AN OVER CONSTRAINED OPTIMIZATION PROBLEM: THE PROLONGED AUTONOMY BIKE (PA BIKE)

Leonardo Frizziero and Luca Piancastelli
Department of Industrial Engineering, ALMA MATER STUDIORUM University of Bologna, viale Risorgimento, Bologna, Italy
E-Mail: leonardo.frizziero@unibo.it

ABSTRACT

The Prolonged Autonomy e-bike o PA-bike is a e-bike that can use a traditional fuel to charge the battery during run or at rest. In this way it is possible to prolong the autonomy of the e-bike. A fuel cell with a reformer or a traditional very small catalyzed piston engine can be used. In both cases the emissions are very limited and the efficiency is very high, since the "traditional fuel" motors work at constant optimum condition. This paper tries to optimize the PA-bike by assembling commercial components. Outsourcing for bicycles should be very easy since commercial part availability is very high. Customization is a very common practice for bikers, since it does not require authorizations. However the problem proved to be over constrained. The commercial components, in particular the electric motor, proved to be an important boundary condition. The result is a single possible solution, or a category of solutions, all similar. This is due to the fact that commercial components are highly standardized for marketing reasons.

Keywords: e-bike, autonomy, optimization.

INTRODUCTION

The Prolonged Autonomy e-bike o PA-bike is a e-bike that can use a traditional fuel to charge the battery. In this way it is possible to use the bike where the traditional gas stations are available. It is sufficient to install a reformer and a fuel cell on the rear carrier, a pair of cables, a battery recharger, and the “upgrade” from e-bike to PA-bike is made. The system starts when the battery is low (for example down to 25%) and finishes its work when the battery is high (for example 75%), independently from the bike position, running or stationary. This is possible because emissions are so low that it is possible also an “indoor” recharging. The fuel cell and the reformer run at full-optimum power, so avoiding all the efficiency and durability problems typical of this type of application. A set of equation has been written for the application. It is then possible to optimize rider comfort, PA-bike efficiency (autonomy) or cost-effectiveness. This is theory. In fact a successful design of a PA-bike requires outsourcing. Mass production reduces costs and makes the project feasible. Here the constraints come. The availability of these products on the market is very limited, with companies that introduce an innovative product and disappear. The PA-bike problem is then over constrained. A solution of this problem is introduced in this paper.

The Law

The European Directive 2002/24/CE49 (Article 1, paragraph h) defines the pedal assisted bicycle as a bicycle equipped with an auxiliary electric motor and with the following features:

- maximum rated power of the electric motor: 0.25 kW]
- Power Engine gradually reduced and finally cut off at the speed of the 25 km / h]
- Power of the electric motor interrupted at any speed if the cyclist stops pedaling

For vehicles that comply with this Directive, and approval procedure is not requested. It is considered in all respects as the traditional bicycles.

The PA-bike theoretical optimization

From the theoretical point of view, a recumbent bike, like the one depicted in Figure-1, is the best choice [lavoro e-bike Fabbri]. Low center of gravity, reduced aerodynamic drag, easy component installation make this solution the theoretical best. Optimization will be performed on this solution.

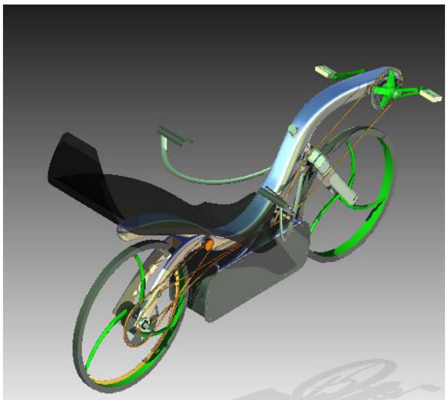

Figure-1. Fabbri’s recumbent e-bike.

The power requirements

The power required to keep the bike running can be evaluated with (1):

$$P = P_f+P_d+P_s \qquad (1)$$

$$F = f_0+k\ v^2 \qquad (2)$$

$$P_d = 0.5\rho S\ C_X\ v^3 \qquad (3)$$

$$P_s = v\ m\ g\ \sin^2(\theta) \qquad (4)$$

$$P_f = v\ f\ mg \cos(\theta) \qquad (5)$$

Two conditions are to be fulfilled, the maximum speed (25 km/h according to 2002/24/CE49) and the maximum slope (40% = 0.7rad =17°). Both should be achieved by the electric motor installed, with the transmission ratio chosen. The maximum nominal power allowed by 2002/24/CE49 is 250W. Starting from these two conditions it is possible to calculate the transmission ratio, given m and rear wheel diameter D_r.

The Cx issue

The bicycle Cx is difficult to measure, Table-1 summarizes a few reasonable values for the “Effective Frontal Area “C_dA, that is the product of C_x and A [Aerodynamic drag in field cycling with special reference to the Obree’s position:

Table-1. Effective frontal area.

Type of bicycle	C_dA [m^2]	Ref.
Touring	0.39	[Gross]
Racing bike	0.299	[Gross]
Time Trials	0.262	[Capelli]
Obree	0.216	[Capelli]
Recumbent	0.19	[Wilson]

It is then possible to calculate the average energy spent by a racer at Tour de France. From Figure-2, a reasonable average racing speed at 0 slope is 35 km/h. The energy necessary to keep this speed with a “regular Tour de France” bicycle is approximately 200 W. This value is calculated with a rider mass of 68 kg and the minimum allowed mass of 6.8 kg for the bike. By assuming that the transmission efficiency is a 97%, the total energy required to the racer is around 210 W. The average bike speed in Copenaghen is 15.5 km/h. For this speed the necessary energy with a touring bike is 37 W, with a bike of 20 kg and a rider of 80 kg. Even considering an efficiency of 90%, the power required is under 40W. For a recumbent bike, that cannot be used in the Tour de France, the power required would be respectively 145W (Tour de France) and 29W (Copenaghen).

Still, the recumbent bike gives an appreciable advantage. For this reason it will be used for this optimization.

The maximum "assisted" speed allowed by the Law is 25 km/h. At this speed the recumbent bike will need only 75W even with a transmission efficiency of 90% and a overall mass of 100 kg.

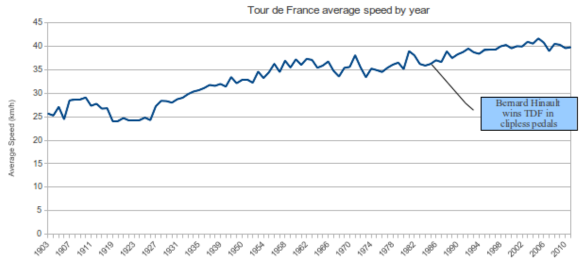

Figure-2. Tour de France average speed by year [1].

The slope

Filbert Street and 22nd Street in San Francisco are two of the steepest navigable streets in the Western Hemisphere, at a maximum gradient of 31.5% (18°). In this condition, the stall torque can be calculated by (6):

$$T_s=0.5\ D_r\ (m\ g \sin(\theta) +f_0\ mg \cos(\theta))/\eta \qquad (6)$$

With a 10% over torque to take into account of acceleration, the torque necessary to max slope torque is equal to 125 Nm for our 100 kg mass.

The battery

A good average energy density curve can be calculated from Table-2 (24V battery packs from AAA Portable Power Corp).

Table-2. Commercial powers pack usable C and charging current.

Battery model	Energy [kJ]	Energy density [kJ/kg]	Cost USD	Unitary cost USD/kJ
LiFePO4 18650	67.2	384	56	0.23
Powerizer LiFePO4	240	333	299	0.34
Custom LiFePO4 Prismatic	1843	283	398	1.01

The advised maximum charging figure is 0.2C. The battery charge should not go under 0.2 C. Over 0.75C the charging level should be decreased. For this reason out APU should charge the battery within this two limit. The practical capacity of the battery is then (7):

$$Ct=C\ (0.75-0.2)=0.55C \tag{7}$$

So usable energy and charging current are summarized in Table-3.

Table-3. Practical values for $LiPo_4$ batteries.

Battery model	**Usable energy** [kJ]	**Usable energy density** [kJ/kg]	**Unitary cost** [USD/kJ]	**Max charging power** [W]
LiFePO4 18650	37	211	1.5	38
Powerizer LiFePO4	132	183	1.9	177
Custom LiFePO4 Prismatic	1013	557	2.3	710

Since the electric motor max power is limited by the law to 250W, an optimal battery should have this charging rate. It is possible to linearly interpolate an "ideal battery" for our PA-bike from line 2 and line 3 of Table-2. This battery should have a maximum "optimum" charging rate of 250W. This battery has a usable energy of 252 kJ and a nominal capacity C of 459 kJ. The cost will be about 500 USD for a mass of 3.12 kg.

The same manufacturer proposes for the e-bike the LFP Battery: 38.4V 9.9Ah that has a C of 1368 kJ and a mass of 3.5 kg. The maximum charging rate is 268W. This is in fact the ideal battery, probably optimized for the application and the battery is no more a variable for our optimization.

The electric motor power density

Theoretically the higher the Voltage the smaller the engine. Technical practical limit is now around 600V. However commercial bike electric motor are in the 24V-48V range. Figure-1 shows data measured for a hub motor.

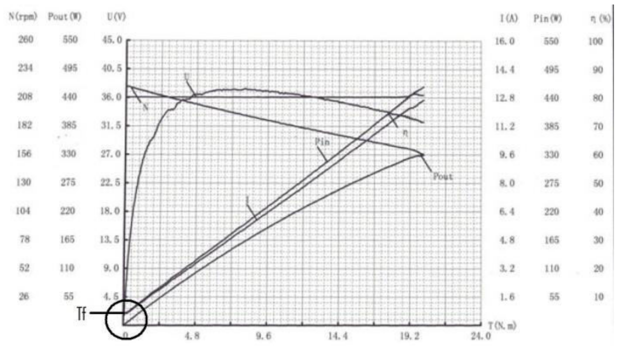

Figure-3. Performance data of Cute Q-85SX electric motor integrated with a double stage planetary reduction gear [http://www.avdweb.nl/solar-bike/hub-motor/motor-test-bench.html].

In Figure-3 the efficiency includes the two stage epicyclical reduction of the gearbox. To this figure the derailleur and chain drive efficiency should be added (8). In the worst case the total efficiency is 86% [29].

$$\eta_m = \eta_d\ \eta_g = 0.81*0.86 = 0.69 \tag{8}$$

This means that a minimum of 31% of the battery energy is lost in the transmission drive. This figure can be improved through a direct CVT belt drive as described below. However, the true advantage is minimum (9).

$$\eta_m = \eta_d\ \eta_g = 0.81*0.97 = 0.78 \tag{9}$$

It is possible to estimate the power density of a commercial e-bike motor from [http://www.electricbike.com/three-250-watt-hub-motors/] to 2.2 kg without the electronic driver. Again, the commercial availability limits the choice available. The electric motor is no more a variable. It can also be seen that efficiency at the level of the “Copenaghen average” are extremely low, the electric engine should work at relatively high speed, with output power above 100W. It can also be considered that a PA bike is heavier than a traditional one. However the influence of bike weight is limited. This motor is more suitable to the Tour de France than city use. Again, with these motors, performance should be optimized, instead of economy.

The CVT

In our case the CVT proposed in paper [lavoro CVT] (see Figure-3). This is a computer controlled V-Belt CVT. Transmissions overall efficiency can be optimized by automatically tensioning the belt to an optimum value.

For this purpose two similar pulleys are inserted in the pedal and wheel hubs. These pulleys are arranged in four radially moving V-shaped arcs (N. 1 in Figure-4). The arcs are moved by a powerful commercial servo-mechanism

(2) through a cam system. A radio command is continuously outputted from the programmable remote control installed on the handlebars. This signal is transformed by the receiver in the hub (3) and it rotates the four cams of the servo (4). Each cam of the servo operates a roller (5) installed on an arc (1). By moving the arms it is possible to vary continuously the transmission ratio. It is also possible to put the belt under tension.

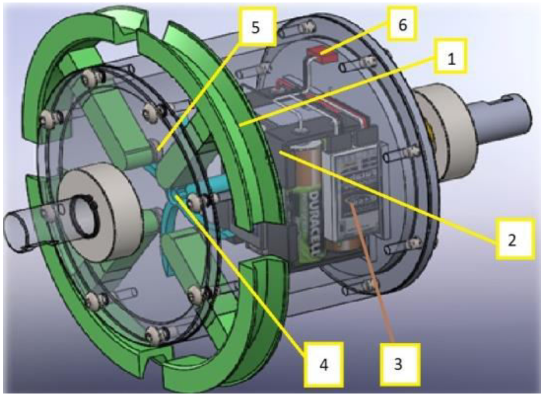

Figure-4. The new concept, this hub is installed both in the front (pedal) and rear (hubs). It is possible to control tension and ratio by moving the arcs (1). The system is controlled by a computerized commercial remote control.

The transmission ratio can be varied continuously from 0.64 to 1.54 (360%). The efficiency is very high, around 98% overall.

The APU (Auxiliary Power Unit) [5-12]

The prolonged autonomy should work in this way. Once the battery charge is below a predefined level, in our case around 20%, the APU is automatically started. At this point the electric motor takes energy from the APU; the remaining energy is used to charge the battery. In order to achieve the maximum efficient and to annihilate the emissions, the APU should work at fixed level, the optimum for efficiency and pollution. This means that, if the electric motor stops, all the energy from the APU charges the battery. The optimum APU output power is then defined by the maximum charging level of the battery. In our case it is 268W. However, it is necessary to reduce this level to take into account of battery deterioration due to time and use. An acceptable value is around 200W. Taking into account the efficiency of the charging device the APU thermal machine should output 210W.

Several reformer fuel cell are available in the 200W range [http://www.samsungsdi.com/nextenergy/portable-fuel-cell.jsp]. The problem is the cost, around 15,000 USD that is unaffordable for a normal customer. Another problem is that, if LPG is used, a purifying filtering system should be installed. Also reformer life is in the range of 300h, a figure that is far from optimal.

It is then necessary to use piston engine APUs, in this field to achieve optimum performance in term of efficiency a unit in the range of the 400 W should be chosen. If an LPG fuel supply system is installed and a catalyst, emissions are virtually null, as proven by the many commercial LPG stoves that do not need an exhaust pipe to the outside. The weight of this system that can be installed below the seat with the battery is about 12 kg, fuel reservoir included. Efficiency can arrive easily at 30%.

Table-4. Bicycle mass breakdown.

Component	**Manufacturer**	**Description**	**MASS** [kg]	**Cost** [€]
Rear rim	Mavick XM 317 disc	26”	0.44	100
Front rim	bTwin	24”	0.38	100
Front fork	Ritchey pro-carbon fork	inclination 48°	0.74	300
Brakes (2)	Magura Marta SL	disk brake	0.6	150
APU	Taizhou LongfaCo., Ltd.	overall	20	80
Battery	AAA Portable Power Corp	LFP 38.4V 9.9Ah	3.5	300
Electric motor	Cute Corp.	All inclusive	4	250
CVT	[CVT articolo]	-	3	120
Seat	Custom made CFRP	-	2	100
Frame	[articolo fabbri]	-	3	100
Others	-	-	1.5	100
Total	-	-	40 kg	1700

Mass breakdown

For the components of the bicycle (steering, brakes, tires etc.), the most convenient solution is to choose among products commercially available. Table 4 summarizes the components chosen and the overall mass. For the rider, the maximum mass of the 95% percentile is 105 kg, fully equipped and additional 15kg may be considered for luggage. The overall mass is then 105+15+40=160 kg, 60% above the standard touring bike (100 kg).

Performance evaluations [13-28]

The first condition is maximum speed that is fixed by the Law at 25 km/h. Since the maximum rpm from Figure-3 is 208 rpm and the minimum reduction ratio of the CVT is 1.54 the maximum fixed reduction ratio from engine to crank is 1.56. The power necessary to keep 25 km/h on plane road can be calculated with (1) and is equal to 88 W. At this power level the efficiency of the engine is around 70%, the amount of energy taken from the battery is 88/0.7=122W. At this power level the available battery will last 252*1000/122=2065s or 14 km.

When the battery reaches the lowest admissible level the APU is started, the APU will charge the battery and energize the electric motor. In this condition the fuel consumption will be (10):

$$Fuel_{cons}=v\ E_{lt}\ \eta_{APU}/P_{25}=25/3600\ 26\ 1000000\ 0.3/122=443\ \text{km/lt} \qquad (10)$$

The APU will take 252*1000/ (200-122) =3230s (nearly 1h) to recharge the battery while moving on level ground at 25 km/h.

The maximum reduction ratio is then 1.56*(1/0.64) =2.43. From Figure-3 the maximum continuous torque of this engine is 20 Nm. The maximum available torque from the engine is then 2.43*20=48.6 Nm. At the maximum slope the stall torque is 180 Nm (equation 6). The rider should then apply a force of $(180-46.8)/L_{arm}=783$ N that for a recumbent bike is high but acceptable.

Economic considerations and perspectives

The cost of a traditional high quality recumbent bicycle is estimated to total around 2, 000 €, the price difference with a normal bike is mainly due to the different size of the respective markets. Out bike will have a price of about twice the cost, around 3, 400 €.

The target market for this type of vehicle is a long-distance daily use. The standard distance of 33 km is considered for this calculation. So a 66 km daily travel is considered. In fact 33 km is the standard marching day of the Ancient Roman Army. With our PA-bike it can be covered in about 2 hours at a reasonable average speed of 16.5 km/h, for a daily total of 4h/66 km. This means that the total fuel cost will be

$$Fuel_{cost} = L_{day}/\ Fuel_{cons}\ Fuel_{price} = 66/443\ 0.8 = 0.12\ € \qquad (11)$$

For an annual cost of 0.12*200 = 24 €/year.

This cost evaluation, however, is over-estimated. In fact it was calculated by assuming to use exclusively the electric motor. This was done to automatically include also the standard maintenance. Auxiliary costs like taxes and insurance are absent for this type of vehicle. Although the e-bike is not comparable to a car for performance and load capacity, the same travel for a small car would cost 6, 127 €/year.

CONCLUSIONS

Even with the commercial components available, that are far from optimized for the specific application, the PA-bike is not only feasible, but also extremely convenient. A daily usage even on medium distances for the European standards is feasible. Environmental compatibility, easy of parking and reduced usage of road surface makes this choice extremely attractive. Further optimization, with non standard component may improve performances in a very important way.

Symbols

Symbol	Description	Unit	Default value
P	Power required by the bike	[W]	-
Pf	Power wasted for wheel to road friction	[W]	-
P_d	Power wasted by aerodynamic drag	[W]	-
Ps	Power required by road slope	[W]	-
f	Friction coefficient	[-]	-
f_0	Basic friction coefficient	[-]	0.004
k	Dynamic friction coefficient multiplier	$[s^2/m^2]$	$6.5\cdot10^{-6}$
v	Bike speed	[m/s]	-
ρ	Air density	$[kg/m^3]$	1.2258

S	Frontal area of Bike + Driver	[m^2]	-
C_X	Drag coefficient	[-]	0.25
m	Bike + Driver mass	[kg]	-
g	Gravity acceleration	[m/s^2]	9.80665
θ	Road slope	[rad]	-
D_r	Rear wheel diameter 26”x1.75	[m]	0.65
C	Battery capacity	[Ah]	-
η_m	Totale efficiency of the transmission	[-]	-
η_d	Mechanical efficiency of the derailleur	[-]	-
η_g	Mechanical efficiency of the electric motor assembly	[-]	-
C_dA	C_xxS - Effective Frontal Area	[m^2]	-
T_s	Stall torque @ start	[Nm]	
T_{st}	Start torque @ start		
L_{arm}	Lever arm length	[m]	0.17
E_{lt}	LPG energy per lt	[MJ]	26
$Fuel_{cons}$	LPG consumption	[km/lt]	
η_{APU}	APU overall efficiency	-	0.3
P_{25}	Power required from the battery at 25 km/h	[W]	
$Fuel_{cost}$	Cost of fuel per day	[€]	
L_{day}	Total distance travelled per working day	[km]	
$Fuel_{price}$	LPG cost per lt	[€]	

REFERENCES

[1] http://bicycles.stackexchange.com/questions/7661/why-arent-tour-de-france-riders-going-any-faster.

[2] Capelli C., Rosa G., Butti F., Ferretti G., Veicsteinas A. and Di Prampero p. e. 1993, Energy Cost and eciency of riding aerodynamic bicycles, European Journal of Applied Physiology. 67, 144-149.

[3] Gross A. C., Kyle C. R. and Malewicki D. J. 1983. The Aerodynamics of Human-powered land vehicles, Scientific American. 249, 126-134.

[4] L. Piancastelli, L. Frizziero, I. Rocchi, G. Zanuccoli, N.E. Daidzic. 2013. The "C-triplex" approach to design of CFRP transport-category airplane structures. International Journal of Heat and Technology, ISSN 0392-8764, 31(2): 51-59.

[5] L. Frizziero, I. Rocchi. 2013. New finite element analysis approach. Published by Pushpa Publishing House. Far East Journal of Electronics and Communications. ISSN: 0973-7006, 11(2): 85-100, Allahabad, India.

[6] L. Piancastelli, L. Frizziero, E. Pezzuti. 2014. Kers applications to aerospace diesel propulsion. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(5): 807-818, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[7] L. Piancastelli, L. Frizziero, G. Donnici. 2014. A highly constrained geometric problem: The inside-outhuman-based approach for the automotive vehicles design. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(6): 901-906, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[8] L. Frizziero, F. R. Curbastro. 2014. Innovative methodologies in mechanical design: QFD vs TRIZ to develop an innovative pressure control system. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(6): 966-970, 2014, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[9] L. Piancastelli, L. Frizziero. 2014. How to adopt innovative design in a sportscar factory. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(6): 859-870, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[10] L. Piancastelli, L. Frizziero, I. Rocchi. 2014. A low-cost, mass-producible, wheeled wind turbine for easy production of renewable energy. Published by Pushpa Publishing House. Far East Journal of Electronics and Communications. ISSN: 0973-7006, 12(1): 19-37, Allahabad, India.

[11] L. Piancastelli, L. Frizziero, 2014. Design, study and optimization of a semiautomatic pasta cooker for coffee shops and the like. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(12): 2608-2617, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[12] L. Piancastelli, L. Frizziero, G. Donnici, 2014. Learning by failures: The "Astura II" concept car design process. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(10): 2009-2015, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[13] L. Piancastelli, L. Frizziero, T. Bombardi, 2014. Bézier based shape parameterization in high speed mandrel design. International Journal of Heat and Technology, ISSN 0392-8764, 32(1-2): 57-63.

[14] L. Piancastelli, L. Frizziero, 2014. Turbocharging and turbocompounding optimization in automotive racing. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(11): 2192-2199, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[15] L. Frizziero, A. Freddi, 2014. Methodology for aesthetical design in a citycar. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(7): 1064-1068, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[16] E. Pezzuti, P.P. Valentini, L. Piancastelli, L. Frizziero, 2014. Development of a modular system for drilling aid for the installation of dental implants. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(9): 1527-1534, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[17] L. Frizziero, 2014. A coffee machine design project through innovative methods: QFD, value analysis and design for assembly. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(7): 1134-1139, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[18] L. Piancastelli, L. Frizziero, G. Donnici, 2014. Study and optimization of an innovative CVT concept for bikes. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(8): 1289-1296, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[19] L. Piancastelli, L. Frizziero, G. Donnici, 2014. The common-rail fuel injection technique in turbocharged di-diesel-engines for aircraft applications. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(12): 2493-2499, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[20] L. Piancastelli, L. Frizziero, 2015. Supercharging systems in small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 20-26, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[21] L. Piancastelli, L. Frizziero, 2015. Accelerated FEM analysis for critical engine components. Published by Walailak Journal of Science and Technology The Walailak Journal of Science and Technology, Institute of Research and Development, Walailak University, ISSN: 1686-3933, Thasala, Nakhon Si Thammarat 80161. 12 (2): 151-165, Thailand.

[22] L. Piancastelli, L. Frizziero, G. Donnici, 2015. Turbomatching of small aircraft diesel common rail engines derived from the automotive field. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 172-178, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[23] L. Piancastelli, L. Frizziero. 2015. Multistage turbocharging systems for high altitude flight with common rail diesel engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(1): 370-375, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[24] L. Piancastelli, L. Frizziero. 2015. A new approach for energy recovery and turbocompounding systems for high altitude flight with common rail diesel engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(2): 828-834, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[25] L. Piancastelli, L. Frizziero. 2015. Mapping optimization for common rail diesel conversions from the automotive to the flying applications. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(4): 1539-1547, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[26] L. Piancastelli, L. Frizziero. 2015. Different approach to robust automatic control for airplanes. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2321-2328, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[27] L. Piancastelli, L. Frizziero. 2015. GA based optimization of the preliminary design of an extremely high pressure centrifugal compressor for a small common rail diesel engine. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(4): 1623-1630, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[28] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel - Automotive to aerial vehicle conversions: An update (Part I). Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2479-2487, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[29] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel - Automotive to aerial vehicle conversions: An update (Part II). Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(8): 3286-3294, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[30] L. Piancastelli, L. Frizziero, G. Donnici. 2015. Common rail diesel-electric propulsion for small boats and yachts. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(6): 2378-2385, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[31] Chester R. Kyle, Ph.D., Frank Berto. 2001. TECHNICAL JOURNAL OF THE IHPVA. The mechanical efficiency of bicycle derailleur and hub-gear transmissions, Human Power Number 52 Summer.

[32] David Gordon Wilson, Bicycling Science, Mit Press, 3rd revised edition (23 april 2004), isbn-10: 0262731541, isbn-13: 978-0262731546.