International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:8, No:5, 2014

Optimal Diesel Engine Technology Analysis Matching the Platform of the Helicopter

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Abstract**—**In the paper environmental impact analysis the optimal Diesel engine for a light helicopter was performed. The paper consist an answer to the question of what the optimal Diesel engine for a light helicopter is, taking into consideration its expected performance and design capacity. The use of turbocharged engine with self-ignition and an electronic control system can substantially reduce the negative impact on the environment by decreasing toxic substance emission, fuel consumption and therefore carbon dioxide emission. In order to establish the environmental benefits of the diesel engine technologies, mathematical models were created, providing additional insight on the environmental impact and performance of a classic turboshaft and an advanced diesel engine light helicopter, incorporating technology developments.

Keywords**—**Diesel engine, helicopter, simulation, environmental impact.

I. INTRODUCTION

THE turboshaft engine provides more power to the helicopter with a lower weight penalty than piston engines, with their heavy engine blocks and auxiliary components. The improvements in fuels and turboshaft engines during the first half of the 20th century were a critical factor in helicopter development. The availability of lightweight turboshaft engines in the second half of the 20th century led to the development of higher-performance helicopters. Turboshaft engines stayed the preferred powerplant for helicopters. In the middle of the 20th century turboshaft engines gradually substituted reciprocating engines having fundamental advantages in terms of engine weight, complexity, reliability, and fuel commonality.

However, turbine engines used in helicopters lose efficiency rapidly as the altitude increases. Because of the power loss at altitude, helicopter operators that often fly in the mountains use helicopters with more powerful engines to compensate it. In most helicopters turboshaft engine incorporates a simple gearbox turning an output shaft at about 6000rpm. The main rotor gearbox of the helicopter reduces this speed to about 350-450rpm, so that a massive construction is needed downstream. Turboshaft engines tend to be expensive and are characterized by both high fuel consumption and carbon dioxide emissions [1], [3].

Higher engine price and poor fuel efficiency for small turbines are considered essential for the light helicopter class. The soaring oil price, high operating costs and growing public concern for environment protection are provided to reduce the environmental impact of rotorcraft operation. There is a substantial potential for pollutant emission and fuel consumption to be reduced by powering light single-engine helicopters with advanced reciprocating engines instead of conventional small turboshaft engines [5], [6].

Ecological reasons have forced the automotive engine technology to adapt to reduced emissions. Automotive engine emissions have become ecology friendly. Automotive industry has developed advanced reciprocating engines, in particular diesel engines for automobiles and trucks featuring low fuel consumption and gas emission. High compression ratio with turbocharging and intercooling, high pressure direct injection with a common rail, pilot injection with a digital control unit are essential to the technologies implemented to obtain such excellent performance improvements. For example, an electronically controlled, common-rail fuel system is used in the GM 4.5L diesel V8′s engine and enables injecting fuel five times per combustion, reducing noise and emissions while enhancing fuel economy.

The next positive repercussion of diesel engine installation on global helicopter design, in comparison to the turboshaft engine, is the interest in lower output speed, which reduces the helicopter MGB (Main Gear Box) reduction ratio, enabling a simpler design and better reliability. The weight saving resulting from the probable elimination of one reduction stage in the gear box in an optimized design will partially compensate the exceedance of diesel engine weight.

II. AIRCRAFT DIESEL ENGINE PERFORMANCE REQUIREMENTS

The indispensable diesel engine performance for an ideal helicopter platform has been established to satisfy the requirements. The maximum power as a function of height is given below (Fig. 1).

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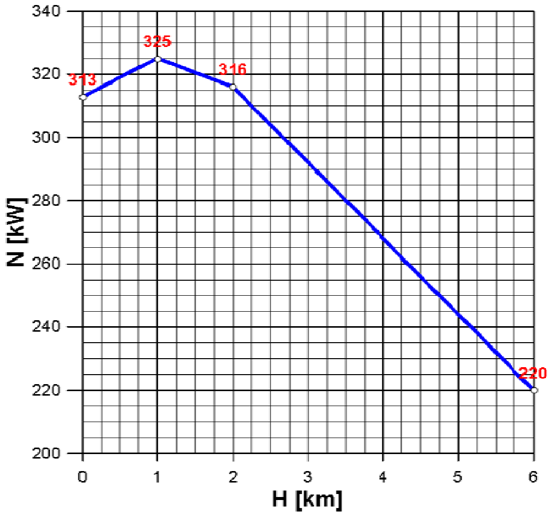

Fig. 1 Essential maximum power vs. altitude

The following assumptions are adopted to develop these characteristics:

1) Static hovering ceiling with ground effect @ 1800 kg and ISA condition no lower than: 2000 m Vmax at Take-Off Power, Sea Level no lower than: 220 km/h,
2) Climbing at Take-Off Power, Sea Level greater than 6 m/s,
3) Minimum range at Sea Level including a reserve of 5%: 750 km,
4) Cruising speed at Sea Level no lower than: 210 km/h,
5) Range with reserve for 30 minutes of flight: 700 km,
6) Flight endurance at best endurance speed no lower than 5 h,
7) Hovering at the height of 1000 m without ground effect, at a helicopter weight of 1800 kg @ ISA condition.

The power characteristics in Fig. 1 allow us to achieve the following qualities:

1) Hovering ceiling with no ground effect H> = 1000 m with a take-off mass m = 1800kg under ISA conditions,
2) Hovering ceiling with ground effect H> = 2000 m with a take-off mass m = 1800 kg under ISA conditions,
3) Maximum speed at a height of H = 0 m with a take-off mass m = 1800 kg at a take-off power, V> = 220 km/h under ISA conditions.

If a continuous power at 90% of take-off mass is adopted, the following requirements can be satisfied:

1) A practical limit with the minimum take-off mass under conditions from -40 °C to ISA +35 °C is not lower than 6000 m,
2) A cruising speed at a height of H = 0m with a take-off mass m = 1800kg, V> = 210km/h under ISA conditions.

The engine developed meets the requirements for specific fuel consumption (SFC) which must not exceed 190 g/kW/h (at an output power level ranging from 50 to 100% of max take-off power).

TABLE I
General Engine Parameters

No.	Parameter	Value
1	Configuration	4 stroke, V90°
2	Take-Off Power	330 kW
3	RPM	3500
4	Fuel comp. at T.O.	185 g/kWh
5	Displacement	4400 cm^3
6	Number of Cylinders	8
7	Number of Valves per Cylinder	4
8	Bore	87 mm
9	Stroke	93 mm
10	Compression Ratio	16
11	BMEP at T.O.	2.75MPa
12	Average piston speed	10,84 m/s

III. General Engine Configuration

The following section shows the basic parameters of the engine structure. There is the result of analysis of the latest design solutions available in diesel engines and design calculations. The optimal configuration was chosen four stroke, eight-cylinder engine in the V system. The resulting performance is consistent with the requirements contained in the call for papers. Overall efficiency of the engine is 44%.

Due to the calculations it was necessary to define engine turbocharging system. Based on available construction solutions in the turbochargers market, turbocharger without the variable geometry was decided to use. Because of the large value of obtained BMEP (max 2.75 MPa), which was results from the TOP and SFC requirements, it was necessary to use pistons made of steel. The crankshaft is designed so that it can be made with forging. Thanks to this and the use of channels in cranks, the weight of 18 kg and the required strength was achieved. The following figure presents the engine design and crankshaft system components design and Table I presents the general engine parameters.

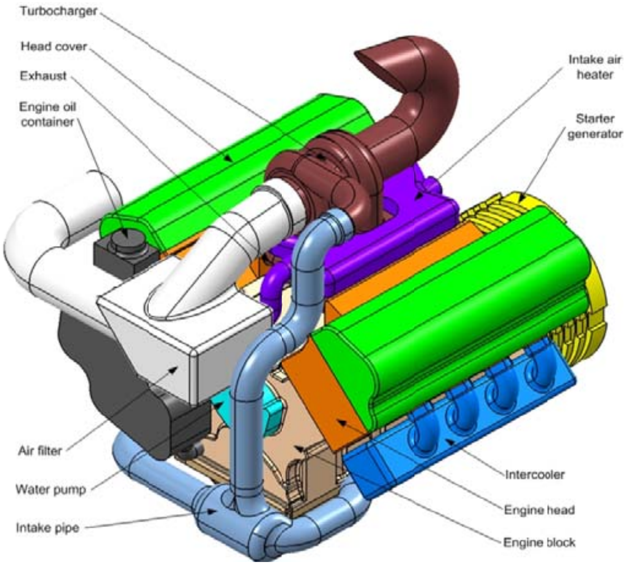

Fig. 2 Engine design

The AVL Boost RT software was used to analyze the parameters of the engine operation in dynamical states. BOOST RT is a real-time capable, system-level, engine simulation tool dedicated to the investigation of transient operating conditions offline in desktop applications and online in HiL environments BOOST RT is the consequent next step to further integrate the well-established BOOST 1D [2].

To reflect the Diesel engine operation in a light helicopter one had to construct a simulation model of this engine based on the same assumptions as used in previous reports. To achieve this, it was decided to create a model containing such compound elements as:

1) The external surroundings model for the intake and outlet defining, among others things, pressure and temperature,
2) The turbocharger model,
3) The inlet and outlet valve models defining, among others things, their dimensions,
4) The model of exchanging heat with the walls of the cylinder,
5) The fuel system model defining, among others things, the temperature and type of fuel,
6) The cylinder model defining, among others things, the combustion model and dimensions of cylinder,
7) The engine model defining, among others things, the number of cylinders, frictional resistances, the engine type and the speed of idle running,
8) The main gearbox model defining, among others things, the gear ratio and efficiency,
9) The torque receiver model (the main rotor).

It was necessary to add that all the conduits through which the charge air is delivered to the cylinder were also defined in relation to their volume, and all the stiff elements of mechanical joints were defined by their inertia in relation to the rotation axis. In the model, also the moment of inertia of the entire main rotor unit of the light helicopter was taken into account.

IV. SIMULATION RESULTS

To compare the emission of toxic compounds of exhaust gases and the fuel consumption of the Diesel engine for turbine engines, there were used the statistical data drawn from the publication [4]. In this document, there is approximate data concerning the fuel consumption and the emission of toxic compounds of exhaust gases in helicopters which are in common use.

For the comparison, there were selected a few models of helicopters characterizing a similar power of the engines to 330 kW. Table II shows a comparison of the selected helicopters along with the engines. The first two rows present the case of the Diesel engine in the light helicopter which is related to the simulation, upper line is in the case of supplying with the original Diesel fuel, second line refers to the supply with B100 biofuel. The next eight rows the selected helicopters with single turbine engines. The last two rows refer to the helicopters equipped in piston engines. Next columns show the comparison of the fuel consumption. Table III shows a comparison of emission of toxic compounds of exhaust gases for a one-hour operation of the engines with the power sufficient for the flight with so-called Cruise Power.. For the designed engine it is 80% of its maximum power, for turbine engines 80% was adopted, whereas for different piston engines 90% (according to the publication).

On the basis of the data from the above tables, data were compared in terms of the emission of toxic compounds of the exhaust gases and the fuel consumption. On Fig. 3, there are presented the power ratios of particular examined parameters in particular maneuvers for three scenarios when the engine was supplied with the Diesel fuel, or with B100 fuel. The next figures display the average fuel consumption and average emission of toxic compounds of exhaust gases in all flight scenarios when the engine was supplied with both fuels. It should be noted that the flight scenarios assume that there may be various duration times of the helicopter flight.

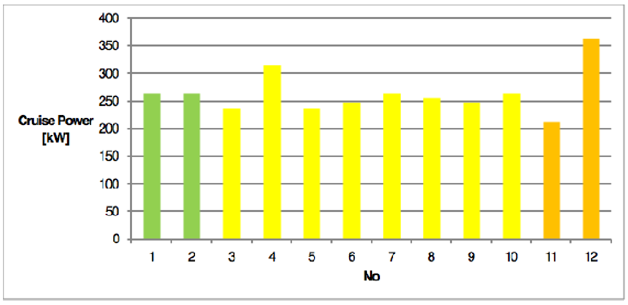

Fig. 3 Cruise Power for different helicopters engines

TABLE II
THE COMPARISON OF THE FUEL CONSUMPTION FOR THE DEVELOPED DIESEL ENGINE AND OTHER TURBINE ENGINES

Helicopter	Engine	Max Power [kW]	Cruisepower [kW]	Fuel consumption [kg/kWh]
IdealHelicopter	Diesel engine - Diesel fuel	330.0	264.0	0.184
IdealHelicopter	Diesel engine - B100 fuel	330.0	264.0	0.270
ALOUETTE II	ARTOUSTE IIC5	295.7	236.5	0.465
SA316B ALOUETTE III	ARTOUSTE IIIB	394.2	315.4	0.428
BELL 206B	DDA250-C20	294.2	235.4	0.463
BELL 206B	DDA250-C20B	308.9	247.1	0.409
BELL 206B	DDA250-C20R	331.0	264.8	0.397
EC 120	ARRIUS 2F	317.7	254.2	0.448
ENSTROM 480	DDA250-C20W	308.9	247.1	0.453
MD 500N	DDA250-C20R	331.0	264.8	0.442
HILLER UH-12A	VO-540-1B	235.4	211.8	0.387
BRISTOL SYCAMORE	ALVIS LEONIDES	404.5	364.1	0.761

TABLE III
THE COMPARISON OF TOXIC COMPOUNDS FOR THE DEVELOPED DIESEL ENGINE AND OTHER TURBINE ENGINES

Helicopter	Engine	NOx [g/kWh]	CO [g/kWh]	Soot [g/kWh]	CO_2 [kg/kWh]
Ideal Helicopter	Diesel engine - Diesel fuel	4.336	0.177	0.00035	0.580
Ideal Helicopter	Diesel engine - B100 fuel	0.709	0.205	0.00117	0.751
ALOUETTE II	ARTOUSTE IIC5	2.579	4.312	0.080	1.464
SA316B ALOUETTE III	ARTOUSTE IIIB	2.885	2.759	0.086	1.348
BELL 206B	DDA250-C20	2.592	4.376	0.081	1.458
BELL 206B	DDA250-C20B	2.347	3.642	0.073	1.287
BELL 206B	DDA250-C20R	2.379	3.248	0.072	1.249
EC 120	ARRIUS 2F	2.636	3.855	0.083	1.412
ENSTROM 480	DDA250-C20W	2.590	4.046	0.081	1.427
MD 500N	DDA250-C20R	2.644	3.626	0.083	1.391
HILLER UH-12A	VO-540-1B	0.755	0.389	0.028	1.219
BRISTOL SYCAMORE	ALVIS LEONIDES	1.511	0.760	0.052	2.395

The change of supply with the Diesel fuel by B100 fuel resulted mainly in the increase of the fuel consumption (Fig. 4) which was caused by a lower energetic value of the substitute fuel. Another side effect of the application of B100 biofuel was the increase of CO emission (Fig. 6), Soot emission (Fig. 7) and CO_2 (Fig. 8). A positive effect of the application of B100 biofuel is a multiple reduction of NO_x (Fig. 5).

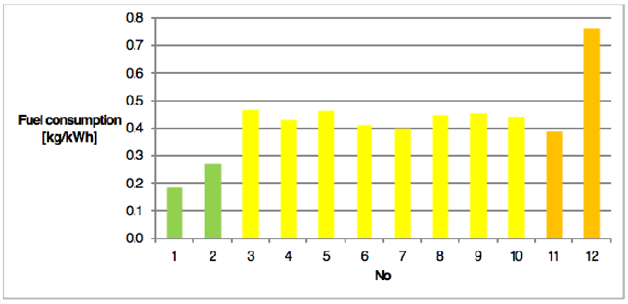

Fig. 4 Fuel Consumption for different helicopters engines

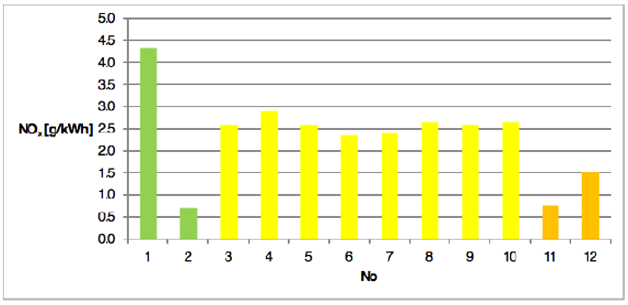

Fig. 5 NO_x emission for different helicopters engines

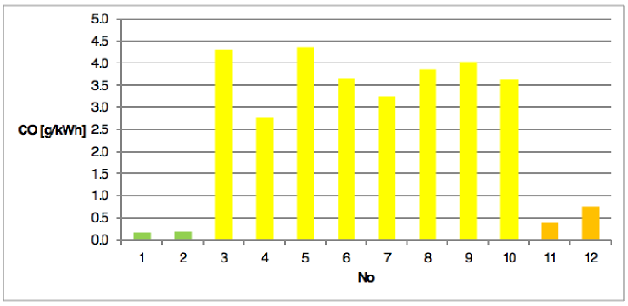

Fig. 6 CO emission for different helicopters engines

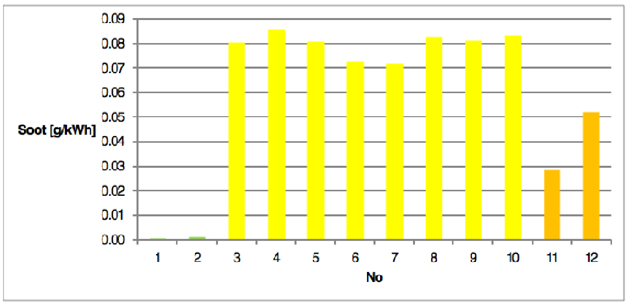

Fig. 7 Soot emission for different helicopters engines

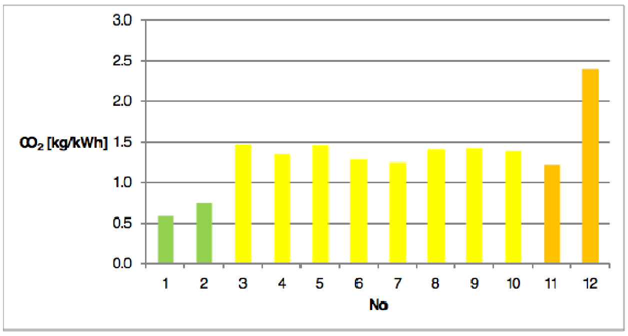

Fig. 8 CO_2 emission for different helicopters engines

V. CONCLUSION

The environmental benefits of the diesel engine technologies were established by applying given mathematical models. Some parts of the models were used to determine the effect of the engine on operating costs. The results were then compared with the corresponding data for current production type turboshaft engine powered light rotorcraft. With an increasing focus on reducing fossil fuel use to minimize climate change authors performed calculations using not only usual diesel fuel, but also bio-diesel fuel. The calculation results demonstrated a significant reduction in fuel consumption and reduction of the carbon compounds emission.

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