LIGHT HELICOPTER DEMONSTRATOR WITH HIGH-COMPRESSION ENGINE: FLIGHT TEST RESULTS

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ABSTRACT

In the frame of the GRC4 program of Clean Sky's Green Rotorcraft Integrated Technology Demonstrator (ITD), Airbus Helicopters led the development of a flying demonstrator based on the H120 serial helicopter and fitted with a reciprocating engine running on kerosene. This engine is called HCE for High-Compression Engine. Airbus Helicopters worked on this research project with TEOS Powertrain Engineering, France, and AustroEngine GmbH, Austria, under the HIPE 440 Consortium. Bench tests started in March 2013. Ground tests were completed in March 2015. The Maiden Flight occurred on November 6th 2015 and the flight test campaign lasts until the end of 2017. The HCE needed to be built from scratch. This paper explains its specifics. It presents the achievements of the research project regarding engine mass-to-power ratio, power output, fuel consumption, torque oscillations, engine movements, rotor speed control and lastly emphasizes on the cooling system performance. The flight tests validated the achievements on these subjects, concluding to full applicability of HCE kerosene piston engine technology to light helicopters with benefits on fuel consumption (-42%), DOC (-30%), hot and high performance and engine price.

SYMBOLS AND ABREVIATIONS

ACARE	Advisory Council for Aeronautics Research in Europe
AH	Airbus Helicopters
DOC	Direct Operating Costs
FADEC	Full Authority Digital Engine Control
GRC	Green RotorCraft
HCE	High Compression Engine
HEX	Heat EXchanger
H/C	Helicopter
ISA	International Standard Atmosphere
ITD	Integrated Technology Demonstrator
MGB	Main Gear Box
MTOW	Maximum Take-Off Weight
Nengine	Engine speed (rpm)
Nr	Rotor rotational speed (rpm)
OAT	Outside Air Temperature
PID	Proportional-Integral-Derivative control
PDR	Preliminary Design Review
SEL	Single Engine Light
SFC	Specific Fuel Consumption
SL	Sea Level
TOP	Take Off Power
TBO	Time Between Overhaul
TRL	Technology Readiness Level

1. INTRODUCTION

The European research program Clean Sky[2] promotes the development of greener aircrafts amongst the actors of the European aerospace industry. The rotorcraft program funds the development of various technology demonstrators called the GRC ITDs (Green RotorCraft Integrated Technology Demonstrators).

Cleansky's environmental targets, consistent with ACARE 2020's objectives, are to reduce Specific Fuel Consumption (SFC) by 30%, CO2 emission by 40% and NOx emission by 53%. These targets shall be achieved via improvements on both the Aircraft and the Engine. The various ITD programs target developments of both.

In the frame of the GRC4 ITD program, Airbus Helicopters led the development of a flying demonstrator of a H120 helicopter fitted with a newly designed reciprocating engine running on kerosene. This engine is called High-Compression Engine (HCE).

For this Research project Airbus Helicopters worked with TEOS Powertrain Engineering, France, and AustroEngine GmbH, Austria, teamed in the HIPE 440 Consortium. The serial H120 aircraft platform is kept as it is (even dynamic systems such as transmissions and rotors). Only the Powerpack (engine and its cooling system) is entirely new.

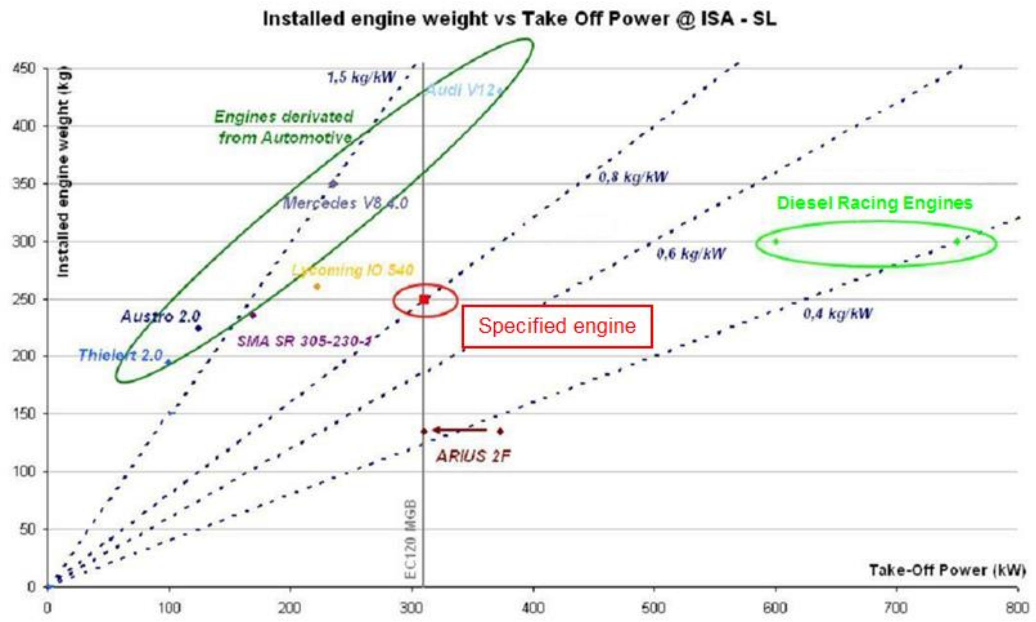


Figure 1. Installed mass-to-power ratio benchmark.

2. A BRAND NEW ENGINE

2.1. Benefits of HCE

In the power class related to H120 engines (over 300kW), the main benefits of the HCE compared to a turboshaft are:

- a lower Specific Fuel Consumption (30% to 50% depending on the power level),
- lower CO2 emissions (equivalent to SFC reduction),
- higher performance in hot/high conditions as the turbochargers limit the impact of OAT and air density on the engine output power,
- lower operating costs (savings on fuel consumption, engine price, maintenance and overhaul).

These advantages come to the price of an additional engine mass. This should however be put into perspective as for a similar distance covered, an HCE powered rotorcraft needs to carry much less fuel. Lower consumption compensates overweight in a short flight time.

2.2. Key design constraints

2.2.1 Weight-to-power ratio

In order to reach a level of helicopter performance comparable to the turboshaft H120's, the mass-to-power ratio of the complete H/C Powerpack (including the core engine and all necessary accessories such as cooling system, FADEC, clutch, etc.) shall fall below 0.8kg/kW. According to the benchmark of existing engines on Figure 1, this means achieving a mass-to-power ratio halved compared to existing piston engines, including aeronautical ones. This is one main challenge of the project.

2.2.2 Reliability and cost reduction

In order to reach a reliability level comparable to other aeronautical piston engines (TBO around 2000h), the main technologies applied to the HCE come from advanced racing self-ignition automotive engines (see core engine description below) used at lower specific power.

Some other technologies applied to the engine are already largely known and used in the automotive industry. Other technologies, still, are more specific to the project needs.

2.2.3 Cooling the engine

For piston engine technology, the heat release to fluids is roughly 15 times that of an equivalent turboshaft (see Figure 2). More stringent: a proper characteristic of the helicopter is to require maximum power when static (hower), i.e. when no dynamic pressure is available to push air through the heat exchangers of a cooling system. The cooling system design also is a main challenge of the HCE practical application.

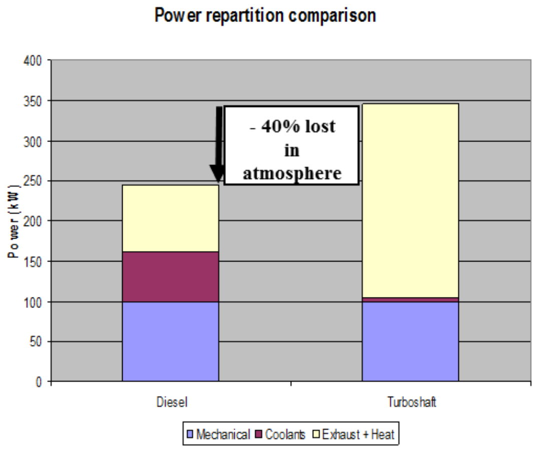


Figure 2. Heat release comparison between HCE and Turboshaft.

2.3. Core Engine architecture

The previous considerations of weight and reliability added to operating costs considerations led to the development of a core engine shown in Figure 3 with the following characteristics:

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

2.4. Powerpack architecture

The Powerpack design was initiated at the end of 2011 by the HIPE440 Consortium. The Powerpack (Figure 4), is composed of:

- The **core engine**, previously described,
- A **multiplier**, to match the right rotational speed at MGB inlet and including the clutch required for engine start,
- A **cooling system** to evacuate the heat released in engine fluids.

The cooling system is made of 5 heat exchangers (2 for coolant, 2 for turbocharged air and 1 for oil). A fan sucks air through in all operating conditions.

Figure 3. HIPE 440 core engine.

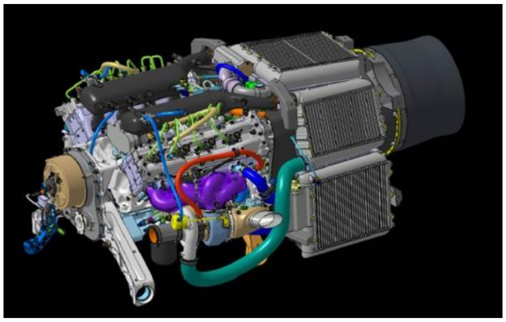


Figure 4. HCE Powerpack.

3. TESTING LOGIC

Because this newly designed HCE brought many innovations, testing played a major role in its development.

3.1. Subcomponents evaluation

The cooling system architecture, particularly innovative and critical for the engine proper performance, was tested before PDR to validate performance expectations and confirm its feasibility. This was the very first test of a critical component of the engine.

3.2. Powerpack tests

Following the design phase, the test campaign started with the first engine rotation on bench in Mar. 2013, less than a year and a half after initiation of the engine development. Calibration and debug activities were carried until May 2014.

The ultimate aim of the bench tests was to run the endurance cycle validating the engine flightworthiness. A set of core engine endurance runs was completed in Sept. 2014. Endurance tests of the complete Powerpack followed, with a final run ensuring the engine airworthiness completed in June 2015.

The engine bench tests also enabled to test the engine suitability for fixed wing application as explained later on in §4.6.

3.3. Rotorcraft integration tests

A series of tests were completed on an Iron Bird from Nov. 2013 to mid-Feb. 2014 at Airbus Helicopters in Marignane, France. The aim of the Iron Bird campaign was to validate the technical solutions to the following main challenges:

- dump the engine torque oscillations,
- dump the engine vibrations,
- master the clutching sequence,
- control the rotor speed (challenging because of a low engine inertia vs a high rotor inertia),
- cool the engine in hover.

Following the positive results at Bench and Iron Bird levels, ground runs were performed by the flight test crew between Feb. 10th 2015 and Mar. 30th 2015. These validated the avionics for engine monitoring and the procedures associated to the new installation.

Subsequent to the successful Ground runs, the Maiden Flight occurred on Nov. 6th 2015. In summer 2016, the test crew was able to fly and validate the installation in up to 32°C OAT. The flight test campaign validated the HCE and rotorcraft installation up to TRL 6, for light helicopter application.

3.4. Technology evaluator

A further step within Cleansky GRC ITD was to integrate the results obtained in the GRC7 Technology Evaluator. This multidisciplinary simulation framework provides performance estimations for h/c that include technologies developed by the GRC programs.

4. POWERPACK ACHIEVEMENTS

4.1. Power output

The engine was calibrated up to 330kW on engine bench. Figure 5 shows the power delivered by the engine during the Maiden Flight. On take-off, 280kW cope with the demonstrator's weight.

4.2. Engine efficiency and power balance

The flight tests measures were the occasion to perform a power balance on the engine to see how combustion heat distributes over engine brake power, engine heat to fluids, engine exhaust losses and other losses.

In-flight measures give the core-engine power balance presented in Table 1. Note that compared to the HCE Powerpack, the core-engine perimeter does not include the cooling system and the multiplier of the rotorcraft installation.

Table 1 - HIPE 440 core-engine power balance at 281 kW brake power output

Brake power / efficiency	38,2%
Heat to water coolant	18,6%
Heat to oil	4,9%
Heat to charge air	5,3%
Fluids total	28,8%
Exhaust heat	31,5%
Other losses	1,6%

Combustion efficiency can be further improved making 42% core-engine efficiency achievable.

Including the fan and multiplier, the H120 HCE demonstrator Powerpack efficiency is 34,5%. Respectively, for the same brake power output of 281 kW, the serial H120 turboshaft has an efficiency of 23%.

4.3. Engine Mass-to-Power ratio

The 0.8kg/kW limit mentioned before is a main challenge for the engine manufacturer, especially as it is combined to stringent requirements on engine reliability and recurring costs. Still, the engine manufacturer succeeded. The Core-engine weighs 197kg. Including the Multiplier and the Cooling system, the complete Powerpack reaches the 0.8kg/kW target.

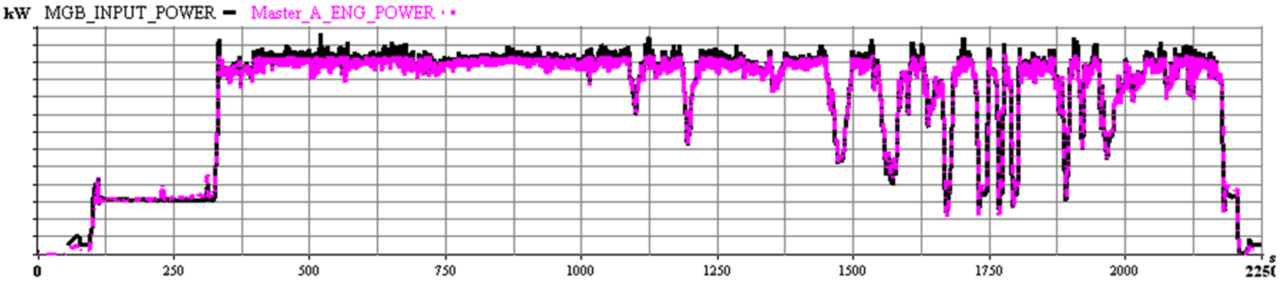


Figure 5. Power output during Maiden Flight. MGB input power in black and Engine power in purple.

4.4. Fuel consumption and emissions

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

During the second flight test, the fuel consumption of the H120 HCE prototype was compared to that of the H120 B (turboshaft) for the same mission. Figure 6 presents the fuel consumption reduction offered by the HCE. It reaches 42% in average, a minimum of 29% above 300kW, and a maximum of 58% below 100kW.

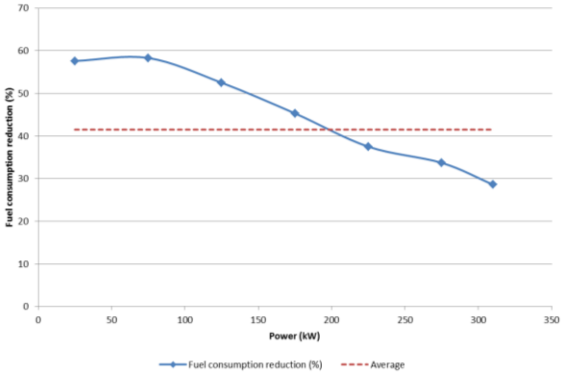


Figure 6. HCE fuel consumption reduction during second flight test. Reference is the turboshaft.

A separate study by the Cleansky Technology Evaluator (GRC7) has shown the benefits of HCE for Single Engine Light helicopters (SEL) on a dedicated comparative duty cycle. Table 2 shows an extract of the results presented by J. Stevens, NLR, at ERF 2016 [3]. These values confirm that Cleansky's target of 30% lower SFC and 40% lower CO_2 emission by 2020 is reached, even exceeded, with a technology already flying today.

An estimated additional 4 to 8% SFC reduction could be achieved via further engine tuning as previously stated in 4.2. The global transmission system could also be optimized. These optimizations will be worked out during a serial phase.

Table 2. Cleansky GRC7 estimations for Single Engine Light helicopters.

Helicopter	ΔFuel	ΔCO2	ΔNOx
Yr 2000 turboshaft reference	0	0	0
Yr 2020 turboshaft with Cleansky improvements (except HCE)	-21.1%	-21.1%	-70.0%
Today's HCE with Cleansky improvements	-68.0%	-68.1%	-76.0%

These simulation results by Cleansky show similar NOx emissions for HCE and turboshaft equivalent helicopters. They are backed by experimental measures giving 0,5 g/kWh CO and 4,2 g/kWh NOx for both HCE and turboshaft (capable of Euro3 automotive regulations for reference). Note as well that depollution solutions are currently available for Diesel piston engines. It is not the case for turboshafts due to a much higher exhaust flow (dual exhaust on HCE with one sixth of turboshaft air flow each, i.e. similar to car's exhaust flow).

4.5. Noise emissions

Near field noise measures – at 20 meters, 240 kW power rating - were performed on the HCE engine. The configuration of the test was: on helicopter, in open field, no engine cowlings, free exhaust, no noise insulation. Results are that the HCE noise is 2 to 3 dB lower compared to that of the serial H120's turboshaft.

Furthermore, improvements on ground perceived noise levels are still achievable, for instance turning the engine exhaust pipe up. Such operation is much more difficult to perform on a turbine as it affects the turbine performance when its impact on the reciprocating engine performance is negligible.

4.6. Fixed-wing capability

The requirements for fixed-wing aircraft application - different load inertia, idling speed and starting characteristics, no clutch necessary -, can be easily managed with the HCE. Specific bench tests simulating propeller drive (Figure 7) proved the HCE fully capable for fixed-wing application, enlarging its market.

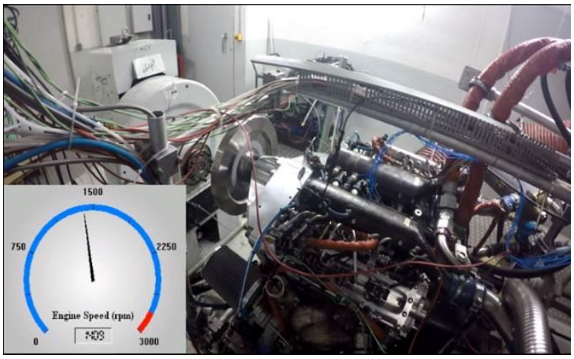


Figure 7 - Bench test of the engine for Fixed-wing application. Inertia of propeller, fixed-wing gearbox, and suitable idle speed.

5. HELICOPTER ACHIEVEMENTS

5.1. Torque oscillations

From the beginning of the project, decision was taken to keep the serial H120 Main Gear Box (MGB) and rotor. Reusing already certified H120 systems limited the risks and expenses of the project, without affecting the conclusions on the suitability of HCE application for helicopters. In return, the engine had to comply with the torque oscillation limit of these elements. This was a main challenge: due to the piston engine dynamic, crankshaft torque oscillations exceeded the limit by far: +/-100 % of mean torque value at TOP as per Figure 8.

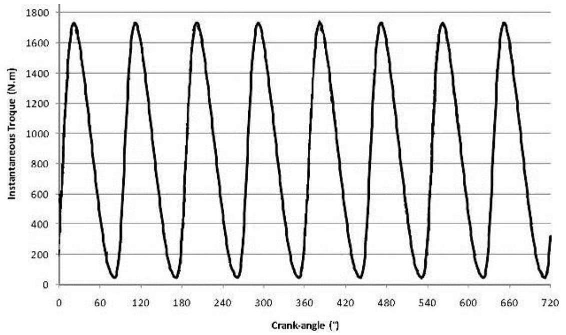


Figure 8. Measured instantaneous torque at crankshaft.

To bring the torque oscillations at MGB inlet to a compliant level, a torsional shaft was placed between the crankshaft output and the MGB inlet. This solution was chosen because particularly light and reliable. In flight recordings of the torque oscillation at MGB inlet with the torsional shaft mounted (Figure 9) demonstrated compliance with the limits of the MGB from standard turboshaft H120.

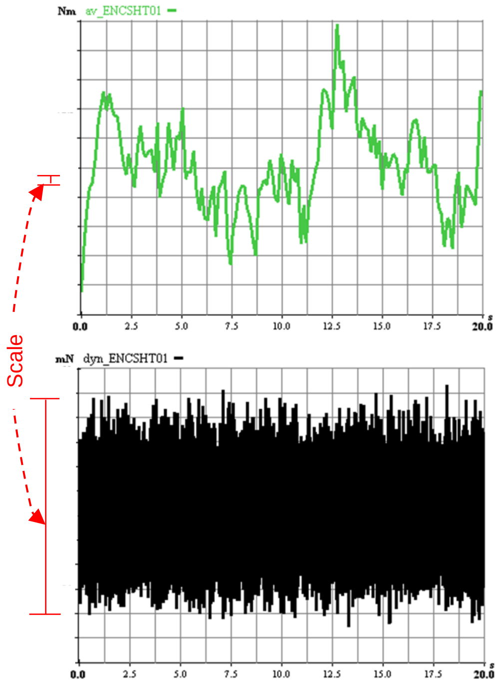
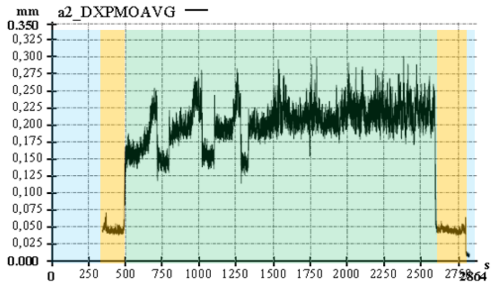


Figure 9. Static (green curve) and dynamic (black curve) part of torque at MGB inlet, function of time, in flight record.

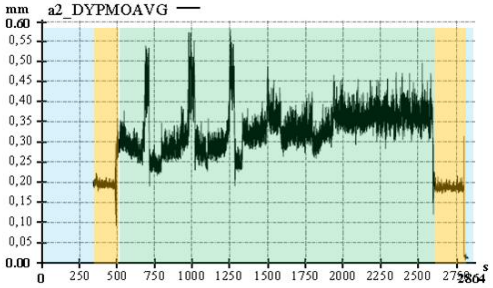
5.2. Engine movements

The HCE installation on the aircraft lets the MGB and engine move independently from each other. “Silent blocs” are integrated in the engine supports to damp vibrations and reduce engine movements. The High Speed Shaft – linking the MGB and the engine - is specifically designed to cope with the remaining relative movements while transmitting torque.

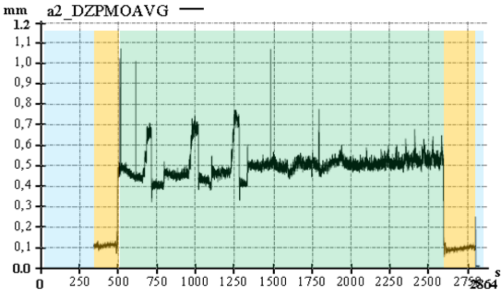
Figure 10 shows the engine movements as measured on Iron Bird during a simulation of a complete flight (start engine to idle, clutch up to flight rotor speed then power variations and back down to engine stop). The measures revealed low movements’ amplitudes (less than 1mm) and compliance with the requirements of the airframe (vibration level) and the High Speed Shaft (fatigue).



Along X-axis



Along Y-axis



Along Z-axis

🟦 Engine stopped
🟨 Engine at idle speed
🟩 Engine at flight speed with load steps

Figure 10. Engine movements (X, Y, Z) as a function of flight time and engine power.

5.3. Rotor speed control

The Rotor speed (Nr) control is based on a PID control without need of an anticipator, as opposed to classical turboshaft's control systems. The Nr control was tuned during the flight test campaign. The proper setting is now operational and "as good as turboshaft control" as per our fully satisfied test crew.

Figure 11 shows the stability and reactivity of rotor speed and engine speed control during a flight with application of significant collective pitch increase and decrease reflected by the power output value recorded on the bottom graph.

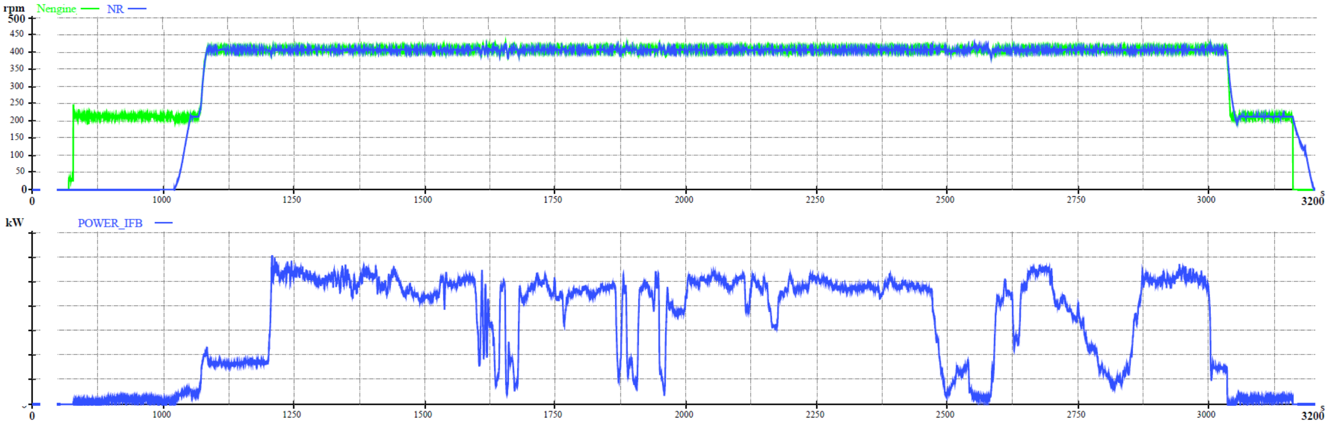


Figure 11. Nr control during flight after PID optimization. On the top graph, rotor speed (Nr) in green, engine speed (Nengine) in blue. On the bottom graph, evolution of mechanical engine power during flight.

5.4. Cooling system

The cooling system was a major preoccupation of the project since the beginning. Stringent flight domain objectives were set to equal the turboshaft H120's performance, or even surpass them in hot and high environment. Because of the engine technology, these imply huge amounts of heat to evacuate – see §2.2.3 - , with significant constraints on weight and size.

5.4.1 Flight conditions and sizing

Hovering is the flight configuration that requires the maximum engine power. Because heat production varies accordingly, hovering flights are the most demanding for the cooling system.

From the demonstrator's pre-studies and specifications, the most demanding flight conditions that the cooling system is required to cope with are:

- SL Hover, MTOW, ISA+20 (35°C)
- 2500m Hover, MTOW, ISA+20 (19°C)

Despite a higher powerpack weight, the payload capacity of the H120 HCE is designed to be competitive with respect to that of the H120 turboshaft: slightly lower at low altitudes, low temperatures but better in hot and high environments.

5.4.2 Architecture

The helicopter main characteristic is its ability to fly any direction or hover. To evacuate heat in any such situation, a mean of sucking ambient air through the cooling system's heat exchangers is required.

Various architectures were modeled and compared to optimize the cooling system with respect to performance, installation and operation constraints and costs. The chosen architecture includes 5 heat exchangers and a fan arranged as shown on Figure 12. The air HEXs are intercoolers, cooling the engine turbocharged breathing air for better thermodynamic efficiency. "Water" refers to the water based engine coolant. Oil lubricates the engine. Figure 13 shows one of the other architectures studied and judged less favorable for demonstrator application.

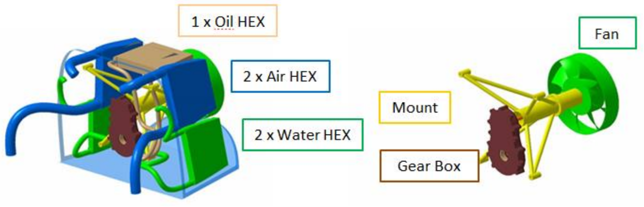


Figure 12. Architecture chosen for the Cooling System.

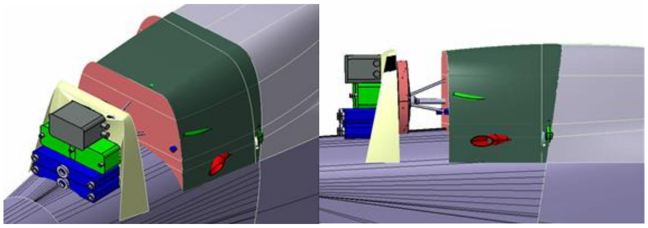


Figure 13 - Another cooling system architecture suggestion - HEXs placed behind the fan.

In the following:

- *hot fluids* refers to the fluids cooled in the cooling system: charge air, water and oil.
- *cooling air* refers to the ambient air sucked through the heat exchangers to evacuate the hot fluids' heat.

5.4.3 Bench tests of Cooling System principle

To validate pre-developments computations regarding the cooling system, a cooling system prototype (Figure 14) was bench tested by AH in their facilities before PDR. The prototype used an existing industrial fan and a cooling box slightly bigger than the actual one. The aim was to test the architecture principle and evaluate the accuracy of theoretical design computations and tools. The cooling box dimensions were later optimized.

The following main concerns were assessed:

- Validity of CFD computations,
- Ability to reproduce the computed design balance of airflow between the 5 HEXs,
- Characterize the cooling system (pressure drops, airflow and power consumption),
- Impact of the configuration on fan performance (flow rate, power consumption),
- Cooling efficiency of the architecture,
- Impact of flow mal-distribution through the HEXs on flow rates and pressures drops

Table 3 presents the essential measures and compares them to pre-design computations. Results were promising and green lights for further development were achieved for all these points.

Internal ducts between each HEX and the fan were tested to evaluate their impact on the cooling system performance. Performance improvements were not significant enough to cover for the added mass and complexity as well as to cover for the impact on fan blades life due to the created anisotropy of the airflow in fan inlet plan. The system thus remains non-ducted.

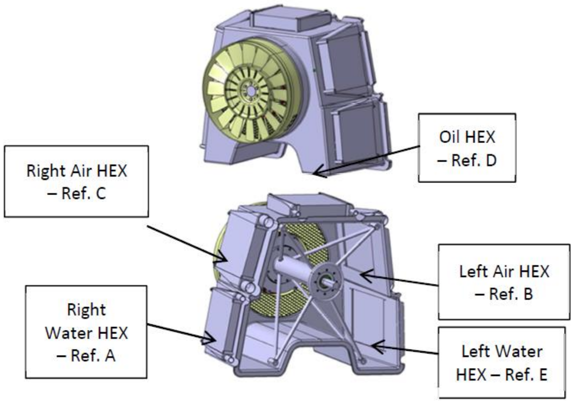


Figure 14. Bench tested cooling box prototype (plexiglass transparent wall opposite the fan)

Table 3 - Bench results of the Cooling System mock-up.

	Values expected		Bench results	
Water HEX x2	22%	1,07 kg/s	22,9%	1,29 kg/s
Air HEX x2	18%	0,86 kg/s	16,7%	0,94 kg/s
Oil HEX x1	20%	1,08 kg/s	20,7%	1,16 kg/s
Total (fan)	100%	4,94 kg/s	100%	5,61 kg/s
ΔP fan	1399 Pa		1436 Pa	
Fan power	-		11,30 kW	

5.4.4 Flight tests and results

After some first flights in around 10 to 20°C OAT, the test crew was able to fly the machine in up to 32°C OAT in summer 2016. The cooling system performance was a success.

Objectives for cooling

Regarding engine cooling, the tests objectives were:

- To verify that the engine temperature limits on hot fluids are not exceeded
- To evaluate the engine heat fluxes and mass flow rates of cooling air through the HEXs to compare with design values and properly tune the cooling system model used afterwards for cooling system design.

Temperature limits

The *hot fluids'* temperatures were monitored on all flights. The temperatures remained within the engine limits confirming a satisfactory behavior and sizing of the cooling system – as an example see Figure 15 : oil and coolant temperatures measures on one of the flights.

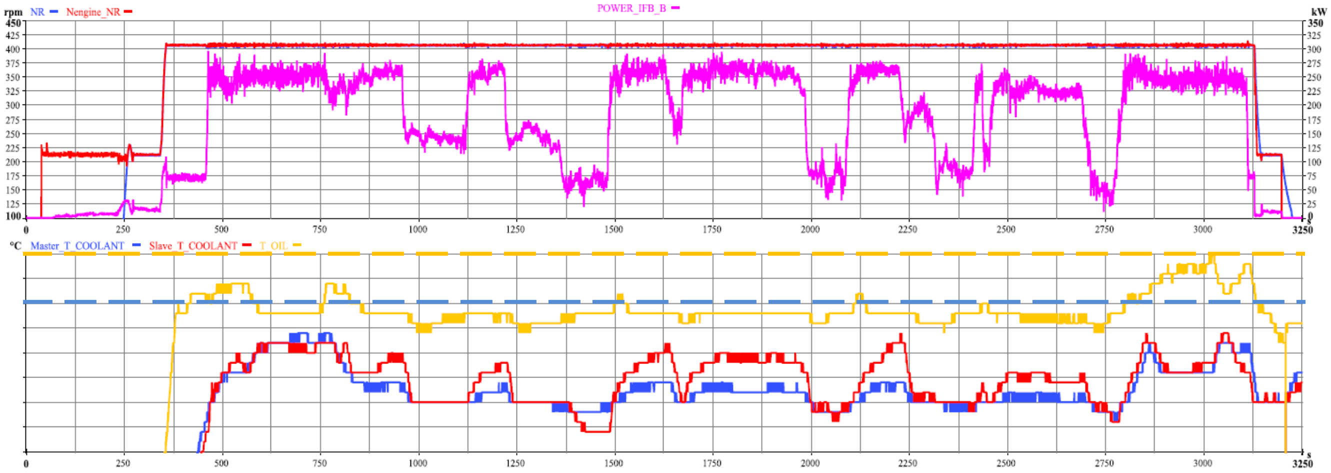


Figure 15. Oil and coolant temperatures on a 30°C SL OAT flight. On top graph, engine power in purple. On bottom graph, oil temperature in yellow, coolant temperature in blue for left bank of cylinders and in red for right bank. Dashed yellow line is the upper temperature limit for oil; dashed blue line for water (same for R/L banks).

Five stabilized flight periods for detailed analysis

Aside from monitoring the temperatures, more precise analyses were performed regarding heat fluxes and cooling air mass flow rates through the HEXs.

These analyses can only be performed when the engine is in steady-state equilibrium. Five stabilized flight periods were thus selected. They are all quite similar and representative: hovering at sea level, 250 $\pm$ 10 kW powerpack brake power, which favors comparisons or averaging.

All the measures and computations mentioned in the following are performed on the five flight tests periods here mentioned.

Engine heat dissipation

In-flight measures of the hot fluids mass flow rates dm_h and their temperatures $T_{h_{in}}$ and $T_{h_{out}}$ at HEX inlet and outlet were performed and enabled the computation of the HEXs' heat fluxes:

$$\Phi_{HEX} = dm_h \, c_{p_h} \, (\mathrm{T}_{\mathrm{h_{in}}} - T_{h_{out}})$$

From these heat fluxes measures, the engine heat dissipation model could be adjusted for better reliability and accuracy.

Cooling air mass flow rates

The mass flow rates of cooling air through each HEX were not measured during flights: an experimental setup would have been too intrusive. The cooling air mass flow rates are instead computed based on in-flight measures of the hot fluids temperatures and on the heat fluxes computations exposed in the section just before. They use the heat exchanger's effectiveness-NTU theory developed by Kays and London [4]. The computation principle is exposed in Figure 16.

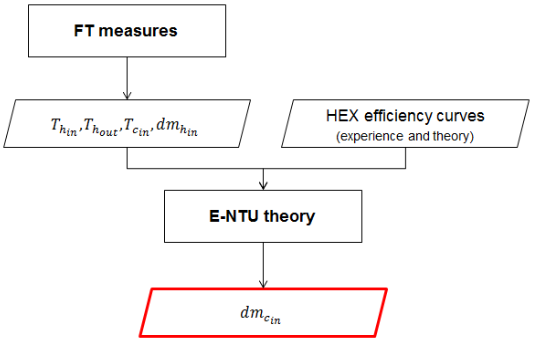


Figure 16 - Principle for cooling air mass flow rates.

Because the five flight periods are representative one of the other – similar flight conditions and engine power -, the results could be averaged. The averaged cooling air mass flow rate distribution is given in Figure 17. The results dispersion was quite high due to high measure uncertainties. However, the dispersion could be reduced as exposed in the next paragraph.

Uncertainty analysis

If computing the cooling air mass flow rates via the effectiveness-NTU method was necessary because an experimental setup would have been too intrusive, an inconvenient of such computation is that measurement errors cumulate rapidly. As a result, the error interval for each cooling air mass flow rate computation was evaluated based on measurement errors evaluations for d_{m_h}, $T_{h_{in}}$ and $T_{h_{out}}$ especially – the precision on

$T_{c_{in}}$ and the efficiency curves is judged sufficient to be neglected.

A specific method to alleviate the uncertainties was developed based on temperature measures calibration, global flow rate balance through the fan, and combination with measurements of other parameters.

Flow rate asymmetries

The cooling air flow rate computations enabled a detailed analysis of the impact of a rotorcraft installation on the cooling system mass flow rates. Some asymmetries were observed – see Figure 17 -, and analyses were performed regarding the impact of the main rotor flow, exhaust gases recirculation and relative wind. These are quite likely to be impacting the performance altogether but more analysis is needed to associate each with a contribution factor.

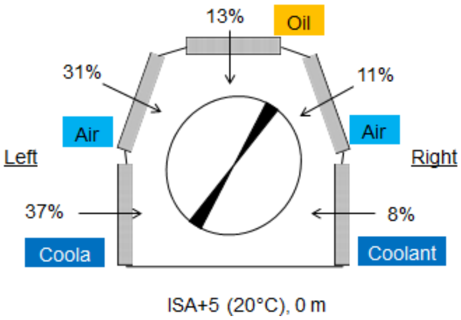


Figure 17 – Averaged cooling air mass flow rate distribution as fractions of the total flow.

5.4.5 Modeling and performance assessment

A numerical model of the complete cooling system – 5 HEX in parallel and a fan - currently installed on the helicopter was developed since the beginning of the project for sizing and performance assessment. The model is built under LMS Imagine.Lab Amesim.

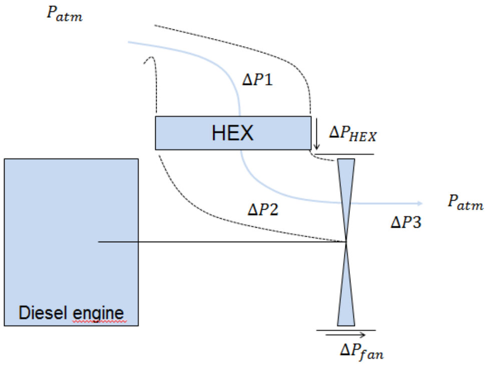


Figure 18 - Cooling air pressure drops.

The main unknowns of the cooling system model are the pressure drops on the five parallel cooling air circuits (one circuit per HEX). Figure 18 presents these pressure drops for a cut plane that includes one HEX. $\Delta P1$ is the pressure drop at HEX inlet,ΔP_{HEX} is the pressure drop through the heat exchangers, $\Delta P2$ is the pressure drop between the HEX and the fan, due to flow expansion and bending, ΔP_{fan} is the pressure rise through the fan and $\Delta P3$ is the pressure drop at fan outlet.

A first iteration of the model was developed for the cooling system design. It included ideal components regarding the pressure drops. These lack accuracy in describing the impact of the cooling box architecture or that of the rotorcraft installation (taking into account the main rotor downwash, heterogeneous flow rates across the HEXs' surfaces, etc…).

Flight tests measures on the cooling system aimed at tuning the initial cooling system model for it to be more representative of the cooling system architecture and rotorcraft installation.

In order to do so, a pressure drop component was included in between the HEXs and the fan – see Figure 19. This introduced pressure drop, called ΔP_{losses}, accounts for additional pressure losses due to the installation. They are linked to the mass flow rate via a pressure drop coefficient. Note that there is one ΔP_{losses} for each of the five parallel cooling air circuits.

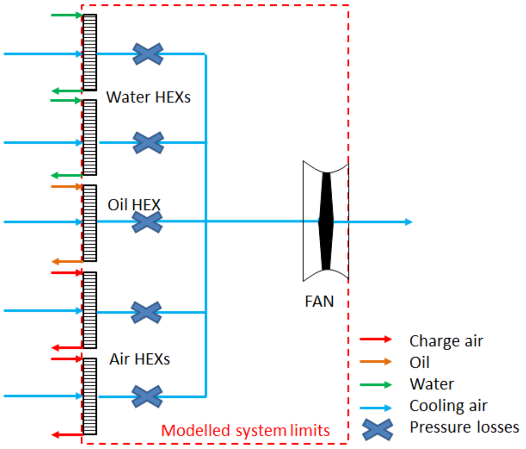


Figure 19 - Cooling system model. "Pressure losses" are the tuned pressure drops introduced in the second model iteration.

The tuning process consists in adjusting the pressure drop coefficients of the five parallel ΔP_{losses} in order to match, for each cooling air circuit, the mass flow rates from the computations exposed in 5.4.4 and Figure 17. In the process, the model parameters relative to flight conditions were set to match the flight conditions of the five flight periods studied.

This second tuned iteration of the cooling system is now suited for more accurate performance evaluations, especially in conditions that were not met during flight tests: hotter, higher or higher engine power (added payload).

6. CONCLUSION AND OUTLOOKS

As shown above, the results obtained on the H120 HCE are very positive. They validate all the technical choices made since the beginning of the project and the benefits of the HCE technology for light helicopters, as Cleansky’s environmental targets are even exceeded.

Airbus Helicopters has started studies and discussions about the possible further development and industrialization of this engine for various applications such as Rotorcraft or Fixed-Wings use.

7. ACKNOWLEDGMENTS

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