a fuel tank of 40 liters and a controller, its weight reaches 130 kg. Its medium consumption is 240 g/kWh when it produces 15 kW and 250 g/kWh when it produces 30 kW. As the Renault Fluence Z.E. is able to be recharged at 22 kW as maximum, the medium consumption will be taken as 245 g/kWh.

1.6.9 Attaching systems

Opel Flexi fix

Opel presented a way of transporting bikes in an easy way. The system is a small tray behind the car that can be hidden when it is not in use. It is a good idea to carry the bikes without the need of buying a trailer. This tray can hold around 40 Kg. so it will be taken into account to design a similar tray like this but more resistant, to hold the internal combustion engine, ICE. The flexi fix system is shown in Figure 14
Some of the possible advantages of this system are the supposed low air resistance and the facility of installing the engine at this height.

**Towbox**

Towbox is the name of the brand of a new transporting system that takes advantage of the hitch hook that one can mount in the back of the car. This system consists of a metallic structure in which a storing solution is placed. There are different options for the storing solution depending on the needs of the customer:

- **Towbox**: Plastic case to carry all kinds of materials.
- **Towbox Cargo**: Uncovered transporting platform for all kinds of materials. An example can be seen in Appendix 2
- **Towbox Dog**: Special plastic cage for the transport of dogs and other pets. This option can be seen in Appendix 2
- **Towbox Ciclos**: Multifunctional platform for the transport of 3 bicycles. This solution can be seen in Appendix 2

To be able to mount this system, the only requisite is to have installed a hitch hook in the back of the car. By means of a lever, one can activate the lock system that incorporates a security clench.
As shown in Figure 15 and Appendix 3, Towbox system has several signaling lights in order to make it visible for the other drivers, and therefore, safe. These lights have been placed taking into account the European normative 74/483/CEE (European Community Comission, 2007), in which the signaling requisites of detachable systems for a car are explained.

![Figure 15. Towbox attaching system. (Towbox, 2012)](image)

1.6.10 Classification tree
The classification tree is a method used to divide a group of possible solutions in several distinct classes in order to facilitate the comparison and pruning between them. (Ulrich & Eppinger, 2007). At least, this method provides four important benefits:

1- Pruning of less promising branches. With this method, it is possible to identify the approaches to the problem that appears not to be very promising.

2- Identification of independent approaches to the problem. With the concept classification tree is possible to have a clearer view of the different ways to approach to the problem. Every way to approach to the problem is represented by a branch.

3- Exposure of inappropriate emphasis on certain branches. It can help to realize if the effort has been equally distributed among the different branches.
4- Refinement of the problem decomposition for a particular branch. As more information is gathered, is easier to find more particular approaches to the problem.

An example can be seen in Figure 16:

![Concept classification tree](image)

**Figure 16. Concept classification tree.** (MVNGU, 2011)

1.6.11 **Brainstorming**

Brainstorming is a concept development method by which a work group exposes several ideas for a purpose in order to have a wide set where to choose (Wright, 1998).

This method is based on two basic concepts:

1- Suspended judgment: Attempt to remove the fear of people to be criticized for exposing their ideas. Due to this, all the possible good ideas are exposed.

2- Multiple concept generation. Development of as many ideas as possible so the "best" idea is not missed.

1.6.12 **Hitch hook types**

In the market, there are several hitch hooks that can be attached to the vehicles (Enganches Aragón, 2012). Some of them are:

Fixed hitch hook. Appropriated when working with small load requirements, as small trailers. They are not supposed to be detached.

Mixed ball: They are normally used in 4x4 vehicles. They include a small cylinder to attach special trailers.
Plate hitch hook. Very appropriated when working with high vertical loads. They are not supposed to be detached. The features of the plate hitch hook model are: “D” value: 17kN and “S” value: 205 kg.

Where the “D value” denotes the maximum horizontal load that it is able to support (Fleetwatch, 2009). “S value” denotes the maximum vertical load.

In Figure 17, there is an example of a plate hitch hook:

![Plate hitch hook](Enganches Aragón, 2012)

In Appendix 5, more information about this hitch hook and its measures can be found.

1.6.13 Solidworks and Solidworks Simulation

Solidworks is a mechanical design automation software that works in Microsoft Windows. This is an easy to learn tool that makes possible for mechanical designers to sketch quickly their ideas, to experiment with operations and dimensions and produce models and detailed drawings. (Dassault Systems, 2012).

Solidworks Simulation is a design analysis system totally integrated in Solidworks. It proportions a screen solution for the next kinds of analysis: tension, frequency, buckling, thermal and optimization.

Solidworks simulation uses the Finite Element Method (FEM). FEM is accepted as the standard analysis method due to its generality and compatibility to be implemented in computers. FEM divides the model in numerous small simple pieces called “elements”, which replace efficiently a complex problem for a lot of simple problems to be solved simultaneously. The elements share common points determined as “nodes”, points at which different elements are jointed together; nodes are the locations where values of
unknown (usually displacements) are to be approximated (Kriz, 2004). The model division process is known as meshing. The behavior of each element is well known under all the situations of possible supports and loads. FEM uses different shapes of elements.

An element response, at any time, is interpolated from the response of all the nodes of the element. Every node is described in detail for a certain number of parameters, depending on the type of analysis or element used. For the structural analysis, a node response is described, generally, for three translations. These are the degrees of freedom of the node.

This software offers different types of studies:

- Static study.
- Frequency study.
- Dynamic study.
- Buckling study.
- Thermal study.
- Design study.
- Non-linear study.
- Fatigue study.

The static studies (or tension studies) calculate displacements, reaction forces, unitary deformations, tensions and the distribution of the safety factor.

When generating the mesh of a model, the program creates the following meshes:

1- Solid mesh: The program creates a solid mesh with 3D tetrahedral elements for all the solid elements in the sketch. This mesh type is suitable for thick solid objects.

2- Shell mesh: The program automatically creates a shell mesh for metallic sheets with uniform depth and surface geometries.
3- Beam mesh: The program automatically uses a beam mesh and identifies joints for structural members that are in touch or those who are not in touch but within a certain distance (tolerance).

4- Mixed mesh. The program automatically uses a mixed mesh when there are different geometries in the model.

Depending on the active meshing options, the program generates one of the next types of meshes:

- Draft quality mesh: The program generates solid tetrahedral linear elements.
- High quality meshing: The program generates solid tetrahedral parabolic elements.

Linear elements are named “first order elements” or “inferior order elements”. Its shape can be seen in Figure 18. A linear tetrahedral element is defined by four angular nodes, connected by six straight edges. Every node has three degrees of freedom that represent the translations in three orthogonal directions.

![Figure 18. Linear tetrahedral element.](image)

Parabolic elements are also named as “second order elements” or “superior order elements”. This kind of element is described in Figure 19. A parabolic tetrahedral element is defined by for angular nodes, six central nodes and six edges.
Generally, for the same mesh density (number of elements), the parabolic elements produce better results than linear elements because: 1) they represent curve edges more precisely and 2) they produce better mathematical approximations. However, parabolic elements require more computational resources.

An important parameter that can be controlled in this program when meshing is the jacobian points, i.e. the number of points placed inside the elements that add more accuracy because every of these points add degrees of freedom. Parabolic elements can follow the curve geometry much more precisely than linear elements of the same size. The central nodes of the edges of an element are placed in the real geometry of the model. In edges to curved, the placement of the central nodes in the real geometry can generate distorted elements with edges crossing with themselves. The jacobian verification is based in an amount of points placed inside every element. This software offers the possibility to choose between 4, 16 or 29 jacobian points or in the nodes. Taking into account that a parabolic tetrahedral element has 4 nodes on the vertices and 6 points in its edges, with 4 jacobian points is enough to have 14 point on each element, which proportions a good grade of accuracy. (Dassault Systems, 2012).

1.6.14 Welding
The welding is a process in which two plastic or metallic objects are joined by means of fusion. This fusion can be carried out by melting both objects to be joint or adding a fusion material. The welding used in this project is arch welding, in which a power station supplies electricity that runs through the fusion material raising its temperature to its melting point. The material melted is deposited between the two objects to joint and when it cools down, it remains solid, constituting a union that can be considered as a rigid joint for further calculations. (Cataluña University, 2004)
To do a good dimension of a weld is necessary to know the stresses created on the weld. In Figure 20 these stresses are represented on an angle welding bead.

Figure 20. Welding measures

Where:

- $S$ is the actual depth of the weld.
- $a$ is the theory depth of the weld.
- $Z$ is the theory width of the weld.

The weld has to be dimensioned calculating the dimension “$a$”.

These stresses are created by the efforts (axil, bending and torsion) that are suffering the pieces welded. Using these equations, the stresses

$$t_{SHEAR} = \frac{F}{A}$$

$$t_{TORSION} = \frac{M_T}{I_p} \cdot \vec{r}$$

$$n = \frac{M_y}{I_y} \cdot \bar{z} + \frac{M_z}{I_z} \cdot \bar{y}$$

Where:

- $t$ are the tangential stresses
- $n$ is the normal stress
• \( \vec{r} \) is the distance from the center of mass of the weld to the point of the weld where the stress is been calculated.

• \( F \) is the force and \( M_y, M_z \) and \( M_T \) are the corresponding moments on each plane.

To use this equation, the area “A” of the weld and the inertias “I_y” and “I_z” from the center of mass of the weld is needed.

The two tangential stresses have to be summed having in mind the direction of each stress. Once the tangential and normal tensions are calculated, they are translated to a coordinate system perpendicular to the welding plane, as shown in Figure 21.

![Figure 21. Detail of welding and stresses.](image)

Where:

• \( \tau_{\perp} \) is the tangential stress perpendicular to the weld.

• \( \sigma_{\perp} \) is the normal stress perpendicular to the weld.

• \( \tau_{\parallel} \) is the tangential stress parallel to the weld.

The dimensioning is done by means of comparing the stresses created by the forces with the maximum allowable stress of the material chosen for the weld

\[
\sqrt{\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{\parallel}^2)} \leq S_y
\]

\[
\sigma_{\perp} = \frac{1}{\sqrt{2}} \times (n + t_y)
\]
\[
\tau_1 = \frac{1}{\sqrt{2}} \ast (n + \tau_y)
\]

\[
\tau_{II} = \tau_z
\]

\(\tau_y\) is the yield limit of the material used for the weld multiplied by the security factor. The security factor, when the structure is not supporting people, is considered as 1.25. (Guerra, 2009). As the stresses are in function of the efforts and the efforts depend of the measure “a”, it can be determine in the last equation.

### 1.7 Limitations

This thesis consists in the improvement of an existing system, the range extender. This thesis has been based on a combination of already existing products and the supporting system has been the object of the stress calculations in order to know if the solution reached is valid.

The result of the thesis is a 3D model of every part designed. The design of the cover case is an estimation of the final dimensions that it should have, as the number or dimension of the cooling holes because information of the range extender is missing.

The connection of the range extender with the batteries of the car has also been estimated, as well as the type of adaptive frame to attach to the car to install the hitch hook chosen.

A square solid beam will be introduced in Solidworks to carry out the convergence study because the computer used does not have enough memory to develop the convergence study with the whole structure designed in this thesis. The only available elements for solid objects in Solidworks are tetrahedral elements. Furthermore, the attaching system has been submitted to a separated analysis because the limitation of the computer to handle a large amount of elements.

All the dimensioning and calculations for this project have been optimized with the purpose of reducing costs in materials in order to have the most economical solution.
2 IMPLEMENTATION

In this chapter, all the steps followed to obtain a solution are explained and developed. For this, the data collected from Chapter 1.6 is processed by means of the methods explained in Chapter 1.5. The solutions obtained are discussed and examined to check their validity for the thesis.

2.1 Study of autonomy of Renault Fluence Z.E

To be able to choose a suitable fuel engine for the car of this problem, it is necessary to know the medium consumption of the car. The NEDC cycle does not provide useful information for this project due to the fact that this test is developed under standard conditions as explained in Chapter 1.6.5. For this problem with the Renault Fluence Z.E., an estimation is going to be made based in the test with the Renault Kangoo, Chapter 1.6.5. This estimation is of a consumption of 20kWh/100 km at 100km/h, which results in an average power need of 20 kW.

As the speed keeps decreasing, the consumption decreases too. For the calculations, the less favorable case is the one that is going to be studied. The results of the medium consumption obtained reflect a very high medium consumption value. This value may not be reached if an efficient driving is carried out or if the vehicle is not carrying on a lot of weight in the trunk or inside. Nevertheless, this is a good result for the calculations of the problem because the addition of a Range Extender supposes an extra consumption of electric energy, and furthermore, it is good to use the most unfavorable case in order to check if the minimum necessary autonomy if fulfilled. Once the estimation of the medium consumption is made, a fuel engine that supplies the needed power is searched.

2.2 Choosing the electric generator

In the case of this project, it is searched an engine, with as much power as possible in order to reduce the six hours of the normal electrical supply. For that, a study of the sales of electrical generators has to be done. Once the medium consumption of the electric car is known, a final comparison of the power of each engine can be carried out in order to choose the most powerful. A resume of the power of each engine can be seen in Table 2.
<table>
<thead>
<tr>
<th>MODEL</th>
<th>POWER (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HONDA ECM-10</td>
<td>7</td>
</tr>
<tr>
<td>TAIGÜER XX8500LE</td>
<td>6</td>
</tr>
<tr>
<td>TAIGÜER ICV840E</td>
<td>8</td>
</tr>
<tr>
<td>MAHLE RANGE EXTENDER</td>
<td>30(max)</td>
</tr>
</tbody>
</table>

Table 2. Power of electric generators.

Due to its maximum power and its good relation weight-power, the Mahle Range Extender will be the engine chosen for the problem in study. Its features, as the specific fuel consumption can be seen in Chapter 1.6.8.

The maximum recharging capacity of the Renault Fluence Z.E. is 22 kW as described in Chapter 1.6.6. This means that the Mahle Range Extender could be working at this capacity as maximum. Once the fuel consumption and the recharging capacity of the Range Extender are known, we can determine the period of time that the Range Extender can be working with a deposit of 40 liters of gasoline in order to know the extra autonomy of the vehicle with the Range Extender mounted. The features of the charging capacity and the specific fuel consumption of the Range Extender are extracted from Chapter 1.6.8, which is proportioned from the company who has developed the Range Extender. These data include the losses caused in the charging process, so for these calculations, no extra losses have been taken into account. To calculate the final autonomy, some calculations are developed. The specific fuel consumption is the amount of fuel consumed for every kW and hour. If we multiply this value by the charging capacity, the amount of fuel consumed in every hour is obtained

\[\text{Specific consumption} \times \text{Charging capacity} = \text{Consumption}\]

\[\frac{245g}{kWh} \times 22kW = 5390g/h\]

Around 5.4 kg of fuel consumed every hour.

As the density of gasoline is 680g/l:

\[\frac{5390g/h}{680g/l} = 7.92l/h\]

Around 8 liters of gasoline are consumed every hour.
As the fuel tank has a capacity of 40 liters:

\[
\frac{40l}{7.92l/h} = 5.05h
\]

This engine is able to work at the charging capacity of 22 kW during 5.05 hours until the 40 liters of fuel are consumed.

To calculate the autonomy of the car with this Range Extender, it would be necessary to know when the Range Extender is going to be switched on, but an approximation can be estimated supposing that the recharge is going to be done when the batteries are totally empty. The different steps that take part in the process can be seen in Figure 22. At the beginning of the process, the batteries are in Point 1 at their maximum capacity, 22 kWh. As the energy consumption has been supposed to be 20 kW and the batteries have a capacity of 22 kWh:

\[
\frac{22 kWh}{20 kW} = 1.1 \text{ hours}
\]

This is 1.1 hours until the batteries are empty. As the speed has been supposed to be 100 km/h:

\[
1.1 \text{ hours} \times \frac{100km}{h} = 110 \text{ km}
\]

There are 110 km of autonomy at 100 km/h until the battery is empty in point 2. After the batteries are empty, a new stage take parts where the Range Extender is recharging at 22 kW and the electric engine is consuming energy from the batteries at 20 kW. As the total capacity of the batteries is 22 kWh:

\[
-20 \times x + 22 \times x = 22
\]

\[
x = 11 \text{ hours}
\]

As the engine is able to work for 5.05 hours as maximum, this means that in these 5.05 hours, the batteries would be recharged 10.1 kWh, Point 3.
At this point, the Range Extender cannot recharge more time because the fuel tank is empty, so those 10.1 kW would give an autonomy of another 50.5 km, Point 4.

![Cycle with Mahle Range Extender](image)

**Figure 22. Cycle with Mahle Range Extender.**

Taking into account that along the travel there will be irregular consumptions as well as use of air conditioning or heating system, which can suppose an extra consumption of 2 kWh (García, Autoblog, 2011), the autonomy will be decreased. Although the consumption depends on the way of driving, the estimations show there will be a good autonomy and this engine is totally valid for the problem. As seen in the calculations during this chapter, the medium consumption (20 kW) is lower than the recharging capacity of the Range Extender (22 kW). With this data, it is possible to think that the car can be only driven with the energy produced by the Range Extender. However, 20 kW is a medium consumption and, in situations when a high power is needed, the car require more power. That is why the electric engine of the Renault Fluence can provide 70 kW of power, as described in Chapter 1.6.4.

### 2.3 Choosing the place to put the engine

In this section, the process followed to select the position of the removable internal combustion engine will be explained. All the possible options will be taken into account; those that are not feasible will be deleted and all that could be interesting to be studied or designed will be selected by means of a classification tree. This method is
explained in Chapter 1.6.10. In order to simplify the problem, the options will be divided into two fields, inside and outside the chassis. Below, all the options of each possibility will be discussed, taking into account the advantages and disadvantages and impossible options will be discarded. First of all, some guidelines about the chassis will be explained.

The chassis is the part of a vehicle that supports the entire load and protects it from impacts. Depending on the shape, it can be classified into different types. The car chosen for this thesis is the Renault Fluence Z.E., whose features can be found in Chapter 1.6.4. It is a three-box configuration with separate compartments for the engine, the passengers and the cargo as described in Figure 24. On Figure 23 there are all the possible positions for the ICE.

![Figure 23. Possible positions of the ICE.](image)

The possibilities inside the body may be separated into the three compartments. The electric engine, as well as the electrical system, is inside the engine compartment of the car so there is not enough space to install another engine in this compartment unless the whole configuration of the electric engine is changed. However, this is beyond the scope of this thesis. The next option is inside the passenger compartment; this is not a valid option as it is discarded because it would eliminate a necessary space for the passengers. The last option is in the cargo compartment, i.e., the trunk. Installing the
ICE here would imply a considerable loss of space for the luggage. However, it is supposed that the customer mostly will use the internal combustion engine for long trips when the space of the trunk will be more useful. Consequently, installing the ICE in the trunk is not the best option. The conclusion is that installing the engine inside the chassis is a bad option and it will be discarded. Furthermore, there is no possibility of doing it without modifying the chassis.

Now, the different possibilities of installing the engine outside the chassis will be studied. The car is divided into three quadrilateral prisms as shown in Figure 24.

Figure 24. Three-box car. (Renault Company, 2010)

Actually, there are 2 positions where the engine may be installed: on the top and at the back of the car. The option of installing it on one side is discarded because this would break the aerodynamics of the car, involving a huge loss of energy in friction. Furthermore, the addition of a box at one side of the vehicle eventually can be dangerous for the safety of the passengers and the rest of people on the road because the driver has to get used to a new dimension of the vehicle and can cause an accident.

Continuing with the option of installing the engine on the top, the possibilities are either to place it above the roof or above the trunk. The option to put it on top of the bonnet is discarded because it supposes a problem for the visibility of the driver and, therefore, for the safety. However, installing the engine above the roof or above the trunk could be two interesting options for a thorough aerodynamic study, in spite of the fact that it has some disadvantages such as the raise of the Center of Mass, which can suppose danger for the safety due to the fact that a high raising of the Center of mass can produce
instability and problems for the handling of the vehicle. The last outside option is at the back, i.e. behind the proper car in a place that allows the trunk to open normally. Here the disadvantages such as the raise of the center of mass or the aerodynamics are not a problem but the chassis cannot hold the engine. Therefore, it is necessary to design a way of holding it.

2.3.1 Analysis of the positions
To decide which position the engine is going to occupy finally, the impact of aerodynamics that supposes the position where the engine will be placed and the change of position of the center of mass will be studied. Supposing that the engine is going to be accompanied by a fuel tank of 40 liters, the approximate dimensions of the final device to be placed can be seen in Figure 25. These two components have been modeled as solids rigidly attached to the surface of the platform. Each of these two solids applies its weight in the most unfavorable condition, a bump and a turn. The dimensions of the Range Extender have been extracted from its technical features (Warth, Bassett, Hall, Korte, & Mahr, 2011), 327x416x481mm and the dimensions of the fuel tank have been calculated by designing a box with the same height and width dimensions that the Range Extender and reaches 40 liters, i.e. 327x416x294mm These dimensions are because the system is supposed to be enclosed in some kind of case.

![Figure 25. Approximate dimensions of the system (mm).](image)

Once the approximate dimensions of the engine plus the tank and the dimensions of the car are known, a CAD model of the vehicle can be made, in order to make a discussion
of the aerodynamic impact of the system and the variation of the center of mass of the car.

**Over the roof**

With the position shown in Figure 26, the car would maintain its total functionality. This means that the mounting of the system would not affect the regular operation of the vehicle. However, the center of mass would be very raised over its initial position. This could mean a problem in stability and, therefore, for the safety of the passengers. Furthermore, the surface in contact with frontal wind would be increased, what would mean a big amount of frictional losses and, therefore, more consumption of energy. In addition, the raising of the engine every time it needs to be attached needs the design of a complicated system or, instead, a high human ability. For all these reasons, this option is discarded.

![Figure 26. System placed over the roof.](image)

**Over the trunk**

With the position shown in Figure 27, the center of mass is displaced upwards but not as much as in the first configuration. The frictional losses due to air resistance are also less than in the first case. However, the adoption of this system means that the trunk cannot be opened while it is mounted. The main use of the system is when the driver needs to cover a long distance, and it is also in these cases when the driver needs the space in the
trunk. Furthermore, to place the engine over the trunk supposes a problem for the safety, as it blocks visibility to the driver. This is why this configuration is discarded.

Figure 27. System placed over the trunk.

At the back

With the position shown in Figure 28, the engine barely affects the height of the center of mass because it is placed in a very low position. In addition, with this configuration the vehicle adopts a more similar drop shape, which is the ideal shape that a vehicle can have in aerodynamics terms. (Hucho, 1987). With the engine in this position, the car can be submitted to understeer or oversteer, which is when the car tends to make a turn in a different trajectory than expected (MotorSpain, 2007). This phenomenon can be produced by a bad weight distribution of the car. If the addition of the Range Extender supposes a high weight, it can produce the bad distribution of weight.
Figure 28. System placed in the back.

For this position, it is necessary to take into account that the trunk must be able to open normally. However, because of the design of the Renault Fluence Z.E., the addition of the Range Extender at the back is not a problem for opening the trunk. Because of these reasons, this configuration will be the one adopted for this thesis.

Within the option of mounting the device in the back of the car, there are different possibilities, as shown in Chapter 1.6.9. However, most of them require to modify the chassis or adding specific supplements for this car model. Because of this, the mounting of the system on a regular hitch hook has been the option chosen, a system similar to Towbox, shown in Chapter 1.6.9. A hitch hook can be mounted in almost any mechanical workshop, and it is an option that allows the owner to take advantage of it for more purposes, such as the mounting of a trailer.

The design of a specific system to attach the Range Extender to the car can be a good choice when looking for an aesthetic option. However, as explained in the previous paragraph, the mounting on a hitch hook is the option chosen because it can be used for more purposes and the Range Extender could be adapted to more electric cars with fewer modifications in the design.

There are more and better options explained in Chapter 2.3 as designing a compartment inside the electrical engine compartment but this would mean to redesign the disposition of the components inside the car and it would suppose a more expensive solution that is
not the purpose of this project. The option selected is not the best but fulfills the purpose for which it is developed.

### 2.4 Hitch hook analysis

For the problem, a plate hitch hook has been chosen, due to the high vertical load that it is able to support, as described in Chapter 1.6.12. The choice of this hitch hook is due to its features in comparison with other models. There is no massive weight difference among the different models, but there is difference in the vertical load that every hitch hook is able to support.

As explained in Chapter 1.7, the possibilities to attach a hitch hook on the Renault Fluence Z.E. are not known. However, this kind of hitch hook can be adapted to every chassis by means of a frame as the one in Appendix 4. The measurements of the hitch hook can be found in Appendix 5. As the chosen hitch hook is able to support a horizontal pulling load of 17kN, the moment created by that force is 1360Nm, as shown in Figure 29.

![Figure 29. Moment in the ball 1.](image)

If a hypothetical weight of 200 kg is placed at 225 mm as the center of mass of the system engine plus tank described in Chapter 2.3.1 in Figure 25, the representative scheme can be seen in Figure 30.
As the moment created is lower than the allowed showed in Figure 29, this hitch hook is a valid option to construct a system in which a 200 kg load is at a distance of 225 mm from the edge of the hitch hook. This hitch hook is considered to be designed for the dynamic conditions that a car is submitted to, i.e. bumps, turns and braking.

Normally, the systems that use the hitch hook as a piece of union with the car also use an attaching system similar to the one that can be seen in Appendix 6 in Figure 65. This is a good solution when the load is mounted over another supporting point, a system similar to the trailer system found in Appendix 6. The regular attaching system blocks the horizontal movement as well as the vertical movement but it does not support high loads because the trailer adds an extra pair of wheels to distribute the weight. Nevertheless, in the case of this project, the requirements are quite different. As this thesis is focused on the design of a supporting structure with no extra wheels, it is necessary to design a different attaching system.

2.4.1 Design of the attaching system

To design an adequate attaching system for the problem in study, the first step is to know which the movement restrictions for the system are. For this step, a simplification of the problem is made, stipulating that there will be an applied load from a certain distance of a support. The union between attaching system and support will be taken as a cylinder due to the fact that it will be removable, i.e. to mount it, the attaching piece will slide from top to bottom of the hook hitch as shown in Figure 33.
Requirements of movements to be blocked in the problem in study are:

- Horizontal movement. (This movement is generated in straight line accelerations as turns or brakings), as described in Point 1 of Figure 31

- Rotational movement around the cylinder. (This movement is generated in turns), as described in Point 2 of Figure 32

- Rotational movement. (Generated by the separation of the applied load and the supporting point), as described in Point 2 of Figure 32

- Rotational movement. (Generated in ramps and brakes), as described in Point 2 of Figure 32.

- Vertical movement. (Generated for the own weight of the system and opposite if bumps), as described in Point 1 of Figure 32

Figure 31. Top view for movement restrictions.
Taking into account all these requirements, a solution has been found adapted to the plate hitch hook. This solution has been reached searching for similarities with the attaching system of Towbox shown in Chapter 1.6.9. As the interior mechanism of Towbox is not known, the solution obtained has been developed searching for a solution that fulfills the movement requirements.

The 3D model of the solution can be seen in Figure 33.
The final solution of the attaching system consists on a box with a four-bar linkage to block the movements, the lever and the heel. The beams structure and the attaching system will slide down in a manner that the hitch hook coincides with the hole for the ball. Once the bottom of the interior part of the attaching system is in contact with the hitch hook, the user will pull the lever in order to pull out the heel and therefore block the vertical movement. This lever will be based in the mechanism of a handbrake, i.e. a rack-pinion mechanism. To free the lever back, the owner of the system must use a key.

Figure 33. Detail of attaching system.
This will also prevent the system from being stolen or deactivated accidentally. This system has the possibility to break because all the loads that has to support. This would make the Range Extender system falls down when the user is driving. Moreover the movable parts will need to be lubricated to maintenance its mobility.

All the pieces for the attaching system are constructed by a molding process that will require building the molds before. All the pieces are designed in a way that will not be a problem to filling the mold.

The designed system is completely manual and requires an effort by the user to lock. It is very simple but effective. it does not contain electrical or electronic components that can fail and require replacement.

2.5 Design of the structure

In this chapter, the process followed to obtain a solution for the supporting system is described. It consists in four main steps: the choice of the shape of the structure, the choice of the most appropriate profile for this problem, the material of which it is constructed and the dimensioning of this profile.

2.5.1 Choice of the shape of the structure

Once the attaching system has been designed, the next step is to think about the chassis that will actually support the engine. The premises to develop concepts by means of brainstorming are that the supporting structure has to be in contact with at least 3 points of the system engine plus tank. This means that just a part of brainstorming has been used because there are premises to fulfill before developing concepts. The concepts of structures have to be in contact with at least 3 points of the box engine plus tank in order to obtain a good stability and they have to be as deep and wide as the whole system to fit all components in a box, this is, 800x450mm. Four concepts have been developed. These four concepts will be submitted to a comparison, in which the length of material is the feature to evaluate. The concept that uses less material will be the chosen one.
**Circular configuration**

This configuration is described in Appendix 7.

To calculate the needed length, it is considered that the profile follows half an ellipse as it can be seen in Appendix 7. For this configuration, just a bar is needed. The manufacturing process is simple because it only requires to be bended. However, the bending process can add residual tensions to the steel, which can be, afterwards, a problem for the structure and its durability.

**Rectangular configuration**

The appearance of this configuration can be seen in Appendix 7. The length needed can be calculated from the dimensions described in Appendix 7.

This configuration presents the advantage of being easy to manufacture, as three bars have to be joint. Nevertheless, a lot of material has to be used in this configuration.

**Parallel configuration**

This configuration is described in Appendix 7. This configuration presents the advantage of having a lot of points in contact with the system engine plus tank. However, the manufacturing process can be complicated as many joints between main and secondary bars have to be made. Furthermore, it is necessary to use two different types of profiles and a lot of material.

**Triangular configuration.**

This configuration and its main dimension are described in Appendix 7.

Taking into account the main dimension of this configuration, the use of material would result in 568.5 mm, i.e., the red line shown in Figure 34, multiplied by two which results in about 1100 mm.
In Table 3, the length of material used in every configuration can be seen:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Length of material (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangular</td>
<td>1100</td>
</tr>
<tr>
<td>Circular</td>
<td>1250</td>
</tr>
<tr>
<td>Rectangular</td>
<td>1600</td>
</tr>
<tr>
<td>Parallel</td>
<td>1500</td>
</tr>
</tbody>
</table>

Table 3. Length of material for configurations.

After describing all the systems, it can be seen that the one that uses less length of material is the triangular configuration, so this configuration is the chosen for the problem.

This triangular configuration consists of two beams welded in perpendicular to a triangular piece of connection; this piece of connection is welded to the attaching system.

Once the triangular configuration with constant shape is known to be the one in which less material is required, the next step is to choose the bar profile. There are some commercialized shapes that are more common and subsequently cheaper and easy to buy. The complete structure is divided in the two main beams.
Figure 35. Triangular configuration

The beams are joined with the attaching system with a weld. Over the main beams will remain a platform showed in Chapter 2.5.4, supporting all the weight of the range extender system.

2.5.2 Profile of the bars
There are several solutions in the market for the choice of a profile for the bars. The chosen profile for this problem is a square tubular profile because it is a very common profile in the market, and therefore, it is cheap. This profile presents a lot of advantages, as its lightness, and a high inertia moment in horizontal and vertical directions. (P. Beer, Jhonston, & T. DeWolf, 2006)

From a steel beam commercial distributor, a table for all the measures of square metallic tubes can be found in Appendix 8. The measure chosen for the structure is 50x50 mm and 3 mm of thickness.

These are the commercial dimensions of square tubular profiles. These profiles are manufactured in hot rolled steel AISI 1010 whose properties are in Solidworks database. They are shown in Table 4:
Furthermore, this steel presents a good weldability because its low level of carbon (Delta school of trades, 2012), which is a necessary property for this problem due to the fact that the two bars will be welded to the attaching piece and the attaching piece to the attaching system.

2.5.3 **Dimensioning the force**
To dimension the force, it is necessary to take into considerations the elements that are going to compose the system over the beams:

- Weight of the system engine plus tank: 130 kg.

- Weight of the cover case: The whole system will be enclosed in a protective case in order to prevent from external agents, as rain or stones. As it is described in Chapter 2.6.1, its weight will be about 3 kg.

- Weight of the lights and license plate: The case will have lights and signals. These components weigh about 2 kg as it is described in Chapter 2.6

All these components add a total weight of around 135 kg.

When designing an element for a vehicle, a very important event has to be taken into account, the bumps. The bumps suppose an overload in a determined instant. For their analysis, the happening in Figure 36 has been supposed.
When the vehicle runs over a bump on the road, this creates a vertical oscillation in the structure of the range extender. In the instant that this oscillation is in the lowest point of its amplitude, the force of the weight is considered as 0. When the oscillation is in the highest point of its amplitude, the force is two times the weight. As this happening has been based on an idealization of a dynamic system to be studied as a static system, a safety factor will be added. The safety factor to be added is 1.5 because of the desire of making a durable product. A higher safety factor will not be considered because it will suppose expend more material than needed. But a risk factor is needed because if the real forces are higher than the calculated forces, the system would cause breakage with the risk of accidents for the user or the drivers around it.

Therefore, as the highest force shown in Figure 36 is two times the weight, this force multiplied by the safety factor gives three times the weight, 3W.

\[
2 \times 135 \, kg \times 1.5 \times 9.8 \frac{m}{s^2} = 3969N
\]

To be able to design a structure for the system that fulfills the requirements of the car, it is necessary to take into account the forces that are created when the car brakes or when it turns.

- Weight: 135 Kg multiplied by three because of the study of a dynamic system as a static system; 405 Kg
• Turns: 135 Kg. An unsafe steering can be considered when the lateral acceleration is 0.5G (Langle, 2009). Supposing that the vehicle of this study can increase this value, the lateral acceleration has been supposed as 1G for more security, i.e. 135 kg. The steering can be at right or at left. As the structure is symmetric, it does not matter the direction of the steering for the study.

• Braking: 135 Kg. An unsafe deceleration can be considered as 0.66G. (Langle, 2009). However, as the conditions for the experimentation are not the same, the maximum deceleration will be considered as 1G, i.e. 135Kg.

In order to see which the worst case is, the possible combinations of forces have been calculated. It includes three different cases:

1- The combination of the three forces (weight, turn and braking).

2- The force created by the weight.

3- The force created by the weight plus the one created by the turn.

Analyzing every one of the three cases, and depreciating the minimal efforts as the compression and the torsion, it shows that the bending moment created by the braking in the beam is opposite to the one that the weight creates. Therefore, the most unfavorable case will be the third one (The force created by the weight plus the one created by a turn).

2.5.4 Solving the problem in Solidworks
For this problem, the studies used will be the static study. To solve the problem, the analysis has been based on the most unfavorable case. The most unfavorable case, as described in Chapter 2.5.3, is when the force created by the weight and the one created by the curve are acting. The process to find a suitable solution in Solidworks will be:

1- Introduction of the structure in Solidworks.

2- Introduction of the boundary conditions and loads.

3- Static analysis of the structure.

If the chosen bar profiles are valid for the load requirements, it will be a valid solution.
1- Introduction of a structure that supports the range extender

The standard profile chosen for introducing it in Solidworks is a 50x50mm with a thickness of 3 mm.

The appearing of points with high stresses was noticed after developing some previous analysis with bars with an angle cut at one end as shown in Figure 37. As shown in Figure 39, the triangular union piece has been designed to attach the beams perpendicularly and avoid high stresses on the point 1 because of the angle of the cut. This piece can be seen in Figure 38.

![Figure 37. Top view of Angle cut bars](image)

![Figure 38. Triangular union piece](image)
The system engine plus tank remains over a platform, and this platform over the beams adding rigidity, a steel platform of 5 mm thick has been added to the system. This platform is made in AISI 1010 as the beams because of its low price and good features as weldability. Its weight is around 15 kg. This platform will add torsion rigidity to the bars and will enclose the system. The union between beams and platform will be taken as a solid union as option in solid works, which means that all the pieces are considered as the same because the two beams will be welded to the platform along all the surface in contact so it is a very resistant union. In Figure 39, the structure of the beams, the union piece and the platform can be seen.

![Diagram of beams, union piece, and platform](image)

**Figure 39. Structure with platform.**

2- **Static analysis of the profile**

For the static analysis of the structure, it is necessary to take into account that two main components remain over the platform: the fuel engine and the fuel tank. These two components have been placed together and centered over the platform.

The Range Extender has been assigned a weight of 82.5 kg, i.e. 70 kg of its own weight (Warth, Bassett, Hall, Korte, & Mahr, 2011) and 12.5 kg of the case, signaling components and connection utilities. The fuel tank has been assigned a weight of 52.5 kg.
Both, Range Extender and fuel tank add their weight as a vertical load and their weight as a horizontal load. However they do not add more rigid to the system model because as an option in Solidworks, they are considered for the calculations as a remote mass applied on the upper surface of the platform.

The appearance of the structure with the platform and the two boxes representing the range extender and the fuel tank can be seen in Figure 40.

The cover case and lights are not represented on the 3D model because their weight are depreciated in comparison with the other parts of the system.

![Figure 40. Appearance of the structure.](image)

The Solidworks model to analyze is submitted to an acceleration of 3G, while the horizontal acceleration, on X axis, of the weight of the components is 1G as explained in Chapter 2.5.3. These accelerations can be seen in Figure 41.
The boundary conditions applied to the structure are for the union piece to be totally constrained because it will be welded to the attaching system. The details of the boundary conditions can be seen in Figure 42.
For defining the mesh, a convergence study has been made to know what the most appropriate size of element to use is. To develop this convergence study, a square bar profile has been submitted to a static analysis because the whole system is not able to be submitted to the convergence study because of the limitations of the computer used. The bar introduced in the study is a cantilever beam of 50x50 mm and 1000 mm length with a load of 100 N at the end as can be seen in Figure 43, using parabolic tetrahedral elements, defined in Chapter 1.6.13.

The chosen point is a little bit separated of the end of the beam because the points near of a sharp corner increase their stress higher and higher never leveling off or converging (Tordini, 2011). The results of the convergency graph can be seen in Figure 44.
As the results show decreasing the size of the elements the stress converges to a value. The graph shows the convergency about at an element of 17 mm. As shown in Figure 44 use a size element higher that 17 mm does not give a good result. The point chosen converges to a stress value of approximately 46.3 MPa. If the size of element chosen is of 4 mm, i.e. \(\log_{10}(4)=0.602\), the stress for that size of element is 46.21 MPa, which means an error of:

\[
Accuracy = \left(1 - \frac{|Convergence\ stress\ value - Chosen\ size\ stress\ value|}{Convergence\ stress\ value}\right) \times 100
\]

If the chosen size of element is 4 mm, the accuracy is:

\[
Accuracy = \left(1 - \frac{46.3 - 46.21}{46.3}\right) \times 100 = 99\%
\]

A very good accuracy is obtained using a mesh with 4 mm of element however that does not mean that the results of the Finite Element analysis are so good because the model used for the analysis does not represent exactly the real system, it is an approximation. A smaller element size has not been chosen because the limitations of the computer to process the mesh.

To make the static analysis of the structure to support the Range Extender system, the mesh has been carried out by doing a mesh control. The mesh control consists in meshing the most stressed zones with smaller size elements. The most critical zones in this structure can be found in the joint of union piece, platform and beams. In these zones, the smallest size of element used is 4 mm, the size obtained from the convergency study as an accurate value. The results obtained from the static analysis are:
Von Mises stress

Figure 45. Von Mises tension.

The maximum stress is about 110MPa at element, as shown in Figure 45, which does not reach the yield limit of the material. There are about 7200 elements composing the model. The most stressed zone can be seen in Figure 46.

Figure 46. Detail of maximum stress zone.
As shown in Figure 46, the maximum stress is on the corner. In the upper edge of the union piece, a chamfer of 3 mm of radius has been added in order to avoid stress/concentration zones.

From this study the resultant forces on the constrained surface, i.e. the face of the union piece in contact with the attaching system are:

- \( F_x = 1.4 \text{ kN} \quad M_x = -930 \text{ N·m} \)
- \( F_y = 0 \text{ N} \quad M_y = -470 \text{ N·m} \)
- \( F_z = -4.2 \text{ kN} \quad M_z = -310 \text{ N·m} \)

These values will be the applied to the surface of the attaching system on its static study as shown in Figure 48.

2.5.5 Estimation of the attaching system
The analysis of the attaching system has been carried out in a separate analysis in Solidworks because of the limitations of the number of elements that the computer can handle. The attaching system has been checked for the stress it has to support. The material chosen is steel AISI 1010. The weight of the attaching system, excluding the lever is around 15 kg.

The boundary conditions applied to the element can be appreciated in Figure 47.
The boundary conditions are applied to the inner superior face and the superior face of the heel where it is totally constraint and the interior semi sphere where the constraint is slider, this is a kind of constraint that does not permit movement in the perpendicular direction of the surface.

The mesh used in this analysis is made of parabolic tetrahedral elements explained in Chapter 1.6.13 it divides the attaching system in about 19000 elements.

The loads involved in this analysis are the ones of the most unfavorable case: the force created by the weight and the one created by a turn, their values are taken from the reaction forces of the previous analysis of the beams, the platform and the union piece. They are applied over the attached surface only on the contour of the welding as shown in Figure 48.
In Figure 49, the results of the maximum stress can be seen.

As it is shown on the result the maximum stress value obtain (35 MPa) is much lower than the stress allowed (180 MPa) it means that the piece could be object of a future work in order to optimize the design and to reduce the use of material. With the current
dimensions the attaching system is over dimensioned, i.e. a deeper analysis could make this system cheaper, as it can make its function with less material.

2.5.6 Calculation of the welding
Different parts of the structure that supports the system of the Range Extender will be joined by means of welding. These parts are the two beams to the platform, the two beams to the union piece and the union piece to the attaching system. The welding used in this thesis is arch welding, as described in Chapter 1.6.14 and the material of the weld is going to be steel S275 because is the easiest to find and the cheapest material (Cataluña University, 2004) and has a good yield limit (430 MPa) that is enough for this problem. The most critical point will be the chosen for the calculation of the welding because it is the one submitted to higher stresses. The welding will be done all over the edge of the union piece in contact with the attaching system. The scheme of the welding to join the union piece with the attaching system can be seen in Figure 50.

![Figure 50. Scheme of the welding.](image)

The measure of the welding that is needed to calculate is the depth of the weld, “a”. It is going to be calculated comparing the stresses created by the forces with the design stress of fillet welds. The requirements will be that the stresses created by the forces do not be higher than the allowable stress.

To calculate the stresses, the forces acting on the structure in the most critical case, the force created by the weight and the one created by the turn as was explained in Chapter 2.5.3, they are going to be taken from the results on Chapter 2.5.4.
• Shears

\[ V_y = 4200 \, N \]
\[ V_z = 1400 \, N \]

• Torsion

\[ M_x = 470000 \, N \cdot mm \]

• Bending

\[ M_y = 310000 \, N \cdot mm \]
\[ M_z = 930000 \, N \cdot mm \]

To calculate the stresses created by the forces and moments, the equilibrium equations that relate the forces with the stresses, explained in Chapter 1.6.14, are going to be used.

And the area and inertias of the welding are:

\[ A = (100 + 100 + 50 + 50) \cdot a \, mm^2 \]
\[ I_y = 145000 \cdot a \, mm^4 \]
\[ I_z = 416000 \cdot a \, mm^4 \]
\[ I_p = I_y + I_z = 561000 \cdot a \, mm^4 \]

All will be in function of “a”, the data that is going to be calculated.

TANGENTIAL STRESS

The tangential stresses are created by shears (1) and torsion (2) and the normal stresses are created by bending moments. The points A, B, C and D are the critical ones because they have more torsion stress.

• Shear

\[ t_y = \frac{4557 \, N}{300 \cdot a \, mm^2}; \quad t_z = \frac{1519 \, N}{300 \cdot a \, mm^2} \]
• Torsion

The tangential stresses created by the torsion can be seen in Figure 51.

![Figure 51. Tangential stresses created by the torsion.](image)

Now the tangential stresses of the torsion are added to the tangential stresses of the shear.

A)

\[
t_y = -\frac{15.19}{a} + \frac{23.01}{a} = \frac{7.82}{a} \frac{N}{mm^2}
\]

\[
t_z = \frac{5.063}{a} + \frac{11.5}{a} = \frac{16.563}{a} \frac{N}{mm^2}
\]

B)

\[
t_y = -\frac{15.19}{a} - \frac{23.01}{a} = -\frac{38.2}{a} \frac{N}{mm^2}
\]

\[
t_z = \frac{5.063}{a} + \frac{11.5}{a} = \frac{16.563}{a} \frac{N}{mm^2}
\]

C)

\[
t_y = -\frac{15.19}{a} - \frac{23.01}{a} = -\frac{38.2}{a} \frac{N}{mm^2}
\]
Normal stresses are created by the bending moments $M_y$ and $M_z$

\[
t_x = \frac{5.063}{a} - \frac{11.5}{a} = - \frac{6.437}{a} \frac{N}{mm^2}
\]

\[
t_y = - \frac{15.19}{a} + \frac{23.01}{a} = - \frac{7.82}{a} \frac{N}{mm^2}
\]

\[
t_z = \frac{5.063}{a} - \frac{11.5}{a} = - \frac{6.437}{a} \frac{N}{mm^2}
\]

NORMAL STRESS

Now that all the stresses are calculated is time to change them to the coordinate system perpendicular to the weld. Remembering that:

\[
\sqrt{\sigma_x^2 + 3(\tau_{xx}^2 + \tau_{yy}^2)} \leq S_y
\]

Replacing in the equation by using the equations of Chapter 1.6.14, and taking $S_y$, the yield limit of the weld, as 430 MPa divided by the security factor of 1.25, the “a” obtained is smaller than the minimum security thickness, so the final “a” will be taken as 3 mm because it is the minimum thickness of welding when constructing a structure.
(Guerra, 2009). As the welding has been calculated for the most critical points, the union of the beams with the union piece will be considered with a welding of the same thickness.

2.6 Exterior design

In this chapter, the exterior of the system is going to be designed. This includes the case to cover it, explained in Chapter 2.6.1, the signals and lights that it must have to drive along open road as shown in Chapter 2.6.2, the security system in case of accident and breaking of the union between the Range Extender and the car, described in Chapter 2.6.3 and the electrical connection of the lights with the car, described in Chapter 2.6.2.

2.6.1 Cover case

The final system must be enclosed in a case that permits a good ventilation of the engine and its admission, at the same time that it protects the engine from external agents such as rain, snow or stones.

The material to use for this problem must be resistant to heat because it will be very close to the engine. Nevertheless, the strength is not a necessary feature because it does not have to carry weight nor support high stresses.

Taking into account all these requirements, the material that fits the best with this problem is Polypropylene (PP) (Moreno, 2012) because this kind of plastic resists temperatures till 150ºC and resists corrosive products. It is also very resistant to impacts and at the same time, it can bend easily, which is very appropriate in case that the cover receives a hit from a stone, for example. The case will also have several small holes in order to permit a good ventilation of the engine. These holes will also allow the engine to admit the air for working and cooling. The dimensions of these holes are not known because the cooling requirements or necessary air flow to work is not known, therefore, the design of the holes is an estimation. The density of polypropylene is 0.9g/cm³. Approximating the dimensions of the case as the dimensions of the system engine plus tank, 800x450x350 mm and the thickness of the cover as 3 mm, the weight of the cover would be 3.34 kg.

Furthermore, in the top, there will be a place for a cap connected with the fuel tank to fill it as shown in Figure 54. This cap will have a clench that permits the owner of the car to open the cap with a key when it is necessary to refill the tank.
In addition, two plastic covers will be added in the ends of the beams to avoid sharp corners. These two plastic covers will be similar to the one in Figure 52.

![Plastic cover for the beams. (ISC, 1999)](image)

The most appropriate manufacturing process of the cover case is injection molding (Textos científicos, 2005) because of the shape of the cover case, described in Figure 54. This shape includes the main protrusion of the enclosing case and the holes for the different ventilation holes and filling cap.

### 2.6.2 Signaling of the system

As this system is supposed to be mounted in open road, it must fulfill the current legislation, in this case, stipulated by the European Community Commission.

Reminding the system Towbox in Chapter 1.6.9, this is approved as an Independent Technical Unit and these kinds of systems have their own normative to fulfill. This normative is the set of laws that stipulate the requisites that these systems have to fulfill, described in Chapter 1.6.9. Although the mission of the system designed for this problem is not the same, the signaling as a ledge of the car can be taken as the same. And, taking into account that the dimensions of the system of this problem are smaller than Towbox, the signaling to mount is the same. This is, two red back reflectors, one orange reflector on each side, a license plate and the lights that include: a white light for the plate, a position light, a rear gear light, two brake lights and two position flashing lights.

The lights will be connected to the car by means of a wire and an adaptor which must be previously installed in the car and whose shape is similar to Figure 53.
This adaptor is similar to the ones that are usually installed when attaching a trailer to the car. The addition of the signaling lights is a requisite that can be considered very useful. It helps the system to be visible for the other drivers and, therefore, safe. The connection for the lights with the car is made by means of a wire and an adaptor, which is very simple and cheap.

2.6.3 Security chain
In case of accident, the system can experiment an acceleration that breaks the attaching system or even the system can receive an impact and separate from the hitch hook. If this happens, the system can become a dangerous uncontrolled mass that can injure someone. To avoid this, two different options exist in the market depending on the type of trailer or system attached to the car (Remolques Lafuente, 2011):

- Systems with brake. These systems include a small wire attached to the car that tautens when the trailer separates from the hitch hook. When the wire tautens, it activates the proper brake that the trailer includes.

- Systems without brake. These systems include a chain that is able to drag all the system if this separates from the hitch hook. This chain is usually attached to the car by means of a shackle.

In the case of the system developed in this thesis, it is necessary to include a chain to ensure that the system is going to remain joint to the car in case that the attaching system breaks. The addition of this chain is object of a further work because it is not known where the shackle can be adapted on the car.
2.6.4 **Final appearance of the exterior design**
The final result of the case and the exterior finishing can be seen in Figure 54.

![Figure 54. Final appearance of the exterior design.](image)

As shown, the small holes for the ventilation are all over the case to ensure a good breathing of the engine. In the back part, there are the two main brake lights and also the two reflecting lights. At the sides, the orange reflecting lights indicate the width of the system. At the top, the cap to fill the tank with the lock mechanism can be appreciated.
3 RESULTS

In this chapter, the results obtained from the different analysis and calculations are going to be exposed:

1. After developing a study of autonomy of the Renault Fluence Z.E., the most suitable engine for this case was concluded to be the Mahle Range Extender, described in Chapter 1.6.8, due to its high power and its good relation weight-power. The system of the Mahle Range extender plus the oil tank is 130 Kg.

2. The autonomy of the Renault Fluence Z.E. with the Range Extender is around 650 km, as shown in Chapter 2.2.

3. By means of a classification tree, the back part of the car was concluded to be the best place to mount the engine in, described in Chapter 2.3.

4. The Range extender system was decided to be mounted on the hitch hook because of the limitation of little information about the chassis of the Renault Fluence Z.E as explained in Chapter 2.3.1. With this place to mount, there is also the possibility of making a system able to be mounted in more car models. This will be accomplished by adapting the chosen hitch hook with an adaptive frame.

5. Making an analysis of the requirements of the movements to be blocked, an attaching system was designed based in the already existing system Towbox, as shown in Chapter 2.4.1. The solution obtained is over dimensioned as explained in Chapter 2.5.5.

6. For the design of the structure that support the Mahle Range Extender and the fuel tank, its shape was chosen as a triangular configuration as shown in Chapter 2.5.1. The type of profile chosen was a square tube of 50x50 mm and 3 mm of thickness made in AISI 1010 steel, described in Chapter 2.5.2. The final result obtained for composing a structure valid for this thesis gives two bars of 542 mm length which weight 5 Kg in total. At the end of the beams a triangular prism union piece has been added in order to reduce the stress on the union, it weighs 890 gr. Over the beams a steel platform has been installed to give more stability to the system. The platform measures are 800x450 mm and 5 mm of
thickness, its weight is 15 kg. Both, the platform and the triangular union piece are made in AISI 1010 steel.

7. The analysis with Solidworks showed the most critical points, explained in Chapter 2.5.4. These points did not reach the yield limit of the chosen material, showing a maximum stress of 108 MPa, and therefore, it was taken as a valid solution. On the analysis of the attaching system the maximum stress obtained was 8 MPa, as shown in Chapter 2.5.5, giving a solution that permits to constraint the system to the hitch hook.

8. The calculation of the welding was carried out showing a necessary thickness that did not reach the limit established by the handbooks for welding. Therefore, the welding thickness that was adopted was 3 mm, as described in Chapter 2.5.6. The welding is present in the union piece with the attaching system as well as in the beams with the union piece.

9. The exterior cover to enclose the system was designed as shown in Chapter 2.6.1, resulting in a polypropylene box with small holes to permit the aspiration and cooling of the engine. The signaling of the cover case and the use of a security chain were indicated. The cover case weight with the signalization and lights is estimated in 5 Kg. There is lack of information related to the engine and the design of the cover case has been considered as a proposition for a future optimization. The weight of the whole range extender system for this project, including the beams, the generator, the oil tank, the attaching system and the cover case is around 170 kg, which is widely valid for the chosen hitch hook.

10. A description of the final dimensions of the designed parts can be found in Appendix 10.
4 ANALYSIS

1. The Range Extender chosen for this thesis is a good solution because, as explained in Chapter 2.2, the autonomy reached is 650 km, which fulfills the goal of Chapter 1.3. This solution to improve the autonomy is temporal because nowadays, the batteries are not developed enough and the usage of petrol is more efficient. The installation of a range extender could become useless due to the improvement of the current batteries in order to increase their energy capacity.

2. The back part was decided to be the place where to mount the engine because it does not affect the visibility of the driver or the raise of the center of mass. The modification on the driving performance of the Renault Fluence Z.E. with the addition of the Range Extender has not been analyzed because of the lack of information of the vehicle. However, the addition of the Range Extender can be a problem in handling because it can produce oversteer and therefore created a risk of security.

3. The solution obtained for the attaching system fulfills the requirements of movements that need to be blocked. It is a valid option, however, as the results show in Chapter 2.5.5, it is over dimensioned, which means that for it to be an optimum option, it has to be submitted to a further work.

4. The bars and platform chosen to make the supporting structure and the disposition of them have been proved to be a valid option as shown in Chapter 2.5.4. The results in Solidworks show that the yield limit is not reached in any part of the pieces of the structure.

5. Some features of the cover case design have been designed making an estimation because of the lack of information related to Mahle Range Extender, as cooling needs or position of the fuel tank. Features of the cover case have been taken into account, as the small holes for the aspiration and cooling and the filling cap. Nevertheless, these features are not known to fulfill the requirements of the Range Extender chosen for this thesis.
5 CONCLUSIONS

From the work carried out during this Bachelor Degree Project some conclusions have been extracted:

- For the EVs to become an interesting alternative to the CO\textsubscript{2} emissions, the energy used to recharge their batteries must be produced by means of renewable energies, as described in Chapter 1.4.

- Mahle Range Extender constitutes a better solution for making an EREV than other commercial electrical generators because of its low weight, small size and high power. However, as this Range Extender is not being manufactured yet, a lot of information from it is missing.

- The back part of the car is decided to be the best place where to mount the Range Extender but, a study of the behavior in handling of the car has not been developed because information from the Renault Fluence Z.E. is missing. This may constitute a risk in safety. The consequence of not developing this study can be a possible instability when driving and an accident.

- It is very important to analyze the forces that take part when constructing a device for a vehicle in order to make a valid design. If the forces taken into account for the study are not for the most unfavorable case, the risk to make a wrong design exists. This supposes a big risk in safety, a rupture in some part of the structure designed. The consequence of this rupture may suppose the damage of the other people present on the road.

- To obtain valid results, it is necessary to develop a model as close as possible as it would look like in reality. If the 3D model is not similar to the model to construct in reality, the FEM analysis can show wrong results that will not help to identify the critical points.

The final result of this project shows the general aspect that a Range Extender for the Renault Fluence Z.E. will have. This Range Extender is composed by the Mahle Range Extender plus a 40 liters fuel tank enclosed in a case. The system will be attached to a hitch hook previously mounted and adapted to this car by means of an attaching system,
which has been designed but must be object of a further work in order to save material and costs.

The problem of the low autonomy of the Renault Fluence Z.E. has been solved by developing this Range Extender system. Also, this system would help to reduce the current massive CO2 emissions. When some person needs to cover long distances by car, this person usually acquires a fuel engine car because of its high autonomy. However, this car is emitting CO2 in short trips too. With the adoption of this system, the Renault Fluence Z.E. would not emit any CO2 emission when the autonomy is covered by the electric batteries, but the system provides the capacity to cover long trips when needed. For this to be a good alternative to the CO2 emissions is necessary that the electricity used to recharge the batteries of the car comes from renewable energies. Otherwise, the production of this electricity could cause a CO2 emission equivalent to the one produced by the consumption of fuel.

The main calculations of this project have been focused in the design of the supporting beams because the knowledge acquired in this Bachelor has been focused in mechanical calculations.

When developing a project in which various existing products are involved, it is very important to know the features in detail of all those products in order to make real calculations and make as less suppositions as possible. This will help to obtain a final product in which its features will be very similar to the product developed in reality.

Although the costs of the beams and attaching system do not suppose a big amount, the Mahle Range Extender itself has a very high price. This, added to the fact that electric cars are expensive in comparison with fuel engine cars, makes all this system an expensive option. Due to this, this system could be interesting to be offered as a renting option, in which the owner of the Renault Fluence Z.E. can rent this system for an inferior amount of its price only when it is required to cover a long distance with the car. The thesis has not followed the time plan established at the beginning. The Gantt diagram, showed in Chapter 1.2 planned the finishing of the thesis at the beginning of June. However, more time has been necessary to finish the report.
6 FUTURE WORK

After obtaining all the results and developing all the analysis, the need of carrying out further work in different aspects was concluded:

- The range extender has to be raised to a certain height to be attached to the car. For this purpose, it is necessary to design a system to develop this task. A possible idea for this system can be found in Appendix 9.

- The attaching system has been designed, but as the results show, it is over dimensioned. A further work will include an optimization and a redesigning of it to make it more efficient.

- A fatigue study can be developed in a further work to check if the designed system can be durable enough.

- The cover case has been estimated because of the lack of knowledge of the cooling needs or the necessary air that the Range Extender requires for a good workability. Once this engine is more commonly known and more data can be obtained of it, the case will be able to be redesigned.

- As well, the platform where the engine and tank will remain has not been designed because the exhaust needs of the engine or the way to fix it to the floor are not known.

- The cap of the cover case has been designed to be mounted in the top of the case but, once again, it is not known the exact place where it should be due to the fact that the fuel tank has been estimated.

- The hitch hook chosen for this problem has been designed to can be adapted to the car by means of a frame. A future work will include a deep study of the adaption of the frame to the chassis of the car.

- The electrical connections have not been object of this project. Most of them have not been studied because a lot of data were missing, as the connection of the Range Extender with the car. When this data is available, a future work can be developed focusing in this aspect.
7 APPENDIX

7.1 Appendix 1
Electric generators.

Figure 55. Honda ECM-10.

<table>
<thead>
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<th>POTENCIA MAXIMA</th>
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<td>GX620K1 VFA</td>
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<td>ARRANQUE</td>
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Figure 56. Specifications of Honda ECM-10.

Figure 57. TAIGÜER XX8500LE.
Figure 58. TAIGÜER ICV840E.
7.2 Appendix 2
Drop-shape justification

Figure 59. Effect of boat-tailing on drag coefficient.

Image extracted from (Hucho, 1987).
7.3 Appendix 3

Towbox

Figure 60. Towbox Cargo.

Figure 61. Towbox Dog.
Figure 62. TowboxCiclos.
7.4 Appendix 4
Adaptive frame for hitch hook

Figure 63. Adaptive frame for hitch hook.
7.5 Appendix 5
Plate hitch hook specifications (Enganches Aragón, 2012)

Figure 64. Plate hitch hook dimensions.
7.6 Appendix 6
Regular attaching systems

Figure 65. Regular attaching system.

Figure 66. Trailer system.
7.7 Appendix 7
Structure configurations

Figure 67. Triangular configuration.

Figure 68. Triangular configuration dimension.
Figure 69. Circular configuration dimensions.

Figure 70. Circular configuration.
Figure 71. Rectangular configuration.

Figure 72. Rectangular configuration dimensions.

$L = 2 \times 416 + 775 = 1607 \text{mm}$. 
Figure 73. Parallel configuration.
### 7.8 Appendix 8
Dimensions of square metallic tubes

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Figure 74. Dimensions of square metallic tubes.
7.9 Appendix 9

Idea for the mounting system

Figure 75. Idea for the mounting system.
8 REFERENCES


Langle, L. (2009). Are you a safe driver? Denton, TX, USA.


