VOL. 10, NO. 2, FEBRUARY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

©2006-2015 Asian Research Publishing Network (ARPN). All rights reserved.

www.arpnjournals.com

A NEW APPROACH FOR ENERGY RECOVERY AND TURBOCOMPOUNDING SYSTEMS FOR HIGH ALTITUDE FLIGHT WITH COMMON RAIL DIESEL ENGINES

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

ABSTRACT

This paper introduces an original method for the preliminary calculations and the turbomatching of a dual stage high altitude turbocompounding system. This method is conceived to use modified automotive commercial turbochargers along with electric motor/generators. The method used is innovative and uses only the data commonly available from the manufacturer. In the example described herein, full power and throttle control are achieved up to 10, 000m (32, 000ft). The engine is a Common Rail Direct Injection Diesel engine derived from the automotive market. The calculation method and the problems connected are widely discussed. For this application turbocompunding is a good option that partially compensates the unavoidable increase in TOW (Take Off Weight). In drones that have relatively large batteries, the ERS (Energy Recovery System) does not increase the air vehicle mass.

Keywords: Energy recovery, turbocompunding system, diesel common rail.

INTRODUCTION

The research in the field of CRDIDs (Common Rail Direct Injection Diesel) is aimed to the design and implementation of engines with increasing power to weight ratio, with reduced costs and with the restore altitude higher possible. In this context the project of the conversion of the Direct Injection Diesel FIAT 1.3jtd16V from the Fiat500-85HP is extremely interesting. In fact this unit is extremely compact and can run up to 6, 000rpm with minor improvements. This fact, together with the very good efficiency of CRDIDs, has led to a very interesting aircraft conversion. For all the above factors, but particularly to enable a higher restoring altitude, it was decided to study a multistage turbocharging system. This solution has the drawback of a greater complication and higher total mass.

In this paper we describe the initial design of a supercharging system that can guarantee full power restoration even at medium altitudes (10, 000m ISA [-50°/+20°]) for general aviation and MALE (Medium Altitude Long Endurance) manned and UAVs (Unmanned Aerial Vehicle).

It should be noted that the commercial offer in this power range is very scarce and it is largely non-compliant with fuel economy requirements for a long flight time.

CRDIDs have a fuel efficiency that is commonly around 150 gr/HPh (42%) and it is virtually not affected by altitude. In the specific case of the 1300jtd, the BSFC (Brake Specific Fuel Consumption) is even better.

For practical reasons, even in these CRDIDs, the energy recovered from the exhaust is far from 100%.

For this reason, the high altitude propulsion system proposed in this paper, once properly tested, may prove to be satisfactory in a field where the concurrency is nearly absent. Even for higher power level, CRDIDs are to be taken into consideration. In fact, powers up to 900HP are available from automotive conversions. In general, the higher the power the more performing is the conversion in terms of power-to-weight ratio.

Evolution of the project

In this section we briefly summarize those various stages of evolution of the project to develop a DID, based on the 1300 FIAT JTD engine, capable of a power output of 150HP.

Clearly, this development had to comply with certain constraints imposed by the type of engine choice. Fortunately maximum power output is required at high rpm so journal bearing loads due to combustion are partially reduced by inertia loads.

It is possible to replace the original cast iron crankcase with a new light alloy unit. Aluminum alloy crankcase may use two different approaches: the ribbed and the double wall design. In the 1300jtd and for the 1900jtd the ribbed approach was used for the new design due to easing sand casting. For economic reasons, however, it was chosen to modify the original cast iron crankcase in order to avoid the necessity of a complex engine mount. This solution compensates, partially, the weight of the massive cast iron crankcase that includes the cooling pump. This massive design is curious for the italian engine design philosophy, that usually tend to privilege multiple bolted small castings instead of a single large one. However the use of as many original components as possible leads to important economic advantages and significantly reduces the time-to-market of the aircraft unit.

For this reason also the original chain assembly was kept, instead of using a carbon fiber reinforced timing belt for the camshafts drive.

©2006-2015 Asian Research Publishing Network (ARPN). All rights reserved.

However it is convenient to use a new aluminum alloy HPP (High Pressure Pump) instead of the original cast iron one to contain the weight. The injection system has then been replaced with a new system, also automotive derived, and a new FADEC. This later from the sporting car market. As usual the exhaust and the intake had been redesigned to allow a more regular flux from-and-to the turbocharger(s). These new components maximize turbocharger(s) performance especially for the pressure ratio that is critical for aircraft applications. Fortunately, the high inertia of the propeller compensates almost totally the turbolag problem even with the new lightweight CFRPPs (Carbon Fiber Reinforced Plastic Propellers).

The use of electric variable pitch was included in the design. However, in modern FADEC (Full Authority Diesel Electronic Control) controlled CRDIDs, it is possible to derive an oil low-pressure-oil-line from a PID-controlled-pressure-reducer-valve (Proportional, Integrative, Derivate). This pressure can be used for a hydraulic variable pitch propeller instead of the traditional bulky oil pump. The FADEC can easily emulate the PID in order to compensate the variations in pressure and their fluctuations in time.

Compression: Basic flow rate

The Basic unboosted Flow Rate (BFR) and the Actual Flow Rate (AFR) are defined as follow (1):

$$BFR = \eta_V V_0 n \frac{1}{\tau} = 6.46 \tag{1}$$

$$AFR = \eta_V V_0 n \frac{1}{\tau} P_R = 14.21 \tag{2}$$

These values are volumetric air flows, but they are converted to normalized mass flow [lb/min] at a temperature of 85 [°F] and a pressure of 13.5 [psi]. It then necessary to calculate the equivalent volumetric flow that is called Corrected Air Flow (CAF) that as usually is converted as a mass flow at the standard condition of 85 [°F] and 13.5 [psi]. The CAF is calculated at the design altitude of 10,000m -ISA+0 (International Standard Atmosphere with a temperature offset of 0K) where the air temperature is -58 [°F] and the pressure is 3.83 [psi] (3).

$$CAF = \frac{AFR\sqrt{\frac{Tf+460}{545}}}{\frac{Ppsi}{13.95}} = \frac{14.21\sqrt{\frac{-58+460}{545}}}{\frac{3.83}{13.95}} = 44.41 \tag{3}$$

From Figure-1, the Holset model HX35 VGT (Variable Gas Turbine) turbocharger seems to be useable.

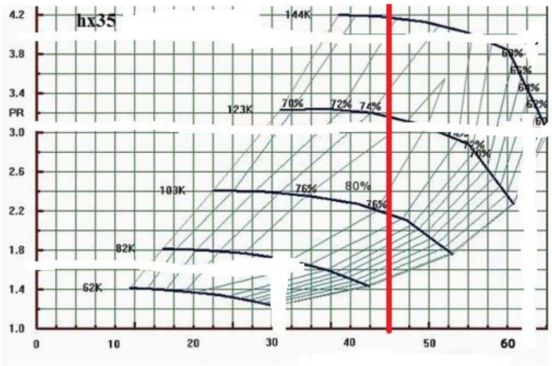

Figure-1. Hx35 compressor map. The red line is the CAF@10, 000m.

Compression ratios from 2.1 to 3.5 are obtainable with an efficiency of 74%. It is possible to have arrived up to 4 with a still very good 72%. However it is advisable to keep the efficiency as high as possible, so the value of $\beta=3.5$ is chosen with a total efficiency $\eta_{TT}=0.74$. The adiabatic efficiency η_{pc} with this compression ratio can be calculated with equation (4):

$$\eta_{TT} = \frac{\beta^{\frac{k-1}{k}} - 1}{\beta^{\frac{k-1}{k}\frac{1}{\eta_{pc}}} - 1} \rightarrow \eta_{pc} = 0.78 \tag{4}$$

It is then possible to calculate the value of the user-defined function IPR ($T_{\text{ingresso, HX35}}$) by using (5) (6) (7) (8)

$$IPR(T_a) = \frac{E(T_a)}{R} = 22.87 \tag{5}$$

$$E(T_a) = \sum_{N=0}^{1} A(N) T_a^{\,N} + A(2)\ln(T_a) = 6.57 \tag{6}$$

$$IPR(T_{out1}) = \frac{\ln\beta}{\eta_{pc}} + IPR(T_a) = 24.48 \tag{7}$$

$$T_{out1} = \sum_{N=0}^{3} B(N)[IPR(T)_{out1}]^{N} = 351.8 \tag{8}$$

with $A(0)=1.386989$, $A(1)=0.184930*10^{-3}$, $A(2)=0.95$, $B(0)= -0.880092*10^{4}$, $B(1)=0.126974*10^{4}$, $B(2)=-0.619392*10^{2}$, $B(3)=1.03530$.

T_{out1} is still acceptable for the second compression stage and the intercooler can be bypassed. For the second compression stage it is possible to use the (3) with the new values of $P_{psi}=\beta P_a=13.41$ and $T_f=T_{out1}$. The CAF for the II compression stage is 16 lb/min. It is then possible to adopt the Garrett GT2052 with the result summarized in Table-1:

©2006-2015 Asian Research Publishing Network (ARPN). All rights reserved.

Table-1. GT2052 output.

	GT2052 output
β	2.65
η_{TT}	0.68
η_{pc}	0.72
P_{outII} [bar]	2.45
IPR(T_{outII})	25.83
T_{outII}[K]	506

In this case a titanium alloy compressor wheel should be adopted to avoid excessive wheel temperatures. The aftercooling is also required. This means that the compressor ratio will be slightly higher along with the output temperature T_{outII}. This turbocharger is far from ideal for sea level operations, so a VGT unit should be adopted instead. Still, for the expansion and turbocompounding calculations, we will use the GT2052 turbine data.

Expansion: I stage GT2052, calculation of the compression specific work Pc

Pc can be calculated as the difference of enthalpy (9)

$$P_c = \Delta h \tag{9}$$

For enthalpy evaluation the equation (10) is used

$$H(T) = \sum_{N=0}^{3} hE(N)T^{N} \tag{10}$$

with hE(0)=0.120740*10^{2}, hE(1)=0.924592, hE(2)=0.115984*10^{-3}, hE(3)=-0.563568*10^{-8}. It is then possible to evaluate H (T_{inII}) = 351, H (T_{outII}) =510 and P_c=158. By assuming that Pc=Pt*η_T=160, it is possible to evaluate the exit temperature T_{outT1}. To do so it is necessary to evaluate the C_{pm} of the exhausts. So it is possible to evaluate H_{outT1} (11):

$$H(T_{outT1}) = H(EGT) - P_c = 915 \tag{11}$$

For the evaluation of the C_{pm}, the following interactive method is used:. At first a tentative value for C_{pm}=1 is assumed. Then we calculate C^{I}_{p} with (12):

$$c^{I}_{pm} = (c_p\,(EGT) \times EGT - c_p\,(T^{IV}_{outT1}) \times T^{IV}_{outT1})/(EGT - T^{I}_{outT1})) \tag{12}$$

it is then possible to calculate a second, more accurate, value for T_{outT1} (13):

$$T^{II}_{outT1} = \frac{H(EGT)}{c^{I}_{pm}} \tag{13}$$

It is then possible to calculate a new, more accurate value, c^{II}_{pm} and T^{III}_{outT1}.The iterations are stopped when (14) is true:

$$|T^{n+1}_{outT1} - T^{n}_{outT1}| \leq \varepsilon \tag{14}$$

In this paper ε is 0.5°C. The $c_{pm,exhaust}$ of the exhaust can be calculated with (15)

$$c_{pm,exhaust} = \frac{\%N_2 c_{p,N_2} + \%O_2 c_{p,O_2} + \%CO_2 c_{p,CO_2} + \%H_2O c_{p,H_2O}}{100} \tag{15}$$

The c_p of N_2, 02, C02 and H$_2$0 can be approximated with (16):

$$c_{p,component} = \frac{A + Bt + Ct^2 + Dt^3 + \frac{E}{t^2}}{\chi} \tag{16}$$

Dove A, B, C, D, E are the coefficients of Table-2, while our "standard" exhaust composition is depicted in Table-3:

Table-2. coefficients of components for (16) from NIST (National Institute of Science and Technology).

	C0$_2$	N$_2$	H$_2$0	0$_2$
A	24.99735	26.09200	30.09200	298-6000
B	55.18696	8.218801	6.832514	29.65900
C	-33.69137	-1.976141	6.793435	6.137261
D	7.948387	0.159274	-2.534480	-1.186521
E	-0.136638	0.044434	0.082139	0.095780
χ	44.0098	28.0134	18.0152	31.9988

Table-3. Exhaust composition in weight used herein.

N_2	75.2
O_2	15
CO_2	7.2
H_2O	2.6

t is the temperature [K] subdivided by 1000. The results are: T^{IV}_{outT1}= 691 and C^{IV}_{pm}=1.32. It is also possible to write (17):

$$P_c = P_t = H(EGT) - H_{outT1} = (H(EGT) - H_{outT1iso})\eta_T \tag{17}$$

It is then possible to evaluate the adiabatic (isentropic) of the ideal turbine expansion that is $T_{outT1iso}$=663 and C_{pmiso}=1.32. It is then possible to write (18) and evaluate p_{outT1}=135045.

©2006-2015 Asian Research Publishing Network (ARPN). All rights reserved.

$$\begin{cases} p_{outT1}v_{outT1} = RT_{outT1} \\ p_{outT1}v_{outT1iso} = RT_{outT1iso} \\ p_{outT1}v_{outT1iso}^{k} = p_{CCT}v_{CCT}^{k} \end{cases} \quad (18)$$

For the II expansion the some procedure is used and the energy available for the turbocompound is calculated: HoutT2=748, T_{outT2}=596, $T_{out2iso}$=573, p_{outT2}=116619. So there is plenty of energy for the turbocompound.

Remarks on EGT and turbine efficiency

The calculation above explained is an example. In fact a more accurate value of turbine efficiency should be used. In our calculation the value η_T=0.8 was used, the right value should be found in an appropriate map that has also the true efficiency, that is probably lower. These maps are not easy to find, in fact the preliminary calculation is made only on the compressor. The matching of the compressor and the turbine is usually made by the manufacturer and only a "boundary check" is to be made on the hot side of the turbocharger. However, for turbocompounding calculation the right values on the exhaust should be used. The solution for the 1300jtd depicted in this paper has several problems. The first one is flexibility. There is no point to use a first stage fixed geometry turbocharger with an EGT of only 750°C. In this case VGTs should be used. This will increase turbocharging efficiency in the various conditions of load, altitude and temperature offset. VGT also improves the flight level at which full throttle authority control can be kept. Over a certain altitude the engine will not accept again full load if the throttle (load) is, even partially, reduced. This is the throttle authority limit flight level. At even higher altitude the engine will fully stop if throttle is reduced. It will then be necessary to descend below the hot starting flight level to restart it. If a fixed geometry turbine is used, EGT may be raised. Commonly EGT of 950°C is accepted for short periods in commercial turbochargers. Garrett supplies "racing" turbochargers as the TR30R (installed on the 600HP Audi Le Mans racing car) with fixed turbine nozzle geometry with wastegates. These turbine wheels can operate continuously with EGTs up to 1050°C. For this purpose Garret uses the Mar-M-247, developed by Martin-Marietta in the seventies for gas turbine engine blades, discs and burner cans. This material is a nickel-based superalloy containing chrome, aluminum and molybdenum. In order to achieve optimal mechanical properties for superalloys, NASA developed the "Grainex" process. This process improves the traditional investment casting technique, with the additional process of mold agitation during freezing to produce homogeneous grain inoculation, resulting in better uniformity of grain structure. The part is the Hot Hiped 1185°C and 170 bar for 4 hours, then solution treated for two hours at the same temperature and aged for 20 hours at 870°C. The process improves Ultimate-Tensile-Strength at room-temperature up to of 1000 MPa. UTS increases with temperature up to 760°C. It is also possible to cool the turbine with air spilled from the compressor. Cooling increases the maximum EGT up to 1400°C, that is the current limit technological value. Variable geometry turbines (VGT) enable greater flexibility of operation and substantially increase turbine efficiency. In many cases, the VGT can replace a wastegate. VGT turbochargers are limited to continuous EGTs of 950°C, with occasional spikes up to 980°C (Porsche 997 twin-turbo). However VGT systems will operate successfully at the temperatures of 1050°C will be available at least on the racing "aftermarket" in the next few years.

CONCLUSIONS

In order to keep the output power constant up to 10,000m, even small CRDIDs require multiple stage turbocharging. The amount of energy that is recovered at the exhaust is a small part of what is available. For this reason a solid method to evaluate engine performance at altitude is necessary. A preliminary design method for turbomatching and turbocompounding is introduced in this paper and it is shown the 150HP common rail DID design to operate up to 10, 000m. The originally conceived calculation method for this application is described along with its limits and the technical option available for high pressure turbocharging.

Symbols

Symbol	Description	Unit	Value
η_v	Engine volumetric efficiency	-	0.85
V_c	Engine displacement	cc	1248
n	Max crankshaft speed	n	5000
τ	# of rev. per cycle	-	2
P_R	Manifold pressure	bar	2.2
BFR	Normalized volumetric nat. aspirated air flow@[85F,13.5psi]	lb/min	6.46
AFR	Normalized volumetric air flow for P_R @[85F,13.5psi]	lb/min	14.21
CAF	Normalized volumetric air flow at design altitude for P_R @[85F,13.5psi]	lb/min	44.41

T_f	Outside temperature	F	
R	Ideal gas constant	kJ/(kg K)	0.287040
η_{TT}	Compressor total efficiency	-	
η_{pc}	Compressor adiabatic efficiency	-	
k	Adiabatic index	-	1.4
P_a	Ambient pressure (10,000m ISA+0)	Pa	26436.3
T_a	Ambient temperature (10,000m ISA+0)	K	223.15
β	Compression ratio (I stage)	-	3.5
T_{out1}	Temperature at the outlet of the I compression stage	K	-
$p_{exhaust}$	Exhaust pressure	bar	2
ETG	Exhaust temperature form engine	K	1023.15
P_c	Compression specific work	kJ/kg	
P_t	Turbine specific work	kJ/kg	
T_{outT1}	Temperature at the outlet of the I expansion stage (Turbocharger closer to the engine)	K	-
C_{pm}	Mean specific heat capacity	kJ/K	
η_T	Turbine efficiency	-	0.8
h, H	Enthalpy	kJ/kg	
$T_{outT1iso}$	Outlet temperature of I espansion (adiabatic)	K	
T_{outT1}	Outlet temperature of I espansion (true)	K	
$_{out2}$	Pedic for II espansion outlet	-	

REFERENCES

[1] Sandrolini S., Naldi G. Le Turbomacchine Motrici E Operatrici, Pitagora.

[2] Yahya. 1983. Turbines, Compressors and Fans. Tata Mcgraw-Hill.

[3] OSNAGHI C. 1982. Macchine fluidodinamiche, CLUP.

[4] L. Piancastelli, L. Frizziero, S. Marcoppido, E. Pezzuti. 2012. Methodology to evaluate aircraft piston engine durability. edizioni ETS. International journal of heat and technology. ISSN 0392-8764. 30(1): 89-92.

[5] L. Piancastelli, L. Frizziero, G. Zanuccoli, N.E. Daidzic, I. Rocchi. 2013. A comparison between CFRP and 2195-FSW for aircraft structural designs. International Journal of Heat and Technology. 31(1): 17-24.

[6] L. Piancastelli, L. Frizziero, N.E. Daidzic, I. Rocchi. 2013. Analysis of automotive diesel conversions with KERS for future aerospace applications. International Journal of Heat and Technology. 31(1): 143-154.

[7] L. Piancastelli, L. Frizziero, I. Rocchi. 2012. An innovative method to speed up the finite element analysis of critical engine components. International Journal of Heat and Technology. 30(2): 127-132.

[8] L. Piancastelli, L. Frizziero, I. Rocchi. 2012. Feasible optimum design of a turbocompound Diesel Brayton cycle for diesel-turbo-fan aircraft propulsion. International Journal of Heat and Technology. 30(2): 121-126.

[9] L. Piancastelli, L. Frizziero, S. Marcoppido, A. Donnarumma, E. Pezzuti. 2011. Fuzzy control system for recovering direction after spinning. International Journal of Heat and Technology. 29(2): 87-93.

[10] L. Piancastelli, L. Frizziero, S. Marcoppido, A. Donnarumma, E. Pezzuti. 2011. Active antiskid system for handling improvement in motorbikes controlled by fuzzy logic. International Journal of Heat and Technology. 29(2): 95-101.

[11] L. Piancastelli, L. Frizziero, E. Morganti, E. Pezzuti. 2012. Method for evaluating the durability of aircraft piston engines. 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. 9(4): 425-431, Thailand.

[12] L. Piancastelli, L. Frizziero, E. Morganti, A. Canaparo. 2012. Embodiment of an innovative system design in a sportscar factory. Published by Pushpa Publishing House. Far East Journal of Electronics and Communications. ISSN: 0973-7006, 9(2): 69-98, Allahabad, India.

[13] L. Piancastelli, L. Frizziero, E. Morganti, A. Canaparo. 2012. The Electronic Stability Program controlled by a Fuzzy Algorithm tuned for tyre burst issues. Published by Pushpa Publishing House. Far East Journal of Electronics and Communications. ISSN: 0973-7006, 9(1): 49-68, Allahabad, India.

[14] 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.

[15] 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.

[16] L. Piancastelli, L. Frizziero, E. Pezzuti. 2014. Aircraft diesel engines controlled by fuzzy logic. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 9(1); 30-34, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[17] 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.

[18] 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.

[19] 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.

[20] 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.

[21] 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.

[22] L. Piancastelli, G. Caligiana, Frizziero Leonardo, S. Marcoppido. 2011. Piston engine cooling: an evergreen problem. 3rd CEAS Air and Space Conference - 21st AIDAA Congress - Venice (Italy), 24th-28th October.

[23] L. Piancastelli, L. Frizziero, E. Morganti, A. Canaparo. 2012. Fuzzy control system for aircraft diesel engines. Edizioni ETS. International journal of heat and technology. ISSN 0392-8764, 30(1): 131-135.

[24] 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.

[25] L. Piancastelli, L. Frizziero, I. Rocchi, 2014. A low-cost, mass-producible, wheeled wind turbine for easy production of renewableenergy. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(1): 19-37, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[26] 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.

[27] 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.

[28] 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.

[29] 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.

[30] 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.

[31] 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.

[32] 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.

[33] 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.

[34] 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.

[35] 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.

[36] 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.

[37] 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.