DESIGN OF A REAL PROTOTYPE OF A HYBRID FUEL CELL SUV: VEHICLE "HÉRCULES"

P.A. Guadix[1], F.J. Pino[2], J.J. Martínez[1], M.F. Rosa[3], and E. López[3]

[1] AICIA, Edificio ESI, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain.
Phone number: +0034 954487471, e-mail: **pabloguadix@esi.us.es**, **jjms@esi.us.es**

[2] Escuela Superior de Ingenieros, Camino de los Descubrimientos s/n, 41092 Sevilla, Spain.
Phone number: +0034 954487471, e-mail: **fjp@us.es**

[3] Instituto Nacional de Técnica Aeroespacial, Ctra San Juan del Puerto – Matalascañas km. 33, 21130 Mazagón, Spain.
Phone number: +0034 959208849, e-mail: **rosaif@inta.es**, **lopezge@inta.es**

Abstract. Hydrogen is becoming one of the most feasible energy vectors to succeed gasoline as fuel. It has the potential to be obtained from renewable energy sources, having almost a null impact on contamination. Oil wells are drying up and oil does not fulfil the ZEV (zero emission vehicle) program of contamination. These reasons lead to think that oil will pass the baton to hydrogen as the next energetic vector for automotive applications. In addition, hydrogen has the advantage of being used directly in fuel cells which have higher efficiency than internal combustion engines (ICE). Project Hércules consists of the construction of a real sport utility vehicle (SUV) prototype of a fuel cell vehicle (FCV) based in the model Santana 350. It will be fuelled by hydrogen obtained totally renewably by using an electrolyser fed by solar energy. This paper shows, in this framework, all the steps that are needed to be covered to specify the power of the fuel cell, battery and electric motor using the simulation tool ADVISOR™ to match the desired specifications.

Key words

hydrogen, fuel cell, vehicle, ADVISOR™, hybrid electric vehicle, HEV

1. Introduction

On road transport is the source of the 18% of greenhouse emission effect and 91% of the emission of CO [1]. This should be sorted out if we desire to keep the planet fit. This is how, in 1990, California embarked on an ambitious strategy to reduce vehicle emissions to zero. This objective was to be achieved through the gradual introduction of electric vehicles (EVs) into the California fleet [2]. The main reason for the slow progress in EVs has been finding the inability of available rechargeable battery systems to provide the energy and power densities needed to make electric propulsion systems competitive with the range and power output of heat engines operated in fossil fuels.

Due to a great effort in developing fuel cell systems, they have been shown as a better alternative to automobiles than EVs to fulfil the zero emission vehicles (ZEV) program. Fuel cell vehicles (FCVs) are rapidly appearing all over the globe. In less than 10 years, FCVs have gone from mere research novelties to operating prototypes and demonstration models. At the same time, government and industry have teamed up to invest billions of dollars in partnerships intended to commercialize fuel cell vehicles within the early years of the 21st century [3].

Hydrogen is, then, becoming one of the most feasible energy vectors to succeed gasoline as fuel. It has the potential to be obtained from renewable energy sources, having almost a null impact in contamination. However, this technology is not well enough developed to be currently competitive mainly because of the relative low cost of buying oil. But, oil wells are drying up and oil as a fuel does not fulfil the ZEV program of contamination. These reasons lead to think oil will pass the baton to hydrogen as next energetic vector for automotive applications. Many efforts are being taken in this direction by car manufacturers, public and private R&D organisations, universities and research centres. In addition, hydrogen has the advantage of being used directly in fuel cells which have higher efficiency than internal combustion engines (ICE). This is the context for which Project Hércules has been thought. The objective of this project is the construction of a real SUV prototype of a fuel cell vehicle (FCV) based in the model Santana 350.

Fig. 1. Model Santana 350

2. Project Hércules

Thus, this Santana 350 will be fuelled fully renewably by hydrogen obtained by using an electrolyser fed by solar energy. The main objective is finishing its construction by July of 2009. The project, which has a budget of around € 9 millions, involves eight companies: Hynergreen, AICIA, Agencia Andaluz de la Energía, Carburos Metálicos, Greenpower, INTA, Santana and Solúcar. The project receives subvention from Corporación Técnológica de Andalucía, IDEA and Ministerio de Educación y Ciencia.

Project Hercules aims a double objective. First of all, it pretends to evaluate how clean and efficient a fuel cell system works in one of its most exigent areas: automotive applications. Secondly, it also pretends to improve the technology of getting hydrogen using solar energy in order to be implemented in Andalusia [4]. So, this project will show lots of results that will led us to study the suitability of using the solar energy indirectly to fuel a car. This suitability is suppose to be studied economically (based on market trends) and energetically, but it will remain unknown until the end of the project, when the evaluation of the prototype will start. That is why this paper shows how to proceed in the design of a FCV and how simulation can help in this process. All of these results are based on the framework of this project.

3. Fuel cell vehicles versus conventional vehicles

A fuel cell is a mechanism that converts hydrogen and oxygen into water throughout electrochemically reactions (without combusting the hydrogen) obtaining continuous electricity.

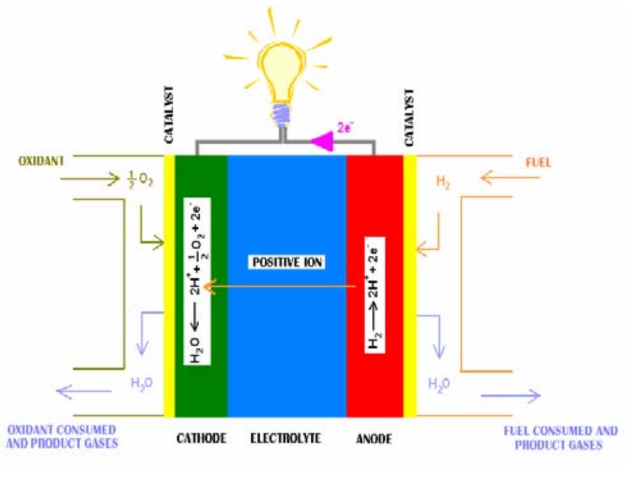

Fig. 2. Schematic of a fuel cell

This mechanism presents several very interesting benefits for being used for automotive applications. The most important one is the potential of zero pollution if hydrogen is got using renewable energy. They also have a better peak efficiency than an ICE engine and much better performance for partial-load conditions, as can be seen in figure 3. This improve in efficiency could make the performance better if we would reform fossil fuel to obtain hydrogen to feed the fuel cell [5]. This performance is very interesting in urban conduction where our vehicles have most of time a partial-load performance. This is the worst efficient way of driving a car and it leads to a higher consume, thus higher contamination. Furthermore, urban environments are those who suffer more from pollution due to much heavier traffic. This is why a fuel cell vehicle is considered a better option than ICE vehicles fuelled by hydrogen, even when the technology of ICE is further developed. Another very important characteristic is that a fuel cell has no moveable part, thus it has less propensity to default and is almost noiseless, eliminating acoustic contamination as well. On the other hand, fuel cell vehicles present several drawbacks, mainly it is a relative new technology that needs to be further developed in order to make it cheaper to be economically competitive. A fuel cell has lower density of power than an ICE because of the necessity of heavier components. Moreover, we have to bear in mind the problem of storing the hydrogen as it needs extremely low temperature (around 10 K) to be maintained as a liquid. If it is stored gaseous, it has much lower volumetric density. The advantages showed present a great potential to improve the performance of ICE. Meanwhile, the disadvantages showed present a big challenge to face that have been partially sorted out by other car manufacturers and research groups as they have already built prototypes and demonstrative models.

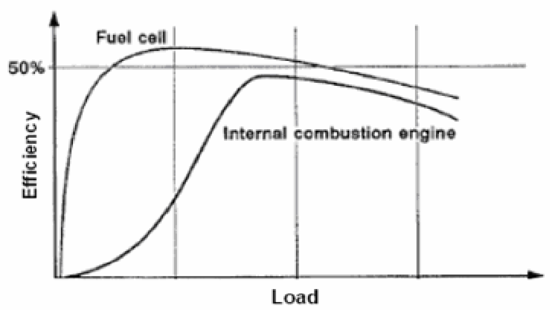

Fig. 3. Energy conversion efficiencies of fuel cell engine versus internal combustion engine [6]

4. Fuel cell hybrid vehicle

The performance of an automobile powered directly by a fuel cell can be improved using a second source of power, the auxiliary power unit (APU), that can take advantage of regenerative break and let the fuel cell operate at more efficient point. These sorts of vehicles are called hybrid electric vehicles (HEVs).

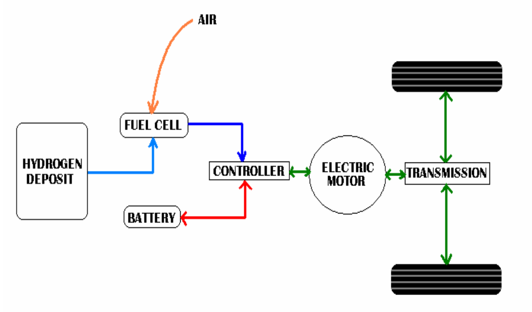

Figure 4: Schematic of a HEV.

The main idea is that the fuel cell is supposed to work at its most efficient point (around 25-30 % of load). When the automobile needs low performance, the fuel cell operates close to its peak efficient point recharging the battery. Meanwhile, when the automobile needs very high performance, it takes energy from the APU [7]. Thus, the use of energy is more efficient. This is the way how Toyota fascinated the world with its famous Toyota Prius. The goal of project Hércules is to evaluate how technologically feasible and convenient is using a fuel cell engine instead of a diesel engine (as Toyota did) in order to take the hydrogen from renewal sources. Thus, sunrays energy could propel a vehicle efficiently in an indirect way.

It is clearly beneficial, in terms of efficiency, to use a hybrid system. For conventional engines, a hybrid vehicle outperforms a conventional one around 30% [8]. This means that with a certain amount of fuel an average conventional car can drive for 100 km, on the other hand a hybrid one could drive for 130 km in average. Thus, the benefit is considerable and the technology is well enough developed to build a hybrid car. In terms of fuel cell vehicles, previous studies have shown that hybridization of FCVs with electrochemical energy storage (battery) provides cost, performance, and operational improvements, as well as fuel economy benefits that are attractive and should be considered [9-11].

5. Components of the propulsion system

Once the typology of the propulsion system has been chosen (hybrid system), the next step in the design of the vehicle is to understand the function of each component of the system and how they affect to car's performance. Thus, a review is shown in this point.

A. Fuel Cell

It is the most important component in the propulsion system of a HEV. It is the one in charge of transforming the hydrogen of the deposit into energy in order to move the vehicle. Thus, it is critical to choose correctly its size and typology. The most suitable typology for automotive application is a PEMFC (Polymeric Exchange Membrane Fuel Cell) because its low working temperature leads to better efficiency of the system [12].

About its size, it is measured related to the nominal power that it can send to the powertrain. The more powerful it is, the better specifications of the vehicle. However, the problem is that the more powerful it is, the more expensive and the more volume it requires.

The cost of a fuel cell is very high. Meanwhile, optimistic assumptions tend to think about 105 €/kW in 2010 [9], the fact is that fuel cells are not produced in mass for the high energy that is needed to propel a vehicle like a Santana 350 (minimum of 40 kW). Thus, currently, the price for this high power and a single fuel cell is around 5,000 €/kW. So, a mistake in the power chosen could be critical in the cost of the project and the specifications of the prototype.

The problem is that if the power needed is underestimated, the performance of the car will be low. The minimum velocity to be able to drive a vehicle in a highway in Spain, needs to be not inferior to 60 km/h (a half the top velocity allowed by sign roads). And, in the case of the prototype it would not be able to evaluate its performance in a highway if a mistake happens in its design stage. If it is thought in a commercial plan, an underestimation could lead to a failure in the model and millions of euros lost. On the other hand, if the power is overestimated, the cost will rise too much unnecessarily. Thus, the calculations need to be done very careful, for the project's sake. Minimum standards will need to be matched tightly.

B. Hydrogen Deposit

The main problem of using hydrogen for on road applications is its low volumetric density, as shown in figure 5.

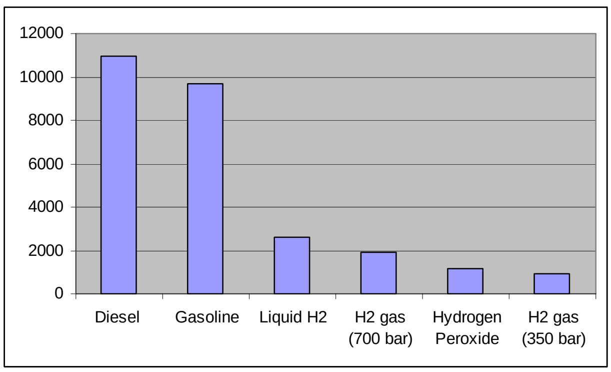

Figure 5: Volumetric density (Wh/L) of different car fuels [12].

This low volumetric density is another challenge in the race for alternative, clean vehicles. A lot of R&D is currently directed to different possibilities to storage hydrogen and there are quite a few very interesting alternatives that could make hydrogen quite competitive.

As cryogenic temperatures are needed to keep hydrogen in a liquid state, it would lead to a very inefficient way of storing hydrogen. Thus, a 350 bar (5,000 psi) pressurised deposits has been chosen as it is a standardised measured widely studied. Pressures over 350 bar makes bigger the inefficiency of compressing the hydrogen. However, new

700 bar deposits are being installed in new FCV-SUV, for example, the Ford Explorer FCV [14] with good results.

The volume of the hydrogen deposit is another key factor in the design of a FCV because the bigger it is, the longer the autonomy, but also the bigger the volume necessary to keep the deposit. Thus, the designer will have to reach to a compromise solution. In this project, the minimum autonomy required is 100 km [4]. It would be possible to be increased in a future when the problem of storing hydrogen will be sorted out better.

C. Battery

The battery is the component of the propulsion system whose function is to storage the left energy when the vehicle requires less energy than the energy produced by the fuel cell. Sporadically, the car will need more power (e.g. peak acceleration), so it will be supplied by the battery. This lead to the conclusion that the higher its capacity and power, the better the car performance. This is true, but again two problems arise: volume and cost. It is, thus, desired the smallest battery that can match the desired specifications.

The ideal performance of the battery consists of an almost constant state of charge (SOC) while the car is being driven. A change of around ±5 % in its SOC could be considered an absolute success. This is not necessary for a well-functioning of the propulsion system. Because of a limited autonomy due to a limited volume of the hydrogen deposit, the most economic performance would be one which could let the battery to discharge little by little through the range of the vehicle. This would let the battery perform properly and would let spend less space and money (especially space). So, the strategy will be to choose the least powerful battery that enables the battery to do its function of APU properly starting with a SOC of 70 % and ending up around 30% during the whole autonomy of the vehicle. Battery manufacturers recommend not to charge the battery over 75 % and not to discharge below 25 % [15].

There are several types of different batteries that could be used in a HEV. They are shown in table I with their features.

TABLE I. – Features of different types of energy storage systems [10]

	Units	PbA	NiMH	Li-Ion	Ultra-capacitor
Energy density	*Wh/L*	75	100	190	5
Specific energy	*Wh/kg*	35	55	100	4
Power density	*W/L*	1600	2000	2800	4500
Specific power	*W/kg*	550	1000	1300	3500
Cost	*$/kg*	10	40	60	15

Currently, the two most used in hybrid vehicles are the nickel-metallic hydrides (NiMH) and litio-ion (Li-ion) ones. NiMHs are the best developed ones as they were the first to be used and the first hybrid ICE vehicles used these ones. Because of better characteristics of Li-ion ones, most of R&D efforts are being made toward these ones. This is why a Li-ion battery has been chosen for the vehicle Hércules. Li-ion's overprice in comparison to NiMH is small if we consider that power used is commonly around 5 and 15 kW.

D. Electric Motor

It is the component of the propulsion system used to convert the electric energy that comes from the fuel cell and battery into movement in wheels. The first idea could be to choose its power as the sum of fuel cell's and battery's power. This is perfectly valid because the balance of energy would be matched. However, the designer could take advantage of a beneficial effect of the electric motors: they can accelerate their spinning velocity creating an extra power during a few seconds. It means they can act as a capacitor storing some energy that they send to the wheels in a few seconds. This improves a lot the acceleration conditions of the vehicle at expense of a bigger electric motor. This beneficial effect would be worthless whenever the power of the electric motor is a 50 % higher than the sum of fuel cell's and battery's power. This is why the power chosen will be in between of 100 % and 150 % of the sum of fuel cell's and battery's power.

E. Controller

The controller is the part of the system that decides how much power should be produced by the fuel cell in each moment depending on the SOC of the battery and the current requirements of the driver. It is a very important part because depending on the strategy chosen the efficiency of the car can be improved considerably.

The first idea for the designer could be to use one that would have been used in a hybrid ICE vehicle. But this is invalid due to a difference in performance between conventional and fuel cell engines. This is why a new one should be designed once the rest of the components have been chosen.

6. Alternatives of election of components' power using ADVISOR™

Once the major aspects of all the components have been discussed, the next step is to choose their power related to the level of performance wished. The case of the vehicle Hércules is the one under study, and as it is a prototype, minimum specifications are not as strict as for a commercial vehicle but there is a minimum as one of the goals of the project is to build a prototype that could drive in a highway normally. There are two alternatives of evaluating it. The first one is to see the specifications of a similar vehicle and adopt them. There is a risk of misinformation doing this. The second alternative is to choose different cycles of drive and evaluate the behaviour of the different alternatives of power of each component in each cycle's conditions. There is a risk of misreflection of reality of cycles tested.

For electing the power of each component, both alternatives have been done. First of all, minimum specifications that Ford demanded to all its commercial vehicles were used as the minimum specifications of vehicle Hércules. These specifications were published in [16] in 1997 in a report done to evaluate the design of a pure fuel cell vehicle, a Ford Aspire FCV. Ford lets its commercial vehicles to outperform a maximum of 15 % of these specifications. These results have been also compared to the ones obtained from the simulation of the behaviour of the Toyota Prius 2000 in ADVISOR™. Finally, the second alternative has been also analysed. The behaviour of the vehicle has been simulated and tested in urban and highway cycles. Finally, a real highway mountainous route that the vehicle will do in its test has also been simulated, in order not to have surprises due to very steep slopes in this route.

7. Minimum specifications for vehicle Hércules

A. *Characteristics of Vehicle Hércules*

Some data has been necessary to be implemented in the simulator. A part of it has been elected making assumptions and other part is reliable and "a priori" measurable. This data is:

- Model: Santana.
- C_D (C_x) = 0.38.
- Weight = 1200 kg (without propulsion system).
- Height of balance mass point: 80 cm.
- Distance between wheels = 2480 mm.

The data with which assumptions have been made involves a process of minimisation of power in order to reduce the total cost. This optimisation has been done in a quality way (as explained in point 5) to define what sort of each component is desired and has been done in a quantitative way to choose the power of each component, always following what was said in point 6. Thus, the other characteristics that involve the components of the propulsion system are:

- Battery: 10 nominal kW Li-ion battery.
- Electric Motor: A synchronic with permanent magnet electric motor with a maximum power of 64 kW.
- Fuel Cell: A PEM fuel cell of 50 nominal kW.
- Transmission: A single geared transmission which weighs 50 kg.
- Fuel: Compressed hydrogen with a pressure if 350 bar (5000 psi) and an energy of 2.79 kWh/Nm^3.

B. *Minimum Velocity Specifications*

In table II, the minimum velocity requirements that a vehicle need to match to be able to be commercialised by Ford (taken from [16]) are presented. It has also been calculated the velocity that vehicle Hércules could provide in these different scenarios (different slopes), so does it with the vehicle Toyota Prius. It has also been worked out the minimum power the fuel cell would need to fulfil 100 % of these requirements proposed by Ford.

TABLE II. – Minimum velocity specifications for vehicle Hércules.

Slope (%)	Minimum specifications by Ford (km/h)	Vehicle Hércules (km/h)	Toyota Prius 2000 (km/h)	Minimum FC power necessary (kW)
0	137	131	163	55
3	105	106	132	49
7	80.5	78	97	54

As was said in point 6, Ford required fulfilling only 85% of these requirements. Otherwise, it strongly recommends to fulfil 100%. Being conscious that vehicle Hércules is a SUV and a prototype, this 85 % has been considered enough. Toyota Prius is clearly better than the vehicle Hércules as it is more powerful, commercial vehicle.

C. *Minimum Acceleration Specifications*

In table III, the minimum acceleration requirements (measured in seconds from a source velocity to an end one) that a vehicle need to match to be able to be commercialised by Ford (taken from [16]) are presented. It has also been calculated for vehicle Hércules and Toyota Prius.

TABLE III. – Minimum acceleration specifications for vehicle Hércules.

Velocity (km/h)	Minimum time by Ford (s)	Vehicle Hércules (s)	Toyota Prius 2000 (s)	Minimum FC power necessary (kW)
0 to 96.6	18.9	33.8	15.3	89
8 to 32	3.2	6	2.5	86
32 to 64	5.4	10.7	5.1	87
64 to 96.6	9.3	16	7	85
88.5 to 105	6.1	12.4	4.3	82

As can be seen in this table, the required power for the fuel cell to fulfil minimum requirements of Ford would be around 85 kW every time we maintain the maximum power of the electric motor as 64 kW. Thus, it would be desirable a higher powered electric motor and a higher powered fuel cell. Due to problems with space to allocate a bigger motor, the extra cost of a bigger fuel cell and motor, and bearing in mind that this is a SUV and a prototype, the members of the project have decided not to be that strict with acceleration requirements.

8. Simulation of different drive cycles

As was stated in point 6, it is very important to demonstrate that the characteristics chosen in point 7.B are suitable for driving the vehicle through a real road. Different cycles have been tested using the simulator tool ADVISOR™. The purpose of this point is to show how the vehicle can be driven in an urban cycle, highway cycle and a real route that the vehicle will cover in its inauguration.

A. *Urban Behaviour*

For assessing how the vehicle Hércules would behave in a hypothetical city trip, the UDDS (Urban Dynamometer Driving Schedule) cycle has been chosen, which is shown in figure 6. This is a cycle developed in USA that takes around 23 minutes to be covered and its length is 12 km [17]. In x-axis is represented the exactly point in time covered to be in a specific physical point and in the y-axis is represented the velocity at which a common vehicle should drive at this moment. If the car cannot reach this velocity, it means that it is not powerful enough to make the driver feel comfortable driving it. If the required velocity is not reach, it would mean that the driver feel the car has reached its top limit.

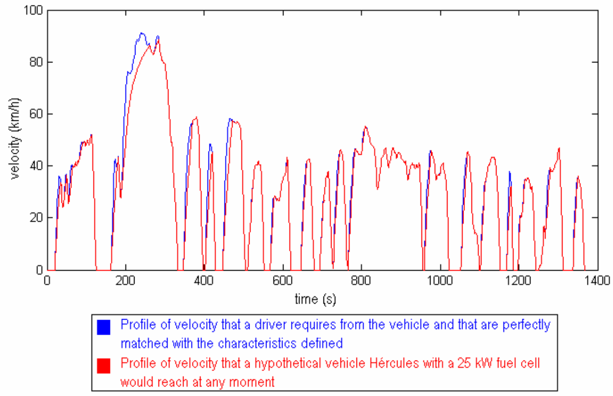

Figure 6: Simulation of vehicle Hércules in a urban cycle

As can be seen after this simulation, vehicle Hércules behaves perfectly when you are driving it in a city because when a driver wish to drive faster and step the accelerator, the vehicle can reach the desired velocity in the time required for a common vehicle. It has also been shown in figure 6 the behaviour of a hypothetical vehicle Hércules with exactly the same characteristics except for the power of the fuel cell, 25 kW instead of the 50 kW that it will have. Its behaviour is represented with a red line and we can see that the vehicle would cause some troubles because the response time would be longer than desired if we would step the accelerator.

Thus, as a conclusion, the characteristics chosen for the vehicle are enough to be driven in a city as a common car.

B. *Highway Behaviour*

The same done in point 7.A has been done in the figure 7, but this time with a highway cycle. The cycle chosen this time is US06 HWY (USA 2006 Highway cycle). It is a 10 km long cycle that comes from the cycle US06 that is included in the “EPA’s Supplemental Federal Test Procedure”. Its main purpose is to monitor the emission of vehicles in the most aggressive conduction behaviour [18].

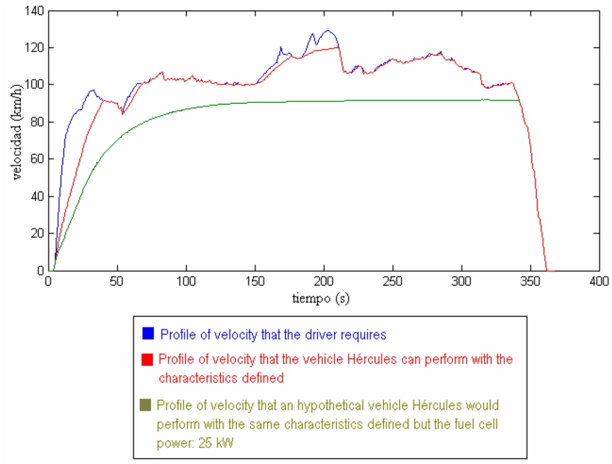

Figure 7: Simulation of vehicle Hércules in a highway cycle

As can be seen from the simulation, the vehicle Hércules presents a deficient perform for the most aggressive conduction in a highway. This outperform is not critic because as we can see, the vehicle can reach the velocities required by the driver, the problem is that it takes long time to do so. The reason of this is the low acceleration of the vehicle, the condition that was relaxed in the vehicle because it requires too much resources and this vehicle will be a prototype, as was explained in point 7.C.

In figure 7 the behaviour if the same vehicle but with a fuel cell power of 25 kW is shown as well. This shows that the outperform of the vehicle would be severe because it is not a problem of acceleration (as with the 50 kW one), the problem is that the vehicle cannot drive faster once it has reached around 90 km/h.

C. *Real Route: Sevilla-Sanlúcar la Mayor*

In the inauguration of the vehicle, it will cover the road that connects Seville with Sanlúcar la Mayor. In figure 8 is presented the cartography of this real route. Due to in Cartography the coordinates of a point are defined in a curve system, they had to be projected in a plane using a specific software [19], giving distances in 10^5m. Thus, the y-axis represents the projected movement from south to north and the x-axis the projected movement from west to east. The thicker line is the one which represents the cartography of the road.

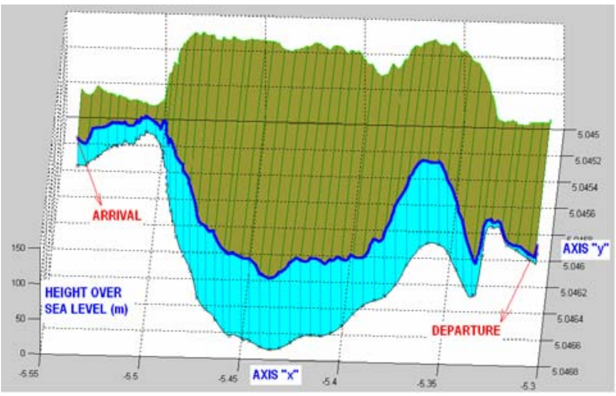

Figure 8: Cartography of the real route Sevilla - Sanlúcar la Mayor

It is a 3D map because the height is an important factor to be considered. This route is especially interesting because it presents parts with a 7% slope, which would be really critical for the vehicle if the power of the components were underestimated. So, it is a good test for the design. In figure 9 is presented the results obtained from the simulation of this route in the simulator ADVISOR^{TM}. This time instead of evaluating the performance of the car related to the closeness to a desired velocity, it has been done supposing the vehicle is always driven at its maximum performance, thus in figure 9 is represented the maximum possible velocity reached in each point of this real cycle.

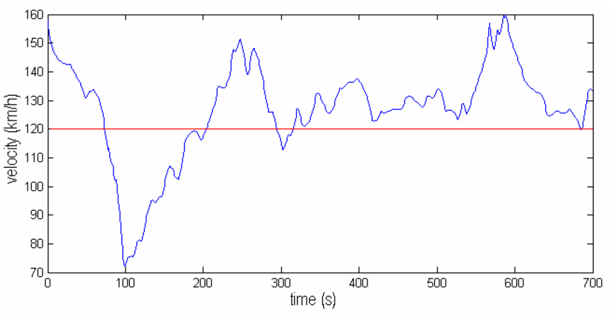

Figure 9: Simulation of vehicle Hércules in the real route which connects Seville to Sanlúcar la Mayor.

In this simulation there are several interesting results. The most important one is that in the worst point of the route, the velocity of the vehicle will be 70 km/h, which is more than the maximum velocity enabled by the sign road there. This means that the vehicle could be driven in this route as any other one. It could be seem that velocities over 137 km/h are wrong, but in this simulation slopes has been considered, this is why when the vehicle is going up, the velocity would seem critic (70 km/h) and when the vehicle is going down the velocity could reach even 160 km/h, which would be thought as very high and discordance to table II. This simulation has shown how important the slopes can be for the results of a simulation of the behaviour of a vehicle in a real route.

9. Autonomy of the vehicle

The last point to treat is the autonomy of the vehicle. The goal of the project is to be around 100 km. But, how much hydrogen would be needed to have this autonomy? And, how much space would it need? These questions are easy to answer whenever the efficiency of the fuel cell system is known and the number of kilometres desired too.

The efficiency of all the components of the propulsion system is broadly known except for the fuel cell system. Due to the high power of the fuel cell, it is difficult to know reliably its exactly efficiency. Because of the high dependence of the autonomy on this variable, it is necessary to be careful with it. This is why it has been supposed to be between 40 and 50 %. These two assumptions have been represented in the figure 10, in which different autonomies are represented for different pressures of storage. In lines 1 and 2 the storage pressure is 350 bar and in lines 3 and 4 the storage pressure is 700 bar. The different efficiencies are also represented, for lines 1 and 3 the efficiency considered is 40 % and for lines 2 and 4 the efficiency considered is 50 %. In figure 10, the main assumption has been considering the vehicle will be driven the whole time in a urban cycle (in a city).

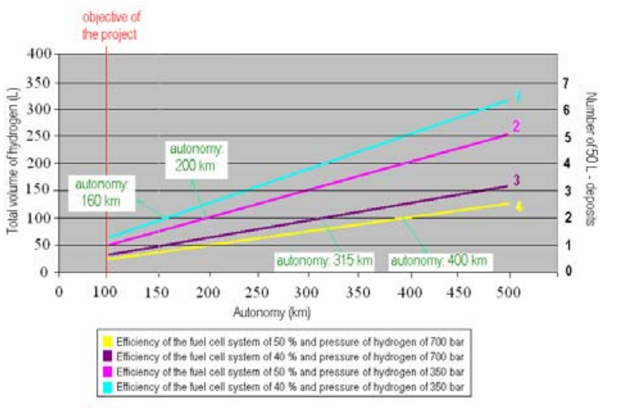

Figure 10: Analysis of the autonomy of the vehicle in a city

Another aspect that should be considered is the size of the deposit. Because of the geometry of the vehicle, the most suitable deposits are the 50 liter-deposits. It has been found that there is space enough for two of them. It means that the autonomy would be between 160 and 200 km if the vehicle was driven in a urban cycle. This quantity could be far improved if a 700 bar deposit would be elected.

It is well known that a vehicle consumes less in a city than in a highway. So, which would be the autonomy of the vehicle Hércules with two 50 liter-deposits in a highway? The same analysis, but for a highway cycle, is presented in the figure 11.

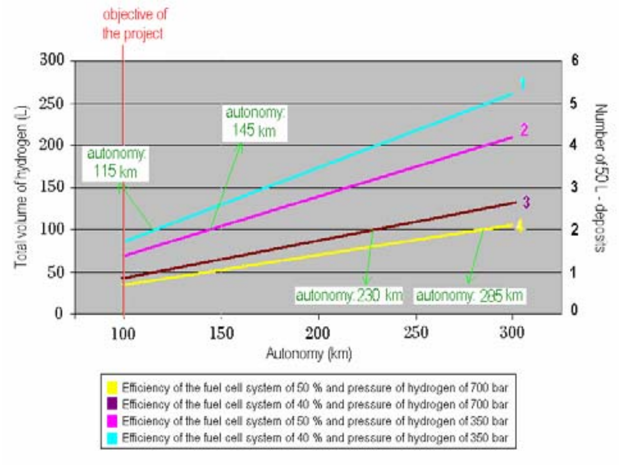

Figure 11: Analysis of the autonomy of the vehicle in a highway

As can be seen in figure 11, the autonomy of 100 km is also over performed if the vehicle is driven all the time in a highway. Thus, the goal of 100 km of autonomy would be possible for vehicle Hércules with 100 L of hydrogen compressed at 350 bar.

10. Conclusions

In this paper has been shown all the steps that have been followed to design a fuel cell SUV using the simulator tool ADVISOR^{TM}. Lots of problems have arisen through this design because very few models have been designed and most of the data are totally secret. Thus, more problems appeared in this design, but here in this project most of the solutions and problems have been treated.

Acknowledgement

I would like to thank Corporación Tecnológica de Andalucía and IDEA as they have supported economically the realisation of “Project Hércules: Renewable Hydrogen Generation from Solar Energy as Fuel to an Electrical Vehicle Based on Fuel Cell Technology”. This project has been granted as “Proyecto científico-tecnológico, singular y estratégico” with the denomination: “PSE-120000-2006-4”.

I would like also to thank to the developers of the software ADVISOR^{TM} as this software has been mainly used for doing all the simulations of this design stage of Project Hércules

References

[1] http://fueltaxinquiry.treasury.gov.au/
[2] California Environmental Protection Agency, Air Resources Board. ”Staff report, 2000 Zero Emission Vehicle Program. Biennial Review”.
[3] US Department of Energy. Energy Efficiency and Renewable Energy. “Fuel Cell Vehicle World Survey 2003”.
[4] Memoria General del Proyecto Hércules. Proyecto singular y estratégico. Convocatoria PSE-2006.
[5] Karl Kordesch and Günter Simader. “Fuel Cell and Their Applications” VCH, 1994.
[6] NATO. “Fuel cell for land, sea and air vehicles. RTO Technical Report”, 2006.
[7] Andre Lanz et al. “Hydrogen Fuel Cell Engines and Related Technologies”. Energy Technology Training Center - College of the desert
[8] California Energy Commission. “Fuel Cycle Energy. Conversion Efficiency Analysis. (Status Report).”
[9] Tony Markel, et, al. “Energy Storage Fuel Cell Vehicle Analysis”
[10] Zolot, et. al. “Energy Storage Requirements for Hybrid Fuel Cell Vehicles”. Proceedings of Advanced Automotive Battery Conference, Nice, France.
[11] Wipke, K, et. al. “Optimization Energy Management Strategy and Degree of Hybridization for a Hydrogen Fuel Cell SUV”.
[12] Office of Technology Policy. Technology Administration. US Department of Commerce. “Fuel Cell Vehicles: Race to a New Automotive Future” January 2003.
[13] http://xtronics.com/reference/energy_density.htm
[14]www.autoblog.com/2006/11/27/ford_to_debut_fuel_cell_explorer_redesigned_escape_hybrid_in_l/
[15] S. Drouilhet and B.L. Johnson. “A Battery Life Prediction Method for Hybrid Power Applications” NREL. January, 1997.
[16] US Department of Energy. “Conceptual vehicle design report pure fuel cell powertrain vehicle”.
[17] www.dieselnet.com/standards/cycles/udds.html
[18] www.sextoncorp.com/Emissions.htm
[19] GEOIDE-DEMO. L.M. Tapiz Eguiluz. (License number 151423022)