LIGHT HELICOPTER EQUIPPED WITH HIGH-COMPRESSION ENGINE

Alexandre Gierczynski, alexandre.gierczynski@airbus.com,
Airbus Helicopters, Marignane (France)

Abstract

In the frame of GRC4, part of Cleansky's Green Rotorcraft ITD (Integrated Technology Demonstrator), Airbus Helicopters has lead the development of a flying Demonstrator based on H120 serial helicopter and fitted with a brand new designed High-Compression Engine (HCE = Reciprocating engine using Kerosene). For this Research project, Airbus Helicopters teamed with Partners selected via a Call for Proposal, successful in February 2011, and organized in the Consortium HIPE 440, made of TEOS Powertrain Engineering, France, and AustroEngine GmbH, Austria.

In the powerclass related to H120 engines (300 to 400kW), the main advantages of HCE compared to turboshaft are:

- Lower Specific Fuel Consumption (minimum 30%, up to 50% depending on mission),
- Lower CO_2 emission at same level as Specific Fuel Consumption reduction,
- Higher performance in hot/high conditions thanks to the superchargers. Power is kept constant up to higher altitude and/or higher ambient temperature,
- Lower operating cost (fuel, maintenance and overhaul).

The only drawback is the additional mass. Therefore the installed engine mass-to-power ratio has to remain below 0.8kg/kW in order to reach similar or better performance than H/C equipped with turboshaft.

After engine tests started in March 2013 – less than 1.5 year after the design start – the Ground tests have been completed in March 2015, and Maiden Flight occurred on November 6th 2015. Flight tests are planned until July 2016.

This paper will explain shortly why Airbus Helicopters needed a brand new engine for this Demonstrator and give an overview of the achievements during Flight tests up to OAT of 30°C (ISA+15°C): power output, fuel consumption, engine mass-to-power ratio, rotor speed control, cooling system, torque oscillations and engine movements.

1. SYMBOLS AND ABBREVIATIONS

ACARE	Advisory Council for Aeronautics Research in Europe
AH	Airbus Helicopters
CSJU	CleanSky Joint-Undertaking
FADEC	Full Authority Digital Engine Control
FP	Frame Programme
GAM	Grant Agreement for Members
GRC	Green RotorCraft
H/C	Helicopter
HCE	High-Compression Engine
ITD	Integrated Technology Demonstrator
kg	kilogram
kW	kilowatt
MGB	Main Gear Box
Nm	Newton-meter
Nr	Rotor speed (rpm)
OAT	Outside Ambient Temperature
PID	Proportional-Integral-Derivative control
rpm	Revolution per minute
SEL	Single Engine Light helicopter
SFC	Specific Fuel Consumption
TBO	Time Between Overhaul
TE	Technology Evaluator

2. INTRODUCTION

2.1. Project Overview

In the frame of GRC4, part of Cleansky's Green Rotorcraft ITD (Integrated Technology Demonstrator), Airbus Helicopters has lead the development of a flying Demonstrator based on H120 serial helicopter and fitted with a brand new designed High-Compression Engine (HCE = Reciprocating engine using Kerosene). For this Research project, Airbus Helicopters teamed with Partners selected via a Call for Proposal, successful in February 2011, and organized in the Consortium HIPE 440, made of TEOS Powertrain Engineering, France, and AustroEngine GmbH, Austria.

The Cleansky environmental targets, in line with ACARE 2020, are to reduce Specific Fuel Consumption (SFC) by 30%, CO_2 emission by 40% and NOx by 53%. These targets shall be achieved via improvements both on the Aircraft and the Engine.

In the frame of GRC4, the Aircraft remained the same (serial H120, modified only to comply with the new engine) whereas the Engine was completely new. Furthermore, because of measurement limitations, only SFC and CO_2 improvements could be evaluated.

2.2. Testing logic

Because of the innovations brought by this new designed HCE (based on technologies known and largely used in the automotive industry, but much less in the aeronautical world), a 3-steps testing approach was used in order to reach the Demonstrator Flight tests.

First step consisted of tests on engine bench. They started in March 2013, less than 1.5 year after the design start of this new engine. The ultimate goal of this test is to run an endurance cycle required for the engine flightworthiness.

Second step was completed on Iron bird from November 2013 to mid-February 2014 at Airbus Helicopters in Marignane, France.

The objective of the Iron bird was to validate following technical challenges related to the installation of this new powerplant:

- Damp piston engine torque oscillations and engine vibration,
- Cool engine during Hover,
- Master clutching sequence,
- Control rotor speed (low engine inertia vs high rotor inertia).

Third step was to Ground- and Flight-test the technology with the H120 Demonstrator also at AH Marignane. The ground tests were completed in March 2015, the Maiden Flight occurred on November 6th 2015. Flight tests are planned until July 2016. They will validate the installation of the HCE up to Technology Readiness Level 6 (TRL 6).

An additional step within Cleansky GRC ITD is brought by GRC7 and the Technology Evaluator giving us, based on European models, the helicopter performance comparison between Single Engine Light Helicopters powered either by turboshaft or by High-Compression Engines.

3. NEED FOR A BRAND NEW ENGINE

In the powerclass related to H120 engines (300 to 400kW), the main advantages of HCE compared to turboshaft are:

- Lower Specific Fuel Consumption (minimum 30%, up to 50% depending on mission),
- Lower CO_2 emission in the same ratio than Specific Fuel Consumption reduction,
- Higher performance in hot/high conditions thanks to the superchargers. Power is kept constant up to higher altitude and/or higher ambient temperature,
- Lower operating cost (fuel, maintenance and overhaul).

The only drawback is the additional mass.

In order to limit the mass penalty and reach a good level of Helicopter performance, AH required a complete installed Powerpack (including the Core engine and all necessary accessories such as cooling system, FADEC, clutch…) with a mass-to-power ratio of less than 0.8kg/kW. You can see on Figure 1 a benchmark including existing aeronautical and automotive piston engines, racing piston engines and the H120 turboshaft. The goal is to achieve a mass-to-power ratio not exceeding twice the turboshaft one but halved compared to existing piston engines.

Finally, in order to reach a reliability level comparable to other aeronautical reciprocating engines (TBO around 2000h), the main technologies applied on the engine design come from advanced racing self-ignition automotive engines (see description here below) used at lower specific power.

The specifically developed Core engine has following key characteristics:

- 8 cylinders in V, 4.6L capacity, 90° angle
- Fueled with Kerosene (Jet-A)
- Fully machined aluminium blocks (cylinder head, crankcase, timing drive casing…)
- Fully machined titanium conrod
- Steel pistons and liners
- Common rail direct injection (1800bar)
- Supercharged (1 turbo per cylinder bank)
- Liquid cooled
- FADEC controlled
- Starter and generator

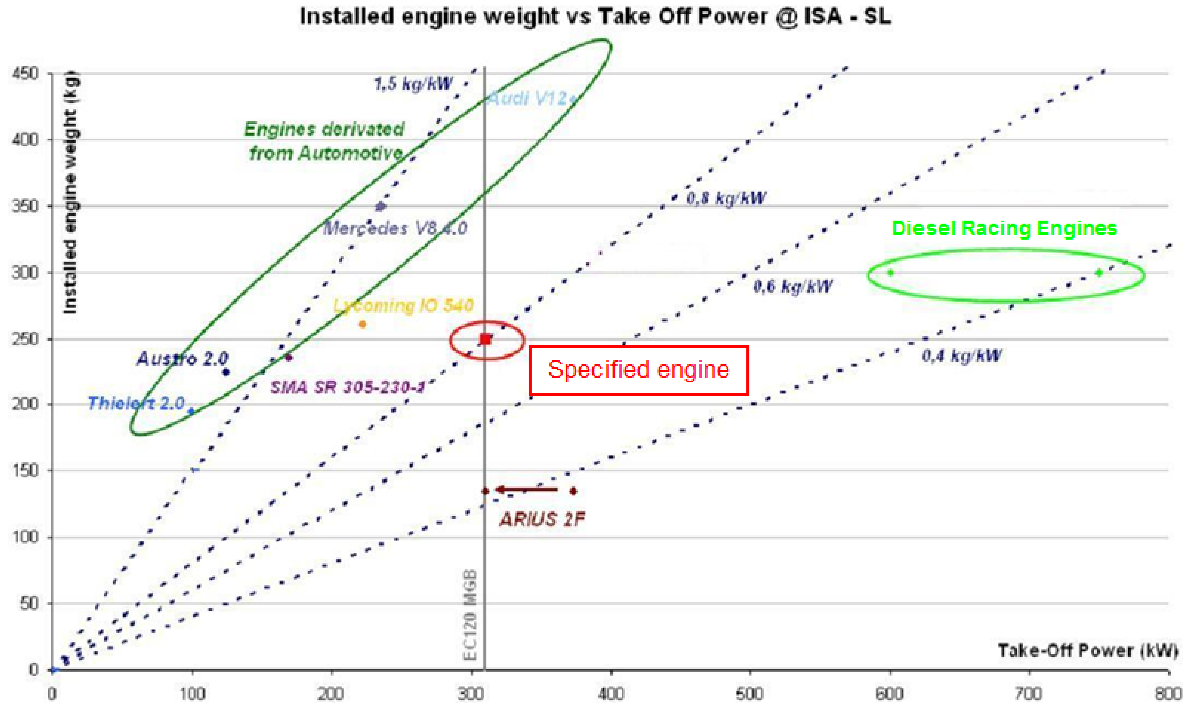

Figure 1: Installed mass-to-power ratio benchmark

4. DEMONSTRATOR ACHIEVEMENTS

4.1. Powerpack results

4.1.1. Test schedule

The Powerpack design was started from scratch in June 2011 by the two Partners TEOS Powertrain Engineering and AustroEngine.

Following the design phase, the testing phase started in March 2013 with the first engine rotation on engine bench. This first step consisted of calibration and debug activities until May 2014. During this step, we experienced some teething issues on the engine, normal for a brand new engine, delaying the calibration work.

Once the calibration work was finished, a first endurance was completed in September 2014 (Core engine configuration only, see §1.1.1). A second endurance (Powerpack configuration, see §1.1.1) ran then until February 2015.

The final endurance (also in Powerpack configuration) enabling the engine airworthiness was completed in June 2015.

4.1.2. Power output

The engine was calibrated on engine bench up to 330kW. One can see on Figure 2 the power delivered by the engine during the Maiden Flight. To hover, 280kW are sufficient for the aircraft take-off weight

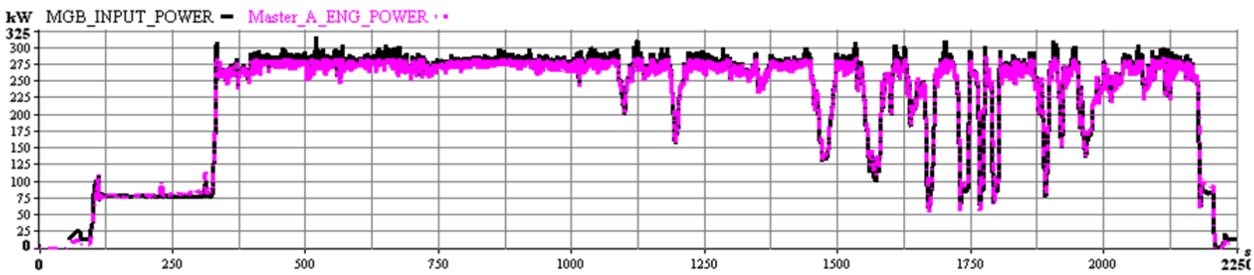

Figure 2: Power output during Maiden Flight

4.1.3. Engine Mass-to-Power ratio

As already explained in §3, the maximum allowed mass-to-power ratio of the installed engine for a helicopter use is 0.8kg/kW. This is a tough task for the engine manufacturer as engine reliability and recurring cost cannot be compromised.

The developed engine, called Powerpack, is composed of:

- A Core engine as described in §3,
- A Multiplier which is a gearbox enabling to have the right rotational speed at MGB inlet and includes a clutch necessary to start the engine,
- A cooling system necessary to evacuate the heat released by the piston engine (roughly 15 times higher than a turboshaft, enabling the better efficiency of piston engines, see Figure 3). It is made of 5 heat exchangers (2 for coolant, 2 for supercharged air and 1 for oil) and a fan sucking air through the heat exchangers in all operating conditions especially hover.

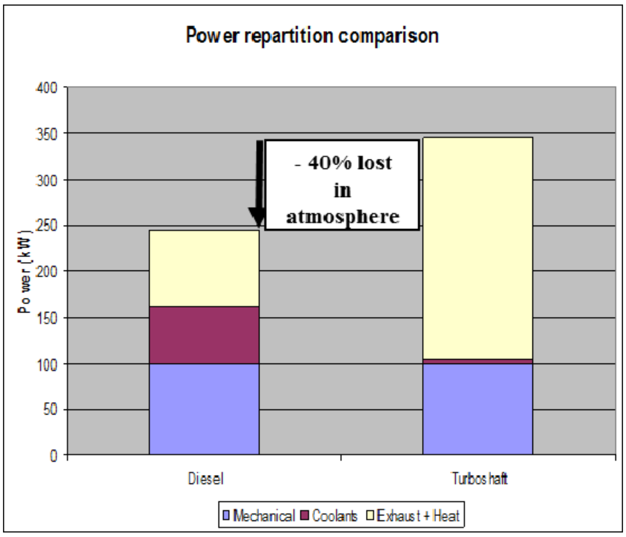

Figure 3: Heat release comparison

The total mass of the Core engine is 197kg. Including the Multiplier and the Cooling system, the final mass-to-power ratio of the complete Powerpack is reaching the 0.8kg/kW target.

4.1.4. Fuel consumption

The main goal of the project is to reduce fuel consumption by 30% minimum and up to 50% depending on duty cycle, compared to the equivalent turboshaft.

Figure 4 and Table 1 present the fuel consumption measured during the second flight, in comparison to the equivalent fuel consumption of the Arrius 2F installed on the serial H120. One can see that the fuel consumption is reduced in average by 42%, with a minimum of 29% above 300kw, and a maximum of 58% below 100kW.

These values show that the objective is fully reached.

Power (kW)	Duration (%)	Fuel consumption (kg)		
		HCE	ARRIUS	delta
0 à 50	29,6%	2,07	4,88	-57,6%
50 à 100	11,0%	2,04	4,88	-58,3%
100 à 150	2,9%	0,72	1,53	-52,5%
150 à 200	5,6%	1,88	3,44	-45,3%
200 à 250	32,7%	13,83	22,13	-37,5%
250 à 300	18,4%	8,60	12,98	-33,7%
300+	0,02%	0,008	0,011	-28,6%
TOTAL	100,0%	29,14	49,83	-41,5%

Table 1: Fuel Consumption comparison during 2nd Flight

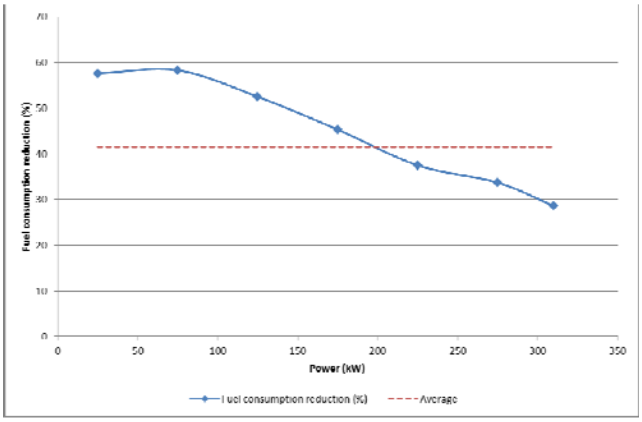

Figure 4: SFC comparison between HCE and turboshaft

An additional 4 to 8% SFC reduction could be achieved by improving the engine calibration, the injection system and/or the combustion chamber design. These optimizations will be worked out during the serial phase.

A separate study made by the Cleansky Technology Evaluator (with the support of GRC7) has shown the benefit of HCE on Single Engine Light Helicopter on a dedicated duty cycle. The results are presented by J. Stevens from NLR on another ERF2016 session [3]. An extract of these results is presented on Figure 5. For the given mission, HCE technology enables to save up to 68 % fuel consumption!

Case	Δ Fuel (%)	Δ CO2 (%)	Δ NOx (%)
1	0	0	0
2	-1.6	-1.6	-2.7
3	-9.9	-9.9	-16.6
4	-0.1	-0.1	-0.1
5	-9.9	-9.9	-54.2
6	-21.1	-21.1	-70.0
7	-68.0	-68.1	-76.0

Figure 5: TE comparison between HCE and SEL

Note: Case 1 = 2000 reference SEL,
Case 6 = 2020 conceptual SEL, with “business as usual” and Cleansky improvements,
Case 7 = Today’s HCE equipped light H/C.

4.2. Helicopter results

4.2.1. Test schedule

Following the engine bench tests, the Iron bird campaign took place at Airbus Helicopters premises in Marignane from November 2013 to February 2014

The main technical topics addressed during this test campaign were the following:

- Rotor speed control,
- Cooling system sizing,
- Clutch sequence,
- Engine vibration and movements,
- Torque oscillations reduction,

The positive results allowed us to pursue towards the Flight Demonstrator. Some of the results obtained during Flight tests will be presented in the next paragraphs.

After preparation of the Demonstrator (using the experience from the Iron bird airframe) and preliminary endurance tests of the Powerpack, the Ground tests started on February 10th 2015 to end March 30th 2015.

These Ground runs done by the Flight test crew enabled us to validate the avionics and all the procedures associated to this new installation. And of course, the Iron bird results were confirmed.

Following the successful Ground runs, the Maiden Flight occurred on November 6th 2015 and until mid of July 2016, the test crew was able to validate the installation up to OAT = 30°C.

Figure 6: H120 HCE demonstrator during Maiden Flight

4.2.2. Rotor speed (Nr) control

The Rotor speed control is based on a PID control without anticipator. After some parameters improvements during Ground runs and first Flights, the test crew is now satisfied with the Nr control and qualifies it “as good as turboshaft control”.

One can see on Figure 7 the rotor speed measurement during a flight where strong collective pitch increase and decrease were done (collective pitch position is proportional to power output value).

This is showing a very reactive and stable Nr control, which is mandatory for helicopter behavior.

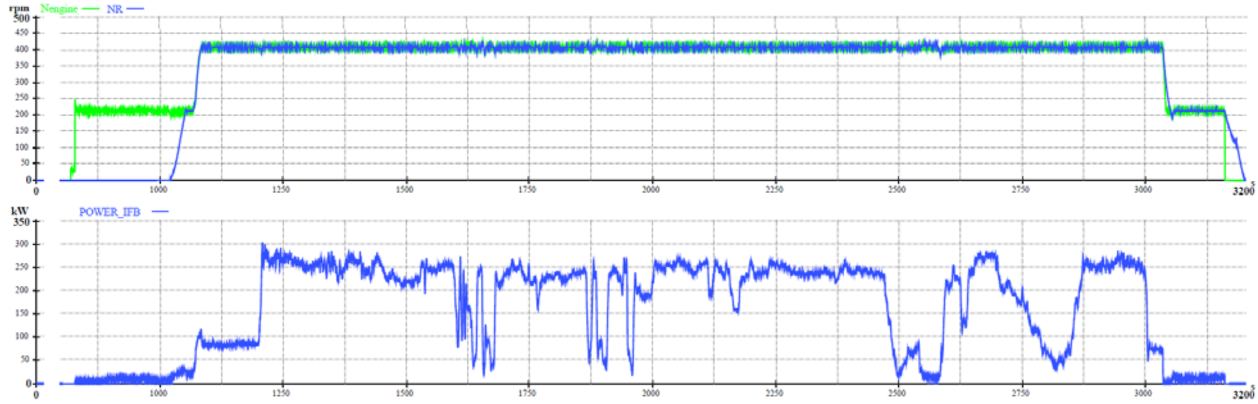

Figure 7: Nr control during flight after optimization

4.2.3. Cooling system

In order to validate the installation, it was decided at the beginning of the project to limit the flight envelop of the Demonstrator to ISA+20°C (35°C at sea level), which is a reasonable temperature achievable in Marignane in summer. After first flights between 10 and 20°C, the test crew was capable to fly at 30°C end of June 2016. The results of this flight for oil and coolant temperature are presented on Figure 8.

One can see that the temperatures remain within the engine manual limits showing good behavior and sizing of the cooling system.

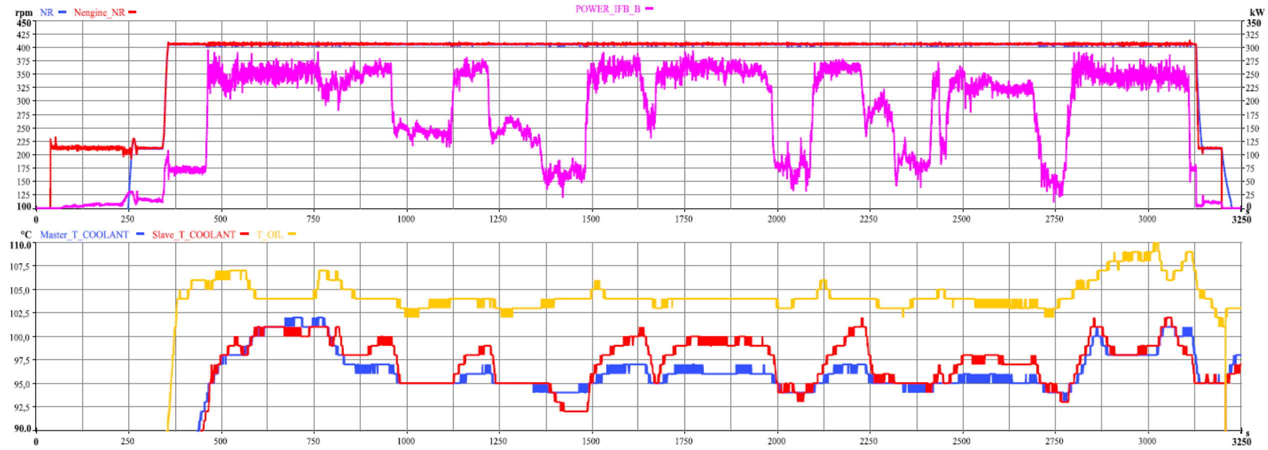

Figure 8: Engine oil and coolant temperatures during a flight at 30°C OAT

4.2.4. Torque oscillations

In order to limit the work and impact on already certified H120 systems, it was decided from the beginning of the project to use the serial H120 MGB and rotor. Therefore it was required to respect a given torque oscillations limit. And due to the combustion principle of HCE, torque oscillations at crankshaft output are much higher than this limit, see Figure 9 (+/-100 %!).

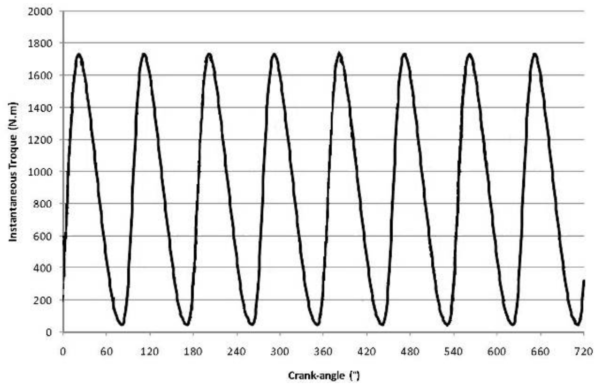

Figure 9: Instantaneous torque at crankshaft

The solution implemented to reduce the torque oscillations is a torsional shaft located between crankshaft output and MGB inlet. This solution is very light and reliable compared to well-known double fly-wheel system used in the automotive industry.

The final torque oscillation at MGB inlet is shown in Figure 10 (green curve = static part of torque, black curve = dynamic part of torque) during a flight.

One can see that the dynamic part of torque to MGB remains relatively constant and within the acceptable limits.

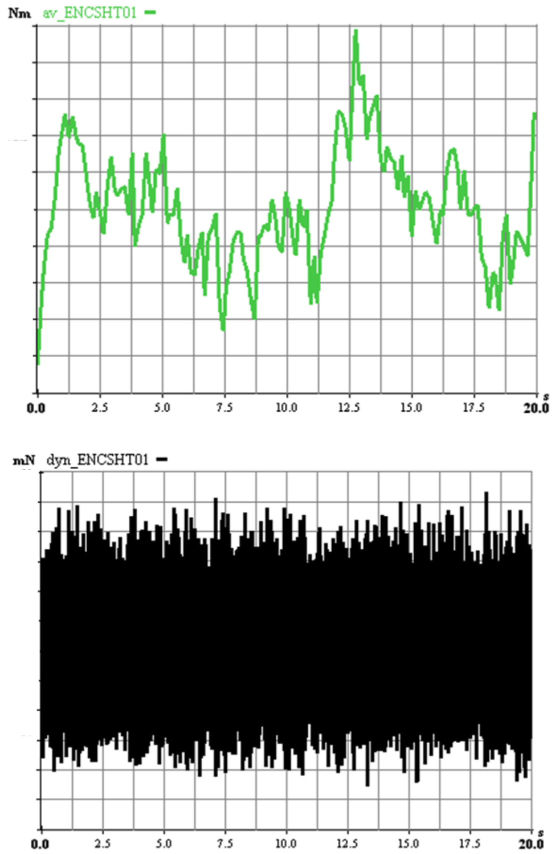

Figure 10: Static (green curve) and dynamic (black curve) part of torque at MGB inlet

Please note that for confidentiality reason, absolute values cannot be disclosed.

4.2.5. Engine movements

Because of the different installation of HCE compared to turboshaft and the use of a High Speed Shaft (link between MGB and engine enabling torque transmission), MGB and engine are moving independently from each other. Furthermore the engine and airframe vibrations need to be segregated (from rotor to the engine and vice-versa).

Therefore silent blocs are implemented in engine supports to damp vibrations as well as reduce engine relative movements.

You will find on Figure 11 the engine movements measured during Iron bird. These movements are very low (less than 1mm) and fully compatible with the requirements of both the airframe (vibration level) and the High Speed Shaft fatigue.

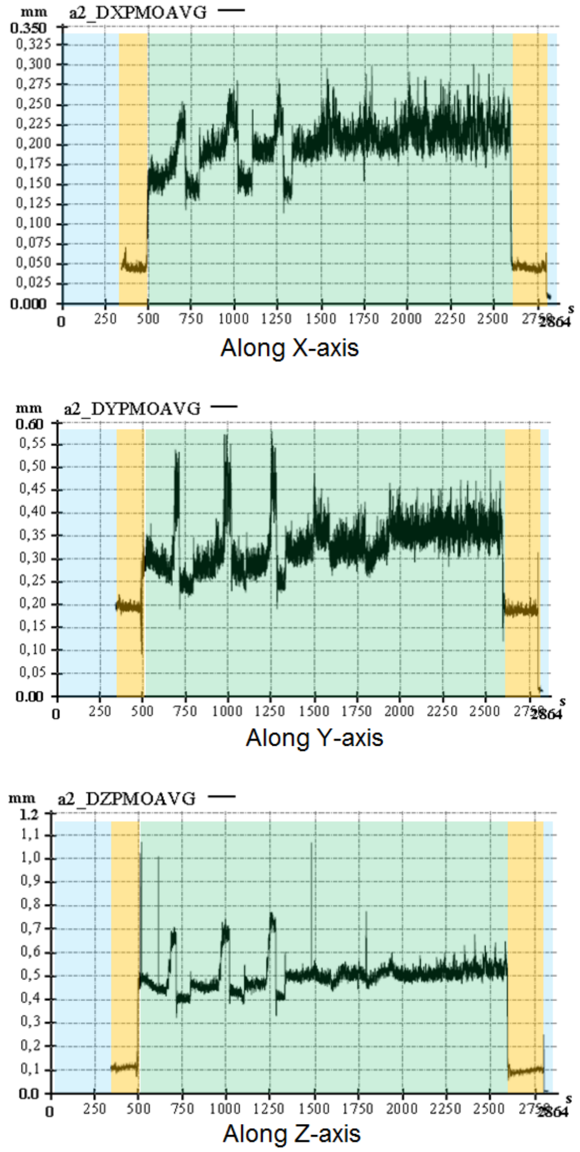

Figure 11: Engine movements (X, Y, Z)

For information:

- Engine stopped
- Engine at idle speed
- Engine at flight speed with load steps

5. CONCLUSION AND OUTLOOK

As you can see on the previous paragraphs, the results obtained so far are very positive and encouraging. They are validating most of the technical choices made since the beginning of the project.

They would need to be confirmed during the Flight tests campaign which will take place in the second half of 2015.

Assuming a success for this campaign, Airbus Helicopters has started studies and Intellectual Property discussions together with its Partners TEOS Powertrain Engineering and AustroEngine about the possible further development and industrialization of this engine for Fixed-Wings and Rotorcraft serial use.

6. ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) for the Clean Sky Joint Technology Initiative under grant agreement n° CSJU-GAM-GRC-2008-001.

7. REFERENCES

1. CleanSky JTI (Joint Technology Initiative) http://www.cleansky.eu
2. Airbus Helicopters http://www.airbushelicopters.com
3. ERF2016-066 paper “CLEANSKY GREEN ROTORCRAFT NEW TECHNOLOGIES – MAXIMIZING NOISE AND EMISSIONS BENEFITS”, J. Stevens, C. Smith, L. Thevenot, R. d’Ippolito, E. Gires, A. Castillo Pardo, V. Pachidis