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Weight driven optimisation for vehicle propulsion determination

Oriol Gallemí[1]

[1] *FIM e-Power Technical Director, Universitat Politècnica de Catalunya, oriol.gallemi@upc.edu*

Abstract

The following paper describes how electric vehicles fit better in the smallest segment and / or urban driving cycles. Vehicle mass always drove the need for high power internal combustion engines (ICE), and the development of high power-to-weight electric motors and high energy storage technologies challenged the standard architecture in the downsized-small vehicle segment. Consequently FIM acts as a technology catalyst and promotes since 2010 a 2 wheeled international championship named "FIM e-Power".

Keywords: BEV, efficiency, motorcycle, vehicle performance

1 Introduction

There is a growing interest towards vehicle hybridisation and electrification, and before starting a new design, a short analysis must be taken to draw main driving parameters.
The performance level of any vehicle in terms of maximum speed (vmax) and acceleration (amax) can be roughly modelled as functions (1) (2) from power (kW), air drag (CdA) and mass (m).

$$v\max = f(CdA(m), kW(m)) \quad (1)$$

$$a\max = f(m(CdA), m(kW)) \quad (2)$$

It is important to note that all three factors CdA, mass and power are strongly correlated and functions type (3) can be built.

$$f(m, CdA, kW) = 0 \quad (3)$$

Cost (€) and specific energy (Wh/km) consumption at NEDC (New European Driving Cycle) are also strongly driven by mass (4)(5).

$$€ = f(m) \quad (4)$$

$$Wh/km = f(m) \quad (5)$$

Thus, mass is the most relevant parameter on vehicle design and analysis [1]. Complexity is often obfuscating mass problems [2]. A proof of this is that average vehicle mass grow up both in US (table1) and Europe (table2) even if the willingness was to decrease it.

Table1: Average vehicle mass US

US	kg
1985	1370
2007	1630

Table2: Average vehicle mass EU

EU	kg
1995	1100
2006	1300

According to this, the mass raises yearly in 0,9% in US and 1,65% in Europe. Sources [3] mention that 0,5 litres of fuel can be saved for every 100kg of decreased mass.

1.1 Hypothesis

Current vehicles have a performance level which can be matched by using electric drive systems.

1.2 Limitations

Scaling factors does not work for thermodynamics, manufacturing or complex hydro/aerodynamics, but offers satisfactory results at first approach. A detailed non-dimensional analysis could fix this, although adding complexity.

Penetration coefficient (Cd) of lightweight motorcycles is trice of a standard M1 sedan although projected surface (A) is about half.

Complexity is one of the limits for packaging in small vehicles. An hybrid drive adds a significant mass in a small vehicle.

1.3 Population

Statistics were used to draw the hypothesis, and current literature [4] carried similar analysis with consistent conclusions matching our models. Merging databases with interested groups could provide better statistics with a larger population for studies in the years to come.

2 Performance

Most of the analyses on electric vehicles are being carried on real scale prototypes [5], both for manufacturing and for measuring simplification, and most of them are not achieving the expected performance levels.

The causes of these unmatching profiles are mainly coming from a poor requirement analysis and a complexity problem which triggers the costs up.

Other root causes are the over specification with above-the-average expectations, the impossibility of scaled prototyping and/or the CAD/CAE abuse, which allows everything in the computer.

2.1 Hypothesis

Vehicle acceleration must be 1G. 0-100km/h in 3 seconds.

Top speed on par with current race vehicles, above 200km/h.

3 Modelling

A simplified parametric model simulator, starting with the NEDC is built as a reference. Any racetrack can be modelled on the same basis. From this, a first approach shows that below 50km/h the rolling resistance and inertia power required are much larger than the aerodynamic load, demonstrating that a light vehicle is required for the first 4 urban loops of the NEDC.

In case of motorcycles, the energy required for the first part ranges from 40 to 60Wh/km.

In the second part of the NEDC, higher speeds are required and average energy consumption raises from 66 to 88Wh/km, with most of the energy being used to compensate air drag.

Motorcycles complete the NEDC averaging from 56 to 74Wh/km in the complete cycle.

In fuel terms, 1Litre of super 98 roughly equals to 10.000Wh, but ICE (Internal Combustion Engines) just have 30% peak efficiency, providing around 3.000Wh at motor shaft.

4 Scales

Scaled models are the main advantage which electric vehicles offer because its energetic source allows doing it, which ICE doesn't, having problems with the gas behaviour and the thermodynamics.

4.1 Scale analysis

When assembling scaled models, all parameters are not affected in the same way. Even if a scale refers only to the longitudes, it has influence also to all the other parameters.

Taking the equations and magnitudes as products with exponents a matrix (table3) can be built.

Table3: Relations between magnitudes

Magnitude	M (kg)	L (m)	T (s)
a		1	-2
F	1	1	-2
ρ	1	-3	
σ	1	-1	-2

As the table shows, there is a matrix with more rows than columns, so there is one degree of freedom.

Considering X as the original size, X' the model size, $\tilde{X}$ is the scaling factor (9).

$$\frac{X}{X'} = \tilde{X} \quad (8)$$

As an example can be done assuming a given 1/10 scaled model vehicle (9).

$$\frac{L}{L'} = \tilde{L} = 10 \quad (9)$$

Empirically, a model vehicle reaches 0-100 in 3seconds and the acceleration must be on par (10). Thus:

$$\tilde{a} = 1 = \frac{\tilde{L}}{\tilde{T}^2} \Rightarrow \tilde{T} = \sqrt{10} \qquad (10)$$

Then, one more parameter is given to define the mass scaling factor.

4.1.1 Case 1

Assuming the use of the same materials, with same density (11):

$$\tilde{\rho} = 1 = \frac{\tilde{M}}{\tilde{L}^3} \Rightarrow \tilde{M} = 1.000 \qquad (11)$$

And consequently this must affect the stiffness of materials by a factor of (12):

$$\tilde{\sigma} = \frac{\tilde{M}}{\tilde{L}\tilde{T}^2} = \frac{1.000}{10 * \sqrt{10^2}} = 10 \qquad (12)$$

That means if mass is still one of the main drivers, the materials bill of the 1:1 vehicle must be 1.000 times larger than in the 1:10.

4.1.2 Case 2

Assuming the use of lightweight materials with the same stiffness (13):

$$\tilde{\sigma} = 1 = \frac{\tilde{M}}{\tilde{L}\tilde{T}^2} \Rightarrow \tilde{M} = 100 \qquad (13)$$

Interesting finding, since the mass is raised just 100 times from the scaled 1:10 model, but density (14):

$$\tilde{\rho} = \frac{\tilde{M}}{\tilde{L}^3} = \frac{100}{1.000} = \frac{1}{10} \qquad (14)$$

Meaning that 10 times lighter materials must be used in the 1:1 vehicle.

4.2 Real performance

Applying the scale factors, empirically (table4):

Table4: Relations between magnitudes

Magnitude	Scale	Small	Big
Longitude	10	0,39	3,9
Acceleration	1	9	9
Speed	3,16	23	72
Height	10	0,14	1,4
Wide	10	0,18	1,8

At this point, the mass scale must be defined.

4.2.1 Case 1

Forcing density scale to 1:

Table5: Relations between magnitudes

Magnitude	Scale	Small	Big
Density	1	8	8
Stress	10	200	2.000
Mass	1.000	1,87	1870
Cost	1.000	350	350.000

Which clearly shows (table5) that the high mass drives to an extremely high cost, not affordable for most of the population.

4.2.2 Case 2

Forcing stress scale to 1:

Table6: Relations between magnitudes

Magnitude	Scale	small	Big
Density	0,1	8	0,8
Stress	1	200	200
Mass	100	1,87	187
Cost	100	350	35.000

Which mainly shows (table6) an affordable vehicle overall, although new materials/shapes must be used to keep the stress under control and decreasing density by an order of magnitude.

5 Conclusion

The FIM (Fédération Internationale de Motocyclisme) has the role of promoting the motorcycle use for transportation, leisure and sports and making this sustainable in terms of environment and evolution.

Figure1: FIM e-Power official logo

The FIM e Power International Road Racing Championship series, manufacturers have the opportunity to test their electric powered motorcycles in extreme conditions. FIM has a strict test platform for any product to be developed and marketed, and the proposal towards light (<250kg), small ($A<0,7m^2$) and efficient (0,85 overall powertrain efficiency) vehicles offers a good balance when talking about racetrack courses. FIM goals are aligned with the European electric vehicle organisation requirements [6].

The target distance for a race event ranges from 35 to 40km, excluding the final lap to come back to the podium. Those 40km at a race pace (220km/h, 140km/h average) may offer up to 220km range at a legal pace on public roads.
Most of the public does not require such a performance on daily basis [7], but the current machines are paving the way towards the future small, lightweight and efficient transportation.

5.1 Next steps

A lot has been done up to this moment. Further work is required to improve both CdA and mass from current vehicles to improve efficiency rather than raising the amount of energy onboard to be wasted.

$$fc = f(PCI, \eta_{motor}, R_{untime}, \eta_{trans}, km, m) \quad (15)$$

By now, no effort has been made to increase the specific energy of a fuel to decrease the fuel consumption (15).

$$range = f(PCI, \eta_{motor}, R_{untime}, \eta_{trans}, v, m) \quad (16)$$

The range is thus affected by this factor (16). Non-dimensional parameterisation of vehicles will allow better modelling and dimensioning before final construction.
A detailed materials study may balance the requirements from the 2 proposed scenarios, varying both density and stress levels to reasonable figures.

Acknowledgments

About the FIM (www.fim-live.com)

Figure2: FIM official logo

The FIM (Fédération Internationale de Motocyclisme) founded in 1904, is the governing body for motorcycle sport and the global advocate for motorcycling. The FIM is an independent association formed by 103 National Federations throughout the world. It is recognised as the sole competent authority in motorcycle sport by the International Olympic Committee (IOC). Among its 50 FIM World Championships the main events are MotoGP, Superbike, Endurance, Motocross, Supercross, Trial, Enduro, Cross-Country Rallies and Speedway. Furthermore, the FIM is also active and involved in the following areas: public affairs, road safety, touring and protection of the environment. The FIM was the first international sports federation to impose an Environmental Code in 1994.

References

[1] S.E. Plotkin, *Examining fuel economy and carbon standards for light vehicles (2008)*, http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DiscussionPaper1.pdf , accessed on 2011-09-05 (page 8 decrease weight, 21 fuel Vs weight, 37 weight trends)

[2] D.E Malen, K.Reddy, *Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients (2007)*, http://www.a-sp.org/database/custom/Mass%20Compounding%20-%20Final%20Report.pdf , accessed on 2011-09-05

[3] S.Pagerit et al., *Fuel economy sensitivity to vehicle mass for advanced vehicle powertrains (2006)*, http://www.transportation.anl.gov/pdfs/HV/366.pdf , accessed on 2011-09-05 (pag 6, menor consum per kg,)

[4] C. Bjelkengren, *The impact of mass decompounding on assessing the value of vehicle lighteighting (2008)*, http://msl.mit.edu/students/msl_theses/Bjelkengren_C-thesis.pdf , accessed on 2011-09-05 (pag 21 increment massa US, reduccio de masssa)

[5] T. Haraguchi, *Reducing fuel consumption by improved vehicle efficiency (2011)*, ATZ autotechnology vol.11 (april 2011), ISSN 1865-6536 (p22)

[6] Going electric, *Four key points for a competitive EU automotive industry and sustainable mobility and growth in 2020 and beyond* (2011), http://www.going-electric.org/news/pr-110517-cars-21-public-hearing.htm , accessed on 2011-09-05 (page 3 urban light veh L7e-M1, safety mass increase)

[7] Pike Research, *Electric vehicles: 10 predictions for 2011 (2010)* http://www.pikeresearch.com/research/electric-vehicles-10-predictions-for-2011 , accessed on 2011-09-05 (page 8 users range)

Author

Oriol Gallemí holds an engineering degree from the Technical University of Catalonia (UPC) and a masters degree in Space Studies from the International Space University (ISU). In 2009 started its PhD involved with Dr Ricard Bosch team (UPC) in a research about electric and hybrid vehicles. From 2010 is the Technical Director of FIM e-Power series.