VOL. 13, NO. 16, AUGUST 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MULTI-OBJECTIVE OPTIMIZATION OF THE COOLING SYSTEM OF A DIESEL HELICOPTER

Luca Piancastelli[1], Stefano Cassani[2], Eugenio Pezzuti[3] and Lorenzo Pompei[1]
[1]Department of Industrial Engineering, Alma Mater Studiorum University of Bologna, Viale Risorgimento, Bologna, Italy
[2]Multi Projecta, Via Casola Canina, Imola, Italy
[3]Università di Roma "Tor Vergata", Dip. di Ingegneria dell'Impresa "Mario Lucertini", Via del Politecnico, Roma, Italy
E-Mail: luca.piancastelli@unibo.it

ABSTRACT

CRDID (Common Rail Diesel Engine) main advantage is the extremely high efficiency (up to 52%), the enormous amount of hours run and the flight readiness. Moreover, diesel fuel is safer than jet fuel and it is available everywhere. Therefore, refuelling flights to airports or dedicated supply lines can be avoided. However, diesel engines are generally heavier than turboshafts and require an additional cooling system. This requirement is particularly stringent during near stationary operations of the helicopter. In fact, if fans are used for the cooling system, the available power is reduced with an increased penalty weight for the installation. For this reason the ejector exhaust system can be successfully used in CRDID powered helicopters. A feasibility study of the cooling system for a CRDID (Common Rail Diesel Engine) on a common light helicopter (Eurocopter EC 120-class) is introduced. Optimization of this system is performed. The total mass available for the CRDID is evaluated starting from fuel consumption and helicopter data. A derivative of an automotive engine is proposed for the turboshaft replacement. The result is that the ejector exhaust (augmenter) is extremely effective. Solid Works Flow Simulation confirms the ejector choice and the design criteria.

Keywords: helicopter, diesel, cooling, efficiency, exhaust augmenter, CFD.

INTRODUCTION

Starting from raw data, the turboshaft engine has a better power to weight ratio than CRDIDs (Common Rail Diesel Engine). In fact, the huge investments in the late 20th century led to improvements in turboshaft that were essential for helicopter development. Therefore, the turboshaft engines are the premium choice for the helicopter power plants. However, the relatively low fuel efficiency in off-design conditions of these engines reduces the turboshaft advantage. The introduction of CRDIDs brought into the automotive market several extremely cost-effective power units with increasingly higher power to mass ratio. In fact, power plant downsizing reduces emissions and increases performances of modern car and trucks. These engines may, in the helicopter conversion, reach an efficiency of 52% without secondary cycles for exhaust energy recovery. Therefore, CRDID have reintroduced the option of powering light to medium single/twin engine(s) helicopters with advanced piston engines instead of traditional turboshafts. This solution contains costs, reduces pollutant emissions and fuel consumption. High operating costs and growing public concern for environment protection have also become essential factor in future choices. In order to meet this objective of an optimum CRDID-helicopter matching, a multi-criteria analysis was undertaken to cover the issues of mechanical and thermal loads and interactions with the helicopter body. This optimization process starts from helicopter expected performances. A primary advantage of CRDIDs is the possibility to use non-explosive automotive diesel fuel. In fact, diesel not only reduces the fire hazards, but also simplifies the supply and storage chain both for civilian and military helicopters. In fact, automotive diesel is the most common fuel in the world. Moreover, in many countries around the world, a private helicopter owner with his own landing site cannot have his own private jet-fuel station. Therefore, he has to refuel at the nearest local airport. This fact is an important limitation in private helicopter diffusion, especially for light, general aviation helicopters. However, the use of a CRDID with FADEC (Full Authority Electronic Control) poses a significant challenge to the designer, who should reduce fuel consumption, noise levels, emissions, purchase, installation and maintenance costs. Both diesel and Jet fuel can be used in CRDID. This gives huge advantages both on safety and on helicopter usability. However, a main challenge is to cool the CRDID at take off, when power output is at top and airspeed can be null. In this paper this problem is fully investigated and the optimal solution of ejector-exhaust cooling is optimized. This paper optimizes the cooling system of a diesel powered Eurocopter EC120 class.

The patched prototype issue

The Eurocopter EC120 date is summarized in the Table-1.

VOL. 13, NO. 16, AUGUST 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-1. a Eurocopter EC120.

Table-1. EC120 data.

Description	value	unit
Empty mass	997	kg
Useful load	7,040	N
TOW	16,818	N
TOW ext. load	17,652	N
TO power	504	HP
Cont. power	449	HP
Fuel capacity	321	kg
Best Arrius F2 SFC	217	g/HPh
Arrius F2 mass	103.5	kg
Battery	28	V
Generator (G) current	50	A
Maximum G current	240	A
Maximum G power	6	kW

Preliminary considerations on the CRDID installation

The CRDID lower SFC (Specific Fuel Consumption) and the excellent off-design performance makes it possible to reduce helicopter fuel consumption of 50% at cruise power setting. Therefore, it is then possible to reduce the fuel mass. For the CRDID power plant the mass M_{CRDID} is then available (1).

$$M_{CRDID} = M_{Turboshaft} + M_{fuel} \times 0.5 = 103.5 + 321 \times 0.5 = 264 \quad (1)$$

This M_{CRDID} is conservative, since the reduced rotor disk loading increases the lift to power ratio of the main rotor. The internal tank can also be reduced in volume and in mass. Another factor to be considered is that the CRDID is not sensitive as sensitive to OAT (Outside Air Temperatures) as turboshaft. Only for temperatures higher than 35 DEG C the power output is reduced of 1% for every DEG C. Diesel engine power output is also insensitive to humidity. This fact is particularly important since no derating is necessary in climates where water vapor levels in air are high. To achieve the required output power an AUDI V6 TDI engine can be used. This engine weights 180kg and can output 450HP@4,000rpm. Therefore, it is possible to use 84kg for engine installation.

The cooling system

The main for the CRDID cooling system is to adequately keep coolant and oil temperature within optimum range in every flight phase. Another important requirement is to avoid fans and other devices that reduce power output. In fact 450HP is the net power to the rotor. Cooling drag is also of concern. In aircraft Meredith ramjet increase net thrust. This solution is not possible on helicopters. The last but not less important requirement is to minimize mass and volume. For CRDIDs cooling problems start with ground operations with the engine idling. In this phase, CRDID tend to overcool. In fact, during idle the CRDID is so efficient that the energy wasted is not enough to keep the engine warm. A thermostatic valve in the cooling system is installed to keep the relatively high temperatures necessary for correct combustion. Therefore a fan is not necessary even when OAT reaches 45 DEG C.

MTOW (Maximum Take Off Weight) takeoff and hover is a very demanding condition, with maximum power and no useful airflow. The propeller swirl impairs the possibility to use induced velocity for the cooling system. Combinations of atmospheric turbulence, crosswinds, high OATs, and irregular ground patterns are most critical conditions. Engine temperatures are should be kept within acceptable limits at full power, zero airspeed for several minutes. Correct position of inlets and outlets ports is critical in helicopters. This arrangement is possible only with adequate cooling inlets/outlets and an efficient forced airflow.

The helicopter climbs at or near full power. However, in this flying condition there is a significant airflow. This airflow produces stable high and low-pressure areas somewhere on the fuselage. Therefore, in climbing, the cooling flow is increased by taking the cooling air at a high pressure area and by positioning the exit of the cooling air at a low pressure point. In the cruise condition the airflow is nearly steady state; the power settings are from 50% to 75%; the speed is high with plenty of airflow and very well defined pressure areas around the fuselage. Theoretically, in cruise it is possible to implement a Meredith cooling duct. However, in the helicopters, the cruise conditions cannot be optimized at the expense of the first three operating conditions or the helicopter will not hover due to excessive weight. Descent is generally characterized by low power setting at quite good airspeeds. On touchdown, the helicopter will slow down with relatively high power settings. Another important concern with a CRDID engine is shock cooling. A proper installation of the liquid cooling system avoids shock cooling and over-cooling. The most efficient solution of the cooling problem is to use electric coolant pumps controlled by the FADEC (Full Authority Digital Electronic Control). In this way it is possible to match the coolant flow with the engine requirements. The best way to optimize the reliability is to simplify of the cooling system. In case of an electric powered system, dual redundancy is strictly necessary. The ejector exhaust solution reduces both the power requirements and the size of inlet and outlet ports. This system works only at relatively high power settings. That is the case of the helicopter. Cooling power is a function of power and efficiency. High power and low efficiency increase the amount of heat to be removed from the engine. The ideal cooling system regulates cooling airflow as a function of engine power setting and temperatures. A cooling system based on exhaust augmenters is independent of airspeed and dependent on power setting. A thermostatic valve can regulate temperatures or a FADEC controlled electric pump. The ejector exhaust allows reduction of cooling drag without compromising engine cooling and requires no additional pilot workload. The absences of fans avoid the subtraction of useful power from the engine.

The cooling air passes through the intercooler and coolant radiator packed together. Then it flows in the exhaust augmenters. Commercially available CFRP (Carbon Fiber Reinforced Plastics) able to withstand to temperatures up to 1000 DEG C can be used to reduce the ejector mass.

For the radiator size, a classical practical formula for modern Euro-0 CRDID claims $f_{radiator}$=18,000 mm^3/HP of a modern finned radiator with a thickness of 2.75" (70mm) and 25 fpi (fin per inch) (1). Equation (1) takes into account of the presence of a suitable air-air intercooler installed in front the coolant radiator. This intercooler will have the same frontal area of the coolant radiator. The aim is to keep the air temperature at CRDID intake below 50 DEG C. This is due to the fact that the intake air is used to cool piston top surface. The lubricant cools the bottom piston surface. A coolant-to-lubricant heat-exchanger is installed on the engine after the lubrication pump. For the AUDI V6 engine, maximum coolant temperature is 120 DEG C and maximum lubricant temperature is 130 DEG C. The cooling circuit is pressurized at 3 bar. Coolant temperature should not drop below 80 DEG C during normal operations.

$$V_{radiator} = P_{Turboshaft} f_{radiator} = 450 \times 18 \times 10^3 = 8.1 \times 10^6 \quad (1)$$

With the thickness of w=2.75", the "frontal area" $A_{radiator}$ of the radiator will be (2):

$$A_{radiator} = \frac{V_{radiator}}{w} = 116 \times 10^3 \quad (2)$$

The most efficient shape for an ejector augmenter is the circular one. Therefore, the radiator diameter will be 0.4m. The augmenter is jet compressor that uses the small high-speed jet of exhaust-gas to move a larger volume of cooling air. In this case, the aim is to obtain a depression that sucks the cooling air through the radiator pack. Therefore, the radiator used has a circular shape. The engine exhaust is inserted inside the duct through a hole at the center of the radiator (Figure-2). Figure-3 shows the 3D model of the radiator pack. In the CFD (Computational Fluid Dynamics) simulation, the radiator is simulated with an equivalent porous media. This area is shown in light grey in figure 3. The augmenter has the inlet, the constant and the diffuser sections (Figure 4). The inlet is shaped for smooth entry of the cooling air and positioning of the exhaust jet. In helicopters, the optimum inlet area is 15% larger than that of the radiator frontal area. This optimum convergent inlet has a Diameter to Length ratio of 5.However, convergent is not critical. On the contrary, the diffuser is extremely critical. The most stringent design requirement in dimensioning the diffuser is to minimize the internal losses. In fact, internal losses reduce the amount of pressure recovered and increase cooling temperatures.

Diffuser pressure drops are the distributed loss, caused by the friction on the duct walls and the concentrated loss, caused by the section variation inside the duct. If the diffuser is too long, the distributed loss is larger than the concentrated loss. If the diffuser is exceedingly short, the opposite concentrated loss prevails. Therefore, a value of the semi-angle opening of the duct of about 7° is common. This is the value most used in the wind-tunnel diffuser. However, with modern polished RP (Reinforced Plastic) construction it is possible to reduce this angle down to about 2°. In this critical application, the geometry of the diffuser causes an increase in the radiator drag and a reduction of the heat-rejection, because of the deviation of the airflow. This deviated flow matches the parallel ducts of the finned radiator differences of pressure drop on the radiator surface. The streamline diffuser is the best design. In fact, in a streamline diffuser the walls follow the airflow, guiding it with best efficiency. However, in this case, the manufacturing costs do not justify the improvement in performance. Therefore, a straight 6 DEG C semi-angle diffuser is used in this paper.

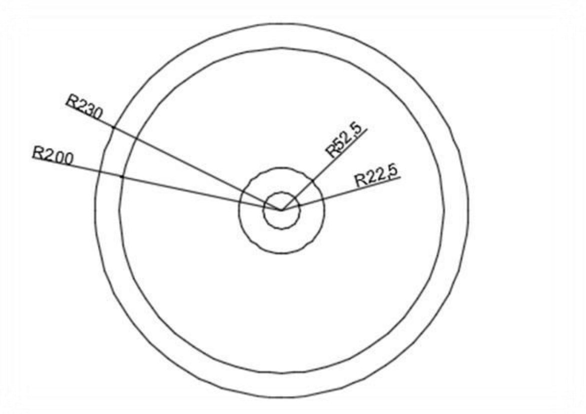

Figure-2. The radiator pack drawing (frontal view).

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

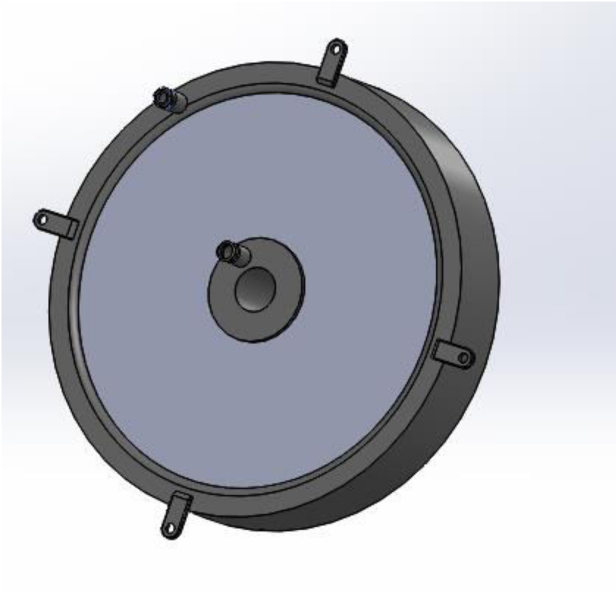

Figure-3. 3D CAD model of the radiator. The finned section is shown with light grey.

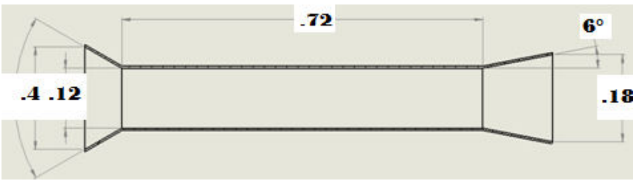

Figure-4. Ejector geometry (schematic).

Augmenter preliminary design

A CRDID will output a mass-flow of 4E-4 kg/(HP s). Therefore, the 450HP CRDID will output 0.18 kg/s at the exhaust. This result is obtained for an air-to-fuel ratio of 20 and a CRDID efficiency of 50%. If the exhaust temperature of Texhaust=650+273.15 K and a gas velocity of 400 m/s it is possible to calculate the exhaust diameter (3) (4).

$$\rho_{exhaust} = \frac{p_{atmr}}{T_{exhaust}R} = 0.38 \quad (3)$$

$$d_{exhaust} = \sqrt{4\frac{Q_{m\_exaust}}{\pi\rho_{exhaust}v_{exhaust}}} = 0.038 \quad (4)$$

The straight mixing section has to be $f_{straight}$=8-10 times the exhaust diameter (5).

$$d_{straight} = \frac{d_{exhaust}}{\sqrt{f_{straight}}} = 0.12$$

The optimum length of the mixing section is 6-7 times the diameter, 6*120=720mm. For the diffuser, the best final diameter is 1.45 times the mixing diameter, so the final diameter will be 120*1.45=174mm, with an angle of divergence lower than 12 DEG.

Cooling system duct installation

The AUDI V6 in helicopter version has a single large turbocharger instead of the multiple units of the automotive version [4-18]. This is due to the absence of the turbo lag problem in the helicopter and the very different rpm range. In the case of the car, even a sport car, the power range is positioned in the first half of the available with a few times where full power or full torque in required by the driver. On the contrary, the helicopter pilot will ask full power at every take-off. This requirement, along with the 3,000 hours TBO (time between overhaul) is fulfilled by surface treatment and replacement of most critical parts in the helicopter engine. Therefore, the turbocharger of the helicopter version is larger and it is positioned tail-ward in the back of the engine. The turbocharger exhausts points to the tail, passes a bulkhead and an air plenum to be inserted in the radiator to discharge the hot gases in the augmenter. The air plenum has multiple grids to take fresh cooling air from the topmost part of the fuselage (see Figure-5).

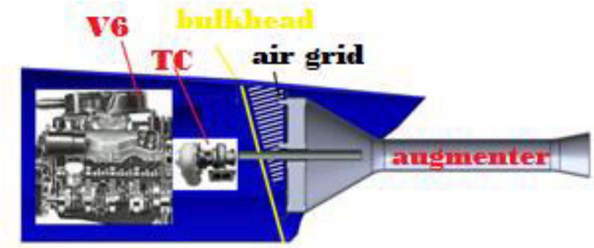

Figure-5. Schematic of engine installation. V6 is the engine, TC the turbocharger.

CFD simulations were done with Solid Works Flow Simulation [1-3]. The relative position of the radiator, the length of the mixing duct and the diffuser were varied to test the augmenter performance. Exhaust gas temperature and velocity were varied to simulate operations from 30% to full load. The worst condition is full load. In addition, the relative position of the exhaust pipe and the augmenter was varied. The results showed that the pipe positioned on the start of the mixing (straight) section is by far the best position. The worst environmental condition for cooling is ISA +25, 1,000m (critical altitude) and 100% humidity (minimum air density)] 19-23].

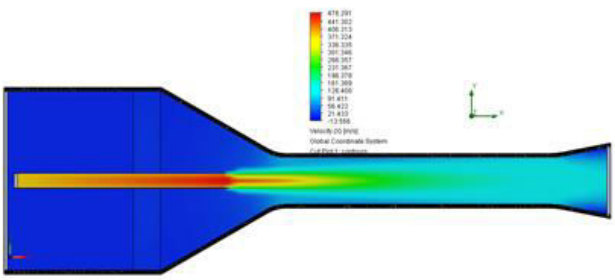

Figure-6. CFD simulation with the exhaust pipe advanced from the radiator of 100 mm (from the radiator).

VOL. 13, NO. 16, AUGUST 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

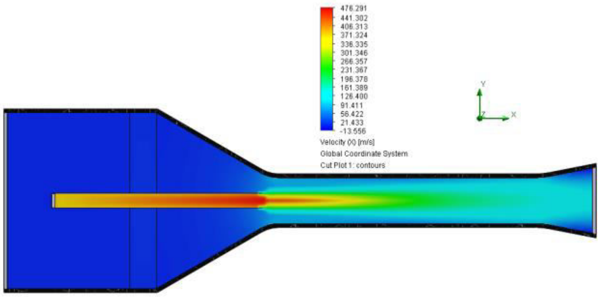

Figure-7. Exhaust pipe positioned at the beginning of the mixing (straight) section (best position).

The simulations of Figures 8, 9 and 10 show that the length of the mixing duct is crucial for the flow expansion and even if the last one simulation show the largest flow speed it is not the optimum because the gas flow is not fully expanded.

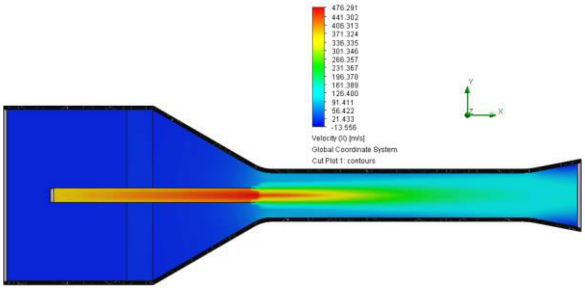

Figure-8. CFD simulation with mixing duct of 0.72 m.

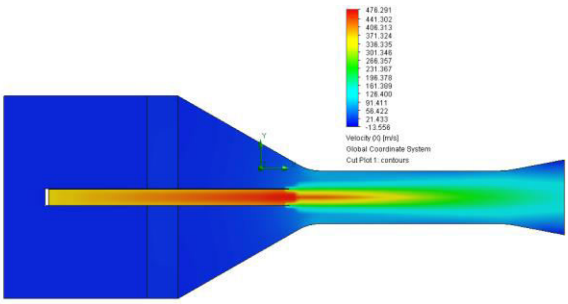

Figure-9. CFD simulation with mixing duct of 0.446 m (optimum).

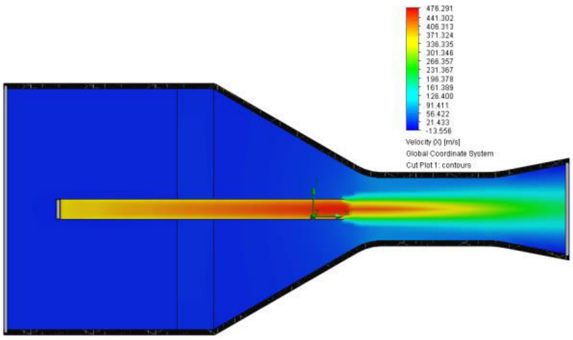

Figure-10. CFD simulation with mixing duct of 0.2m.

The solution with the mixing duct with a length of 446mm is therefore the best solution, even if the best installed duct length is complicated by the interaction with the air flow field of the helicopter rotor. An increase in the mixing length is not cost effective (Figure-11).

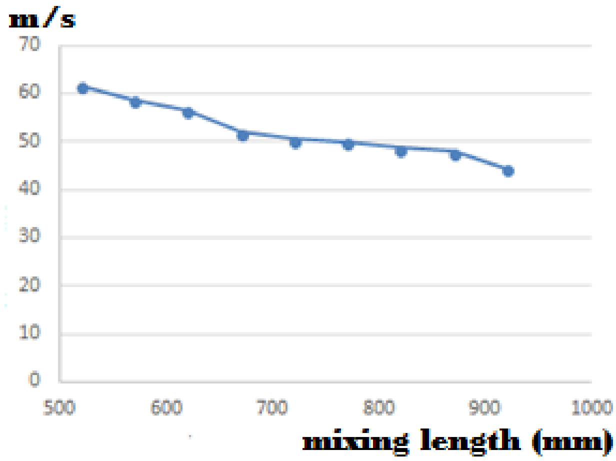

Figure-11. Mixing length vs. average speed at augmenter exit.

The diffuser is important for best augmenter/ejector performance (Figure-12).

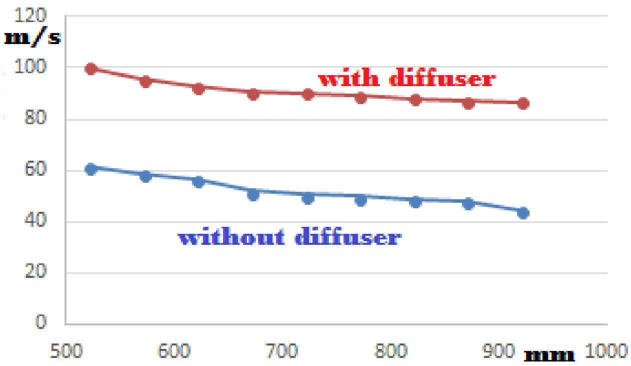

Figure-12. Augmenter performance with (red) and without diffuser (blue) for various mixing duct length.

CONCLUSIONS

CRDID (Common Rail Diesel Engine) main advantage is the extremely high efficiency (up to 52%), the enormous amount of hours run and the flight readiness. Moreover, diesel fuel is safer than jet fuel and it is available everywhere. Therefore, refuelling flights to airports or dedicated supply lines can be avoided. However, diesel engines are generally heavier than turboshafts and require an additional cooling system. This requirement is particularly stringent during near stationary operations of the helicopter. In fact, if fans are used for the cooling system, the available power is reduced with an increased penalty weight for the installation. For this reason the ejector exhaust system can be successfully used in CRDID powered helicopters. A feasibility study of the cooling system for a CRDID (Common Rail Diesel

Engine) on a common light helicopter (Eurocopter EC 120-class) is introduced. Optimization of this system is performed. The total mass available for the CRDID is evaluated starting from fuel consumption and helicopter data. A derivative of an automotive engine is proposed for the turboshaft replacement. The result is that the ejector exhaust (augmenter) is extremely effective. From the initial design it is convenient to reduce the mixing duct length. Diffuser is strictly necessary to preserve efficiency. The final optimization should be performed with the velocity field induced by the main rotor [24-26].

REFERENCES

[1] L. Piancastelli, L. Frizziero, S. Marcoppido, E. Pezzuti. 2012. Methodology to evaluate aircraft piston engine durability edizioni ETS. International Journal of Heat & Technology. ISSN 0392-8764, 30(1): 89-92, Bologna.

[2] L. Piancastelli, L. Frizziero, G. Donnici. 2015. The Meredith ramjet: An efficient way to recover the heat wasted in piston engine cooling. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 10(12): 5327-5333, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[3] L. Piancastelli, A. Gatti, L. Frizziero, L. Ragazzi, M. Cremonini. 2015. CFD analysis of the Zimmerman's V173 stol aircraft. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, Volume 10, Issue 18, pp. 8063-8070, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[4] 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

[5] 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

[6] 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.

[7] 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

[8] P.P. Valentini, E. Pezzuti E. Computer-aided tolerance allocation of compliant ortho-planar spring mechanism. Int. Journal Of computer applications in technology, 53: 369-374, ISSN: 0952-8091, doi: 10.1504/IJCAT.2016.076801

[9] E. Pezzuti, PP. Valentini PP. Accuracy in fingertip tracking using Leap Motion Controller for interactive virtual applications. Int. Jour. On interactive design and manufacturing, p. 1-10, ISSN: 1955-2513, doi: 10.1007/s12008-016-0339-y

[10] E.Pezzuti E, PP. Valentini P. Design and interactive simulation of cross-axis compliant pivot using dynamic spline. Int. Jour. On interactive design and manufacturing, 7: 261-269, ISSN: 1955-2513, doi: 10.1007/s12008-012-0180-x

[11] L. Piancastelli, S. Cassani. 2017. Maximum peak pressure evaluation of an automotive common rail diesel piston engine head. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(1): 212-218, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[12] S. Cassani. 2017. Airplane Design: The Superiority Of Fsw Aluminum-Alloy Pure Monocoque Over Cfrp "Black" Constructions. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 377-361, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[13] L. Piancastelli, S. Cassani. 2017. Power Speed Reduction Units For General Aviation Part 2: General Design, Optimum Bearing Selection For Propeller Driven Aircrafts With Piston Engines. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 544-550, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[14] L. Piancastelli, S. Cassani. 2017. Power Speed Reduction Units For General Aviation Part 5: Housing/Casing Optimized Design For Propeller-Driven Aircrafts And Helicopters. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(2): 602-608, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[15] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviation part 3: simplified gear design piston-powered, propeller-driven general aviation aircrafts. Asian Research Publishing Network (ARPN). Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(3): 870-874, EBSCO

Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[16] L. Piancastelli, S. Cassani. 2017. Power speed reduction units for general aviationpart 4: simplified gear design for piston-powered, propeller-driven “heavy duty aircrafts and helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(5): 1533-1539, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[17] L. Piancastelli, S. Migliano, S. Cassani. 2017. An extremely compact, high torque continuously variable power transmission for large hybrid terrain vehicles. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(6): 1796-1800, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[18] L. Piancastelli, S. Cassani. 2017. Mapping optimization for partial loads of common rail diesel piston engines. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2223-2229, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[19] L. Piancastelli, S. Cassani. 2017. High Altitude Operations With Piston Engines Power Plant Design Optimization Part V: Nozzle Design And Ramjet General Considerations. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(7): 2242-2247, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[20] L. Piancastelli, R. V. Clarke, S. Cassani. 2017. Diffuser augmentedrun the river and tidal picohydropower generation system. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(8): 2678-2688, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[21] L. Piancastelli, M. Gardella, S. Cassani. 2017. Cooling system optimization for light diesel helicopters. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(9): 2803-2808, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[22] L. Piancastelli, S. Cassani. 2017. Study and optimization of a contra-rotating propeller hub for convertiplanes. Part 1: vto and hovering. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(11): 3451-3457, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[23] L. Piancastelli, S. Cassani. 2017. On the conversion of automotive engines for general aviation. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(13): 4196-4203, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[24] L. Piancastelli, S. Cassani. 2017. Convertiplane Cruise Performance with Contra-Rotating Propeller. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(19): 5554-5559, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[25] L. Piancastelli, S. Cassani. 2017. Tribological Problem Solving In Medium Heavy Duty Marine Diesel Engine Part 1: Journal Bearings. Journal of Engineering and Applied Sciences. ISSN 1819-6608, 12(22): 6533-6541, EBSCO Publishing, 10 Estes Street, P.O. Box 682, Ipswich, MA 01938, USA.

[26] A. Ceruti, T. Bombardi, T., and L. Piancastell. 2016. Visual Flight Rules Pilots Into Instrumental Meteorological Conditions: a Proposal for a Mobile Application to Increase In-flight Survivability. International Review of Aerospace Engineering (IREASE). 9(5).

Symbols

Symbol	Description	Unit
$P_{turboshaft}$	Turboshaft max power	HP
$f_{radiator}$	Radiator volumetric factor	mm^3/HP
$V_{radiator}$	Radiator volume	mm^3
w	Radiator thickness	mm
$\rho_{exhaust}$	Exhaust gas density	kg/ mm^3
$T_{exhaust}$	Exhaust gas Temperature	K
R	Air specific gas constant	J/(kg K)
$Q_{m\_exhaust}$	Exhaust mass flow	kg/s
$v_{exhaust}$	Exhaust gas velocity	m/s
$f_{straight}$	Area ratio radiator/mixing duct	-