EC130B4 POWERPLANT: DESIGNED FOR LOW NOISE, ECONOMICS AND TOP-LEVEL SAFETY

François-Xavier GAULMIN
Eurocopter
Aéroport Marseille-Provence
13725 Marignane Cedex
France

Summary

The latest « Ecureuil » helicopter version, the EC130B4, is arriving on the market after a JAA and FAA certification in December 2000.

This paper presents the engine installation innovations of this new helicopter :

- a Variable Main Rotor speed system (for low noise)

- an electrical and automatic engine power control back-up system (for more economy and improved safety).

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1 - Introduction

The well-known, light one-engine market leader « Ecureuil » helicopter family grew once again early this year with the EC130B4 arrival on the market. The EC130B4 was JAA and FAA certificated in December 2000.

This new EC130B4 is a derivative of the existing AS350B3, but is significantly modified. As far as the engine installation is concerned, two innovations are integrated in the EC130B4 :

- a Variable NR law, for low noise, and maintained performance,

- an electrical and automatic engine power control back-up system , for improved safety and more economy.

The aim of this paper is to present those two innovations, after a general presentation of the helicopter itself, and of its engine installation.

2 - EC130B4 presentation

The EC130B4 is the latest Ecureuil version, both FAA and JAA certificated in December. It is a derivative of the previous AS350B3.

The main features are as follows :

- Introduction of a fenestron® (for reduced noise)

- New, wider cabin, to accommodate one or two additional passengers

- New canopy for better visibility

- Engine having a dual-channel FADEC, with an electrical and automatic engine power control back-up system (no training for FADEC failure required) and a variable NR control system (for reduced noise and maintained performance)

- Dual hydraulic circuits (no training for hydraulic failure required)

- New landing gear.

Of course, as a derivative of the AS350B3, the EC130B4 profits from the in-flight service accumulated by the Ecureuil family, with in particular the same mechanical assemblies, the same rotor, the same avionics, and so-on…

3 - EC130B4 engine installation

The EC130B4 is equipped with a 630 kW TURBOMECA ARRIEL2B1 engine. This engine belongs to the ARRIEL2 engine family, installed in particular on Dauphin (AS365N3, EC155B) and Ecureuil aircraft (AS350B3).

The ARRIEL2B1 is equipped with a dual-channel FADEC, and therefore the EC130B4 becomes the first single-engine commercial helicopter to be equipped with such a technology. The dual – channel architecture allows the engine fuel control system failure rate to be reduced compared to the existing hydro-mechanical fuel control systems or to existing one-channel FADEC technology.

4 - Variable Main Rotor speed system

4.1 - Background

The aim of the engine control system is to keep the Main Rotor speed (hereafter referenced as NR) at a given target speed. On most helicopters, this target NR speed is more or less constant, as the engine and rotor designs, as well as the engine control system design, are easier and simpler in this case

Nevertheless, for a given criteria (say : performance, as an example), the optimum NR depends on the flight conditions. In addition, depending on the criteria used, the optimum will also differ. As an example, noise or performance criteria do not lead to the same optimum NR. A high NR is penalizing, from a noise viewpoint, in some flight conditions (for example economical cruise near the ground). On the contrary, a high NR is generally valuable for performance, at least in some given flight conditions.

Therefore, in the past, the constant selected NR was traditionally the result of a compromise, with the drawback of a non-optimized NR in many aspects.

Today, the introduction of the digital engine control system makes it possible, more easily than before, to define complex variable NR laws dependent on several parameters. Eurocopter has studied various possibilities in past 5 years. We are going to present how these possibilities were used in the particular case of EC130B4.

4.2 - EC130B4 targets

The EC130B4 was submitted to various constraints, specific to that helicopter :

- constraints associated with a wider cabin and additional passenger (higher take-off weight compared to the AS350B3 : 2400 kg vs 2250 kg),

- constraints associated with the aggressive noise targets (in order to satisfy Grand Canyon National Park noise rule),

- and constraints associated with the searched commonality with the existing AS350B3 Ecureuil helicopter (same main rotor as an example).

The NR was therefore to be decided taking into account those various constraints. This resulted in the following NR targets for the EC130B4:

- 400 rpm in hover conditions, to keep the height/velocity diagram unchanged, compared to AS350B3, with same main rotor, despite the certificated weight increase of 150 kg (2400 kg versus 2250 kg). For the low point of height/velocity diagram, this could be obtained only by a NR increase (more energy in the main rotor to be compatible with the weight increase). This also improves the altitude/side-wind conditions,

- maximum 388 rpm in low-altitude cruise flight conditions between 50 and 120 kt (intermediate cruise), to meet, in particular, the US Grand Canyon National Park standards,

- at least 390 rpm in low-altitude maximum continuous power conditions (fast cruise), to maintain maximum continuous torque-limited performance,

- 394 rpm in high altitude cruise conditions, which means improved performance where noise annoyance is less important, in altitude (knowing that the fenestron® already guarantees a significant noise reduction in all flight conditions).

As it may be seen, those targets required the definition of a variable NR system, able to automatically control the NR between 387 and 400 rpm. Of course, this cannot be possible without taking into account the pilot and his perception of the NR variations.

4.3 - Variable NR from pilot viewpoint

The experience of Eurocopter, through flight tests achieved over the past 5 years as part of various research programs or other applications, is that the variable NR system is to be defined with caution. Indeed, a NR variation will require engine power variation. With the existing fixed NR systems, the pilots are used to see engine power variation only when they move theirs controls (mainly collective pitch, and also, to some extent, rudder pedals). This perception is very important for them. If engine power does vary, but not as the result of such an action on the controls, they are used to think that a problem occurs. Therefore, a "good" Variable NR system is a system that will not modify this pilot perception. This is possible only if :

- NR variations and associated engine power variations are still correlated with pilot actions on the controls,

- NR variations and associated engine power variations are smooth enough.

Of course, change in NR may not be correlated to pilot action if the variation is so slow that it is dynamically undetectable. For example, if the variation is correlated with altitude, as on some existing Eurocopter helicopters, the engine power variations that are induced are so slow and small that they are drowned in normal pilot control adjustment.

4.4 - EC130B4 Variable NR laws

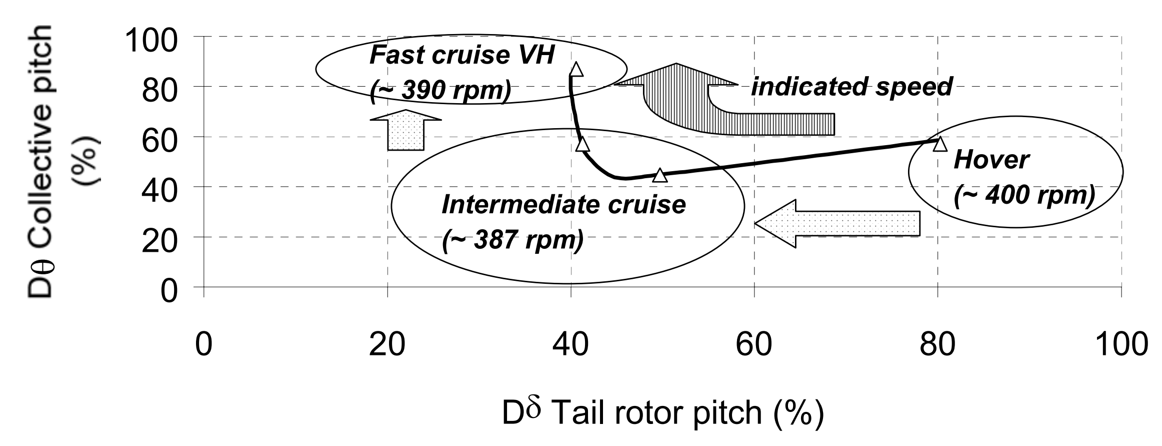
To achieve the EC130B4 NR targets, it has been decided to use a combination of collective lever and rudder pedal position, associated with an altitude effect (it is reminded that the collective lever position is representative of the collective pitch (Dθ) and the rudder pedal position is representative of the tail rotor pitch (Dδ)) :

NR = f (Collective Lever position, Rudder pedal position, Pressure altitude)

Indeed,

a) This law makes it possible to easily discriminate, for a given altitude, the 3 main flight phases identified above (hover, intermediate cruise, fast cruise), by an adequate collective pitch / tail rotor pitch combination, as may be seen on Fig 1, for a given weight and a given altitude.

Fig 1 : Typical low altitude acceleration from hover to VH



Hover : intermediate collective pitch / high tail rotor pitch,

Intermediate cruise : intermediate collective pitch / low tail rotor pitch,

Fast cruise : high collective pitch / low tail rotor pitch,

An adequate tuning does make it possible to define the correct NR = f (Dθ, Dδ) to satisfy the NR targets identified for EC130B4.

b) It makes it possible to increase slowly NR with altitude for cruise conditions

The altitude effect just consists in increasing NR for cruise conditions without modifying NR in hover conditions.

c) The NR variations are correlated with pilot actions (on the collective lever or on the rudder pedals) therefore the pilot can easily manage the NR variations.

Of course, the NR variation associated with a tail rotor pitch increase needs to be smooth and filtered, as the NR shall vary only on stabilized conditions, and not on dynamic maneuver (like on a "spot turn" maneuver). It is also to be noticed that, dynamically, the transition from hover needs to be achieved while maintaining a high NR on the initial acceleration (up to a sufficient speed). Therefore, the "tail rotor pitch" effect needs to be filtered with a long response time – which is implemented in the law.

4.5 - EC130B4 Variable NR system

The aim of the engine control system is to maintain the NR at a given target NR* speed (in fact, the engine control system controls the free turbine rotational speed NF, and not the NR, therefore in the following discussion NF instead of NR will be used).

The engine control system compares the actual NF with the target NF* and, depending on the delta, calculates an engine NG (and therefore fuel flow) increase or decrease, to cancel the delta. In addition, the NF control loop anticipates the NF variations through the collective lever position measurement (if the collective lever position increases, the NF control loop increases the NG - and therefore the fuel flow - without waiting for the NF to drop). This is basically how current engine NF control systems function today.

On the EC130B4, the engine control system is a FADEC. Starting from this situation, it is easy to understand that it is not more difficult, for the FADEC, to achieve the basic NF control function with a variable target speed rather than with a fixed speed. This is the advantage of numerical technology.

Therefore, the most simple way of proceeding is to introduce the variable NR law described here above in the FADEC itself, to achieve the NF/NR variations. The only issue is to provide the adequate information to the FADEC: Dθ, Dδ, Zp (see Fig 2).

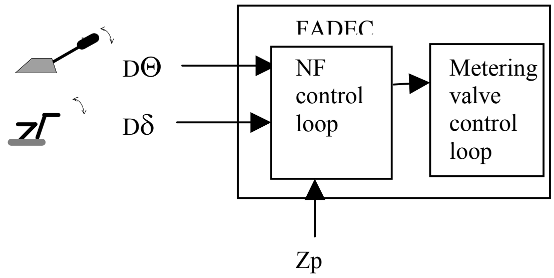


Fig 2 : Variable NR system

As already stated, on current helicopters, the collective lever position is a parameter that is already provided to the FADEC in order to anticipate the power needs of the helicopter. The ambient pressure is also supplied to the FADEC. Therefore, for the EC130B4, the only physical modification is to install a potentiometer on the rudder pedal (representative of Dδ). Therefore the variable NR system on the EC130B4 costs only the addition of a potentiometer, which means that all the advantages drawn from the system are not translated into complexity !

4.6 - Flight test results

The aircraft NR law, as measured in flight, is as shown on Fig 3.

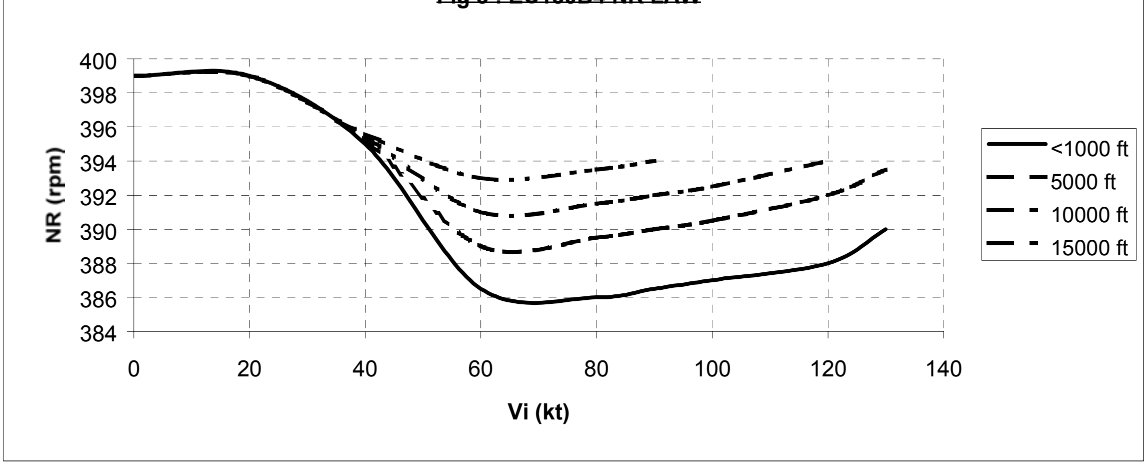


Fig 3 : EC130B4 NR LAW

As may be seen, the targets that have been initially set are met. The flight tests have showed smooth NR variations, and pilots have stated that, due to the parameters selected (position of controls), NR variations were easy to anticipate and understand.

4.7 - Noise reduction

The noise reduction achievement is quite significant:

- As far as the ICAO annex 16 requirements are concerned, the noise level of the EC130B4 in fly-over is 84,2 EPNdB, that is 8,6 EPNdB less than the maximum authorized level !

- As far as the FAA Grand Canyon National Park requirement is concerned, with 1 pilot + 6 passengers, the noise level is 0,8 EPNdB less than the maximum authorized level.

4.8 - Conclusion on the variable Main Rotor speed system

On the particular EC130B4 application, due to the numerical engine control system (the FADEC), it was possible to introduce, quite simply, a variable NR law, dependent on the collective lever position, the rudder pedal position, and the pressure altitude.

This law makes it possible to meet all the targets that were set for this helicopter and especially allows, in addition to the noise reduction associated with the introduction of the fenestron® on this helicopter, an additional noise reduction by decreasing the NR in all the low-altitude intermediate cruise conditions (from 60 to 120 kt). Furthermore, performance are kept or even improved, and especially for the low point of the altitude/speed diagram.

5 - Electrical and automatic engine power control back-up system

5.1 - Background

For a single-engine helicopter, like the EC130B4, the issue of the engine failure is considered very carefully during the design and development phases.

From a very general viewpoint, the engine is considered to be failed if the engine, and its power control system, is unable to maintain the NR "efficiently" (in stabilized conditions but also in transient conditions). For example, a mechanical failure (such as a bearing failure), or a fuel pipe failure generally cause an in-flight shutdown.

Of course, the engine power control system itself, understood as the system that controls the position of the fuel metering valve, can be one of the causes of an engine failure. It may cause, for example :
- erroneous NR control,
- Unacceptably slow engine acceleration / decelerations,
- Risks of engine surge or of flame-out. Those engine power control system failures are referred to as "major" control system failures.

On pure hydro-mechanical units as well as on first-generation FADEC, in order to allow the pilot to go on using the engine power, even in case of an engine control system major failure, a manual and mechanical back-up is generally provided. This back-up allows the pilot to overcome the control system by directly controlling the fuel flow, either with a lever or with a twist grip on the collective lever. Thus, an engine power control system failure does not result in an engine failure, as it is possible for the pilot to maintain NR by adequate action on the back-up control.

Nevertheless, these manual back-ups do have some drawbacks : in case of an engine power control system failure, the pilot workload is significantly increased, as he has to control not only the aircraft with its normal controls (collective lever, cyclic lever, rudder pedals) but also the engine fuel flow. Therefore the pilot is generally to train for the engine power control system failure, to guarantee his ability to manage the aircraft in this situation.

5.2 - EC130B4 targets

The EC130B4 is equipped with the ARRIEL2B1 engine, the engine power control system of which is a FADEC. The Ecureuil AS350B3 was already equipped with a FADEC, but with a single-channel architecture and a manual and mechanical back-up. In case of an engine power control system major failure (usually referred to as "FADEC major failure", altough the FADEC itself is generally not failed), the FADEC stops the stepper motor that controls the fuel metering valve ("fail freeze concept", for maximum safety, as there is no engine power variation when the failure occurs) and causes a red light to illuminate on the warning panel, with an associated aural warning. The pilot only has to increase or decrease the fuel flow by moving a twist grip installed on the collective lever to increase or decrease the fuel flow depending on the power required by the helicopter, to maintain the NR.

For the EC130B4, the target was to make another step toward :

- the pilot comfort, in case of engine power control system failure, by limiting the workload,

- an economical advantage, by canceling the necessity for training periodically,

- an improved safety, by reducing the FADEC major failure rate (= cases where the pilot has to use the engine power control back-up system).

Starting from existing Ecureuil version (one-channel FADEC + mechanical and manual back-up), this was possible :

- by introducing a dual-channel FADEC architecture,

- by introducing an electrical and automatic independent back-up, in case of FADEC failure.

Indeed, the first action results in a reduced FADEC major failure rate (therefore the rate of use of the back-up will be reduced). The second one results in a situation where, if a FADEC major failure occurs, then a back-up control system is engaged automatically and controls the fuel flow automatically to maintain the NR, without any pilot action. Therefore, after a FADEC major failure, the pilot’s workload is not increased, and as a consequence, training for FADEC failure is no longer necessary, which is a real economical advantage.

The following presentation will focus on the electrical and automatic back-up, which is the major innovation. Indeed, even if it is the first time such a FADEC is installed on a single-engine helicopter, the dual-channel FADEC architecture is already known on other commercial helicopters (like the EC155B for example).

5.3 - Technical targets of the electrical and automatic back-up

The detailed design targets of this engine power control back-up system were defined as follows :

- be automatic, as already said,

- be independent from the dual channel FADEC, to avoid common failures,

- be as simple as possible, to be reliable and cheap (it shall not be a “third FADEC channel”, but a simple system, as a back-up should be)

- be efficient as far as engine accelerations or decelerations are concerned, to demonstrate that the in-flight minimum and maximum transitory NR are acceptable, and therefore that training is unnecessary,

- include anti-surge and anti-flame-out protections

5.4 – Description of the EC130B4 electrical and automatic engine power control back-up system

The selected design is based on the principle of all engine power control system : to keep the NR (in fact the free turbine rotational speed NF) constant by moving a fuel metering valve. If the NR/NF is too low, it is necessary to open the fuel valve to increase engine power ; if the NR/NF is too high, it is necessary to close the fuel valve to reduce engine power.

Therefore the idea is to use a NF measurement, to compare it to a target NF* and to increase or decrease the fuel flow depending on the delta.

More precisely :

- Engine fuel metering system : the ARRIEL2B1 engine fuel flow may be controlled even after an engine power control system major failure : indeed, the ARRIEL2B1 fuel metering system is equipped not only with a main metering valve but also with a back-up metering valve. In case of a major failure, the main valve is frozen and therefore, the fuel flow metered by the main valve is kept constant (“fail-freeze” concept). Now, the back-up metering valve may be used either to increase or to decrease the fuel flow compared to the fail-freeze fuel flow. This back-up metering valve is equipped with an anti-flame-out stop.

- Back-up system : the back-up system is made of the 3 following components :

- a NF sensor, installed on the engine free turbine (different from the NF sensors used by the FADEC),

- an electrical DC actuator, to control the back-up fuel metering valve

- an electronic card, which acquires the NF and calculates the voltage to apply to the electrical actuator.

It must be noticed that the system is simple (to be cheap and reliable), as it uses only one sensor.

See Fig 4.

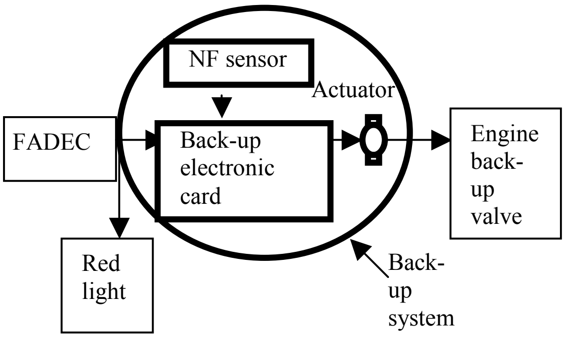


Fig 4 : electrical and automatic back-up system

- Operation : in case of an engine power control system major failure, the FADEC causes a red light to illuminate on the warning panel and activates the electronic card with the same signal and the electronic card calculates the voltage to be applied to the electrical actuator. Equations are as follows :

- if $NF < NF - \delta$, then increase fuel flow at a given speed (corresponding to a given dWF/dt)

- if $NF > NF + \delta$, then decrease fuel flow at a given speed (corresponding to a given dWF/dt)

- dWF/dt is defined so as to protect the engine against surge.

The system is built so that no untimely activation of both FADEC and back-up systems (at the same time) is possible. It must also be noticed that both the FADEC and the back-up system are qualified under the relevant EMI/lightning regulations.

5.5 - Operation and performance

From an operational viewpoint, when FADEC major failure occurs, a red light is illuminated (associated to an aural warning) to warn the pilot. Nevertheless, no immediate action is required, as the back-up system is automatically engaged and the fuel flow is automatically metered by the back-up fuel valve. The pilot must only avoid fast collective pitch variations ("cautious piloting"), as the back-up NF control is less efficient, of course, than the FADEC control system, but this is the normal recommendation for minor failures.

Indeed, the system has proved to allow efficient engine accelerations and decelerations in the whole flight envelope. The minimum and maximum NR obtained with various collective pitch variations were demonstrated to be within the helicopter authorized minimum / maximum NR values. The pilot does not see a significant difference between the helicopter/engine behavior with the FADEC (with a minor failure) or with the back-up system. Several pilots (including pilots from the Authorities) have tested the system and all have agreed that no training for the back-up was necessary.

5.6 - Conclusion

The electrical and automatic engine power control back-up system, as it is, meets the targets that were set :

- the back-up is simple and reliable,

- in case of FADEC major failure, the pilot goes on without any particular action and any significant workload increase (pilot comfort)

- the engine behavior is similar enough with the back-up system and with the FADEC so that it is possible to cancel the training to the FADEC major failure (economical advantage)

- globally, safety is increased, due to the dual-channel FADEC architecture and to a particularly easy-to-pilot back-up.

6 – General conclusion

The EC130B4 engine installation includes many innovations, the aim of which is to improve the competitiveness of the aircraft on various aspects :

- reduced noise
- improved economics
- increased safety.

The engine installation contributes to the noise reduction by the introduction of a variable NR law, which allows low NR to be used in flight conditions where there is a noise annoyance risk, while maintaining performance in the rest of the flight enveloppe.

The engine installation contributes to the economy by the introduction of an electrical and automatic power control back-up system, which makes the pilot training to the FADEC failure unnecessary.

Last but not least, the comfort for the pilot of an automatic and smooth back-up system in case of engine power control system failure, and the reduced failure rate of this power control system due to the dual-channel FADEC architecture, do contribute to the increased safety.