LOSS OF OIL BEHAVIOR OF EUROCOPTER GEARBOXES FROM AS350 TO EC225

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Abstract

The aim of this document is to relate the evolution of Eurocopter gearboxes design in order to continuously improve safety in loss of oil conditions and to be compliant with the latest regulation requirements.
Loss of oil conditions directly affect the global behavior of a gearbox. In fact, gearboxes are in normal use often lubricated by pressurized oil. This kind of system ensures non metal-metal contacts in loaded areas and a good cooling of mechanical elements.
Therefore in loss of oil situations gears and bearings have to support a progressive decrease of the contacts quality that leads to local overheating in these areas. As there is no more cooling ensured by the oil, these numerous locals overheating generate a global increase of all elements temperatures.
These phenomena force the designer to invent dedicated solutions to guaranty a satisfactory behavior of the gearbox. Eurocopter has always worked on that subject, and often anticipated standards requirements.
First tests dated from the development of AS350 gearbox in the late 70’s. This experience was then applied to Super Puma MKI. Then it appears a difference of behavior from small gearboxes towards much more powerful ones. Technologies were improved for the MKII, and for Tiger gearbox specific requirements of high survivability deeply influence the design.
Development and research activities for nearly 30 years are presented and the last development step is introduced : the new "back up system" specially developed for the EC225 medium-heavy helicopter.
Test results are commented to evaluate benefits of the different technologies that have been developed over the years.
To anticipate this behavior, recent numerical models have been developed. They conduct to a global virtual model of gearbox temperatures in loss of oil conditions. It gives to designer the ability to anticipate loss of oil gearbox's behavior.

1 Role of lubrication for gearboxes

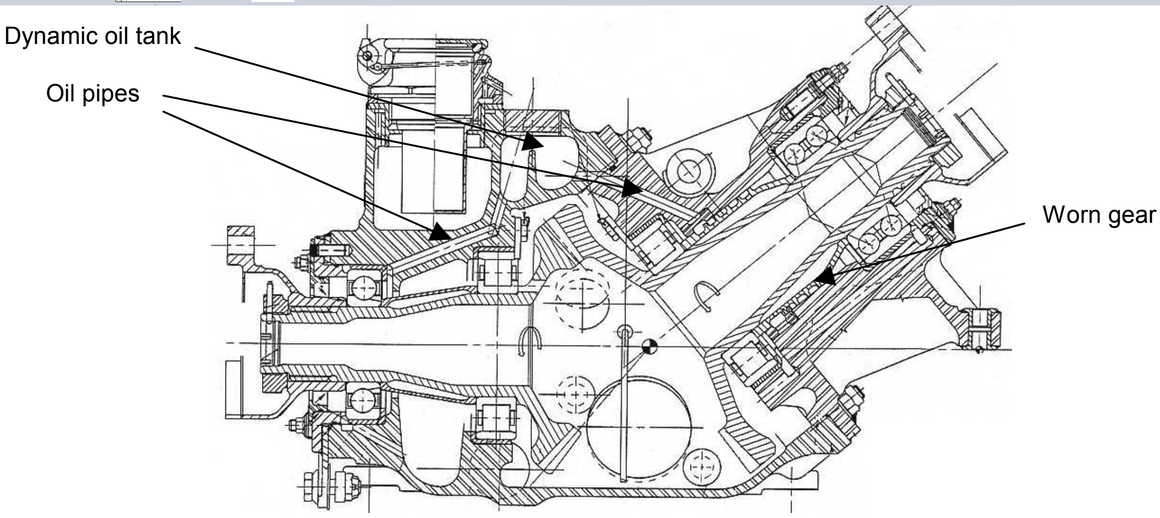
The lubrication in gearboxes has 3 main roles. The first one is to install a continuous film of oil in the loaded contact areas. This film allows a decrease of the coefficient of friction and consequently a decrease of thermal losses generated by contact forces. In the same time, with sometimes the help of special additive it ensures the absence of any metal-metal contacts that could rapidly leads to wear, micro welding or scratches.
The second one is to ensure cooling of contacts areas in gears and bearings. The oil flows capture heat at the contact and conduct it towards a heat exchanger.
The last role is to participate to the monitoring of the gearbox. Oil flows have to drive particles to chip detectors, without creating uncontrolled local recycling. Moreover the oil tank temperature represents a kind of average temperature for the gearbox.

2 Typical suitable technologies

The simplest way to lubricate a gearbox is to use grease, but this kind of lubrication is not efficient for cooling and monitoring the gearbox. Some research activities have been done on that topic in the eighties in Eurocopter on an AS350 gearbox. A dedicated design of the housing with cooling fin had been made to ensure a forced air-cooling. As the results were not so good in terms of temperature map and leakage this kind of lubrication has been no more developed.

If you use oil instead of grease, there are two ways to lubricate a gearbox, without pressure or with pressure.

The basic way to lubricate without pressurized oil is to make gears splash into oil. This situation can be improved using a centrifugal effect and collectors to fill some little dynamic tanks. Then gravity conducts lubricant on non-splashing area. Additive to that Eurocopter uses sometimes as on the AS332 intermediate gearboxes a worm gear to conduct oil in an opposite way of the gravity.



Example of splash lubrication (Super Puma Intermediate gearbox)

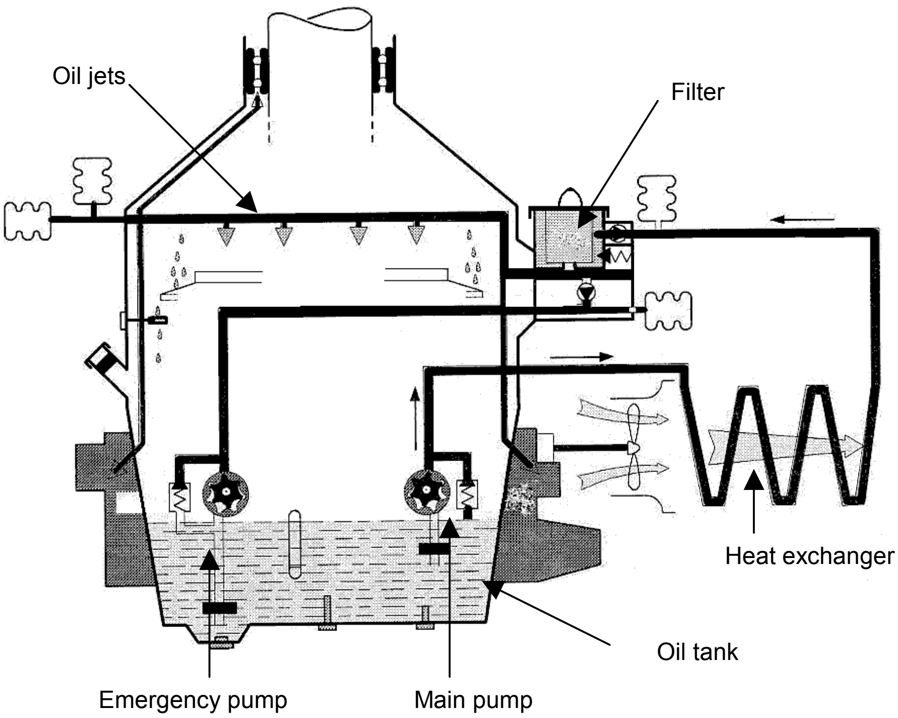
This method is reserved to simple mechanisms.

For more powerful gearboxes, oil pressurized system has to be used. A more complex design has to be done because these systems require :
- Oil jets
- A pressurized oil circuit
- A filter to protect jets from particles
- A pump to ensure flows and pressure
- A tank to collect oil and feed the pump

This architecture does not ensure cooling and is used for example on EC120 gearbox. It introduced a first weak point, the pump that has to be design in a proper way.

If some cooling is needed, a heat exchanger has to be installed. As it must be located outside the gearbox it introduces another weak point in the oil circuit. To ensure a proper lubrication even in case of heat exchanger failure (leakage), Eurocopter gearboxes are often suited with an emergency circuit, which imposed the introduction of an emergency pump.

All these constraints imposed a quite complex design to lubrication system of high power gearbox.



Example of pressurized and cooled lubrication system (Super Puma main gearbox)

3 Loss of oil situation

A loss of oil situation happened if a gearbox has lost its lubrication function as descried in the previous paragraph. To examine the consequences on the aircraft, failures modes and functionnal hazard assessment will be described.

3.1 Failure mode analysis

The following array summarized the typical failure modes for each system :

Kind oil lubrication	Failure modes	Possible failures
Splashing	- Total loss of lubricant	- Leakage on the gearbox
Pressurized	- Total loss of lubricant - Loss of oil flow	- Leakage on the gearbox - Breaking of pump
Pressurized with a cooling unit	- Total loss of lubricant - Loss of oil flow	- Leakage on the gearbox - Leakage on the cooling unit - Breaking of 1 pump
Pressurized with cooling unit and emergency circuit	- Total loss of lubricant - Loss of oil flow	- Leakage on the gearbox - Commun breaking of both pumps

The more the lubrication system complex is, the more the number of possible failures increases.
The addition of an emergency circuit really improved the reliability of the system because it allows a loss of the cooling function without a loss of the lubrication one. This architecture is not mandatory by regulations but Eurocopter often fitted his powerfull gearboxes with an emergency pump (Super Puma, EC155, Tiger).

3.2 Mechanical consequences on gearboxes

The total loss of lubricant and the loss of oil flow have practically the same consequence. It is a stop of lubrication and cooling. These new conditions introduce major changes in loaded contact areas.

The first physical change is an increasing of temperatures in contact areas. These imposed a decreased of oil viscosity. Additive to that, the loss of oil feeding ensures a decrease of oil film size. This can lead to metal-metal contact, scratches and micro welding which will strongly increased the coefficient of friction. This increase of the coefficient of friction will increase thermal losses.

As temperatures grow up thanks to contacts behavior, mechanical parts will start to have some thermal expansions. As it only exists local heat sources, temperatures are not homogenous on the whole gearbox. This can generate differential thermal expansion that can modify plays in bearing or gears.

At the end with a continuous over heating run, pieces can reaches their annealing temperature and loss their mechanical characteristics.

These phenomena are general for all gearboxes, but a good behavior in loss of oil conditions is more difficult to reach on high power gearboxes. In fact the efficiency on a reduction stage only depends of the technologies employed. Thermal losses are proportional to the transmitted power, and as constitutive materials are practically the same in small or big gearboxes, the over heat generation is more difficult to bear for high power gearboxes.

Now detailed mechanism of degradation will be described.

Teeth contacts :

Micro welding and scratches generate an increase of roughness that leads to a decrease of the efficiency and so to an increase of thermal losses. This situation leads generally to spalling that can generate tooth breaking.

Example of scratches on a spiral bevel gear in loss of oil situation

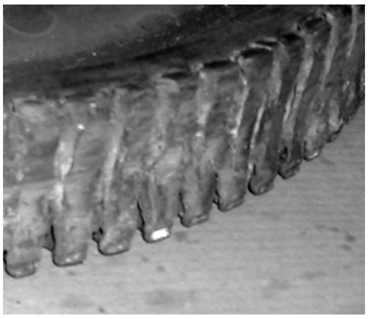
Thermal expansions of elements:

Differential thermal expansion can reduce in significant way radial or axial plays. On a gear, if meshing clearance is not big enough it can appear a double contact on driving and non-driving side of teeth. This leads to decrease of the efficiency of the reduction stage concerned.

On bearing, an abnormal thermal expansion can jam the cage. It creates internal forces in the bearing that are often strong enough to break the cage and to let free rolling element. Moreover the over heating caused by plays reduction can also leads to a creeping of inner or outer race.
In both cases, these situations lead to a potential displacement of the shaft that can interrupt the meshing process or jam the gearbox.

Loss of materials properties:

An overheating on a long period of time allows reaching the tempering temperature of elements. In this situation, teeth can losses their ability to transmit high loads. A collapse of teeth can append.



Example of teeth collapse

3.3 Consequences on the aircraft

There are two main types of consequences on the aircraft. The first one is the loss of rotors driving that lead to an autorotation. The second one is the jamming of gearbox that can lead to a jamming of the main rotor. This situation unfortunately causes the loss of the aircraft.

As these two situations have to be as much as possible avoid, it is very important for manufacturer to control the behavior of its gearbox in loss of oil situation.

As it is impossible to make such an event extremely remote with a complex lubrication system, manufacturers have to demonstrate the ability of their gearbox to pass successfully test asked by JAR.

4 Recall of JAR27 and JAR29 requirements

The paragraph that covers loss of oil situation in JAR 27 and 29 is the 927 (c). The level of performance asked for light and heavy helicopter is not the same.

Recall of 27.927 (c) Amendment 3:

« It must be shown by tests that the rotor drive system is capable of operating under autorotative conditions for 15 minutes after the loss of pressure in the rotor drive primary oil system. »

Recall of 29.927 (c) Amendment 3 :

« (c) *Lubrication system failure.* For lubrication systems required for proper operation of rotor drive systems, the following apply:

(1) *Category A.* Unless such failures are extremely remote, it must be shown by test that any failure which results in loss of lubricant in any normal use lubrication system will not prevent continued safe operation, although not necessarily without damage, at a torque and rotational speed prescribed by the applicant for continued flight, for at least 30 minutes after perception by the flight crew of the lubrication system failure or loss of lubricant.

(2) *Category B.* The requirements of Category A apply except that the rotor drive system need only be capable of operating under autorotative conditions for at least 15 minutes. »

For light aircraft and Category B aircraft the JAR requirement is to be able to function properly during 15 minutes without loads, after a total loss of oil.
For “Category A” helicopter, the target is to function properly with specified loads during 30 minutes after total loss of oil.

As it is more difficult to control the behavior of high power gearboxes, the requirement for “category A” aircraft is much more difficult to reach than the other one.

These exigencies are not so old, but Eurocopter has always anticipated requirements and works for many years on improving gearbox behavior in loss of oil situations.

5 EC technological choices to improve loss of oil behavior

For more than 30 years, 4 axes have been developed by Eurocopter transmission team, which are :

- gearbox architecture
- Materials capability
- Residual lubrication
- Additive external systems

The objective on the architecture is to avoid too compact assemblies and to control thermal exchanges between several heating sources. It has been successfully apply on the Tiger main gearbox which includes a simple epicyclical stage and a big combiner wheel.

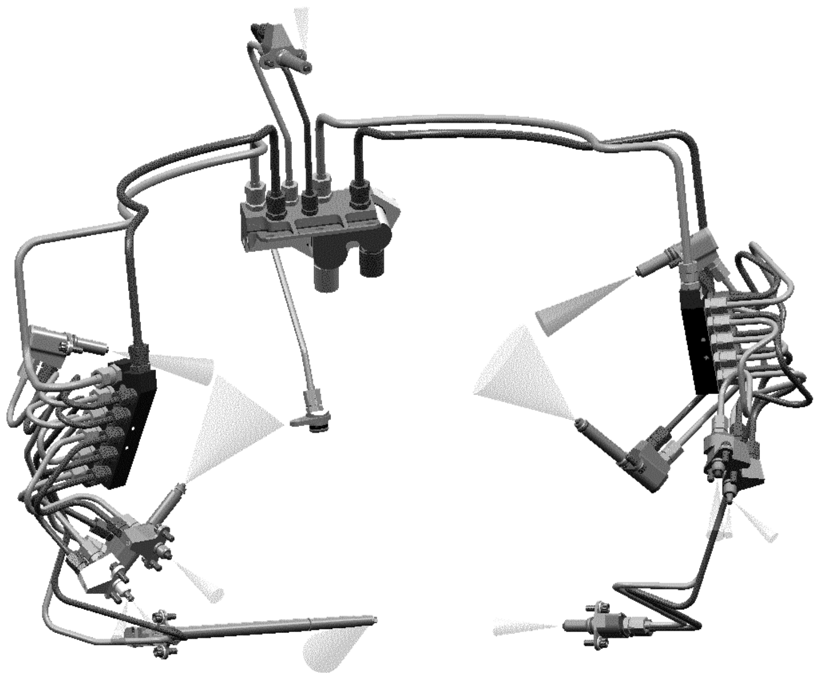
For materials, the idea is to use some alloys that have a very high temperature of tempering. So Eurocopter has begin to use high temperature steel for bearing as M50 and M50nil, on Super puma high speed module for example.

For gears and integrated raceways Eurocopter has developed is own deep nitriding on 32CDV13 steel. Its behavior is much better than carbonized steel on high temperature because its temperature of annealing is more than 3 times higher. This has been widely use on many Eurocopter gearboxes.

Another way of research was to decrease the coefficient of friction using specific surface treatment (silvering, …).

Some other research activities have conduct to a patented design of scoops that allows a local recycling of oil. The only remaining problem with such a design is the particles caption by chip detectors in normal situation.

The last axe that has been explored thanks to research program and that has been applied on EC225 (last Super Puma version) is the use of an external system that sprays a cooling fluid inside the main gearbox. Severals sprays have been design to cool all hot points of Super puma main gearbox in loss of oil situation.



EC225 cooling fluids sprays and pipes

The spraying is ensured by a mixed of air and fluid (Eurocopter patent). A dedicated system of air and fluid feeding module has been specially design.

This system is engaged by the crew has soon the oil pressure alarm lights on.

6 EC gearboxes performances in loss of oil situation

For EC gearboxes, the loss of oil behavior is always demonstrated by tests.
The test program is often quite similar and it is conduct in this way :

- Run at the maximum continuous power with normal lubrication
- Stabilization of temperatures
- Gravity draining of the gearbox
- Oil low pressure alarm lights on
- Decrease of the power to the minimum one for flight with maximum weight
- Running after total loss of oil during 30 minutes
- A landing is performed (maximum take off power)
- Additive time is done

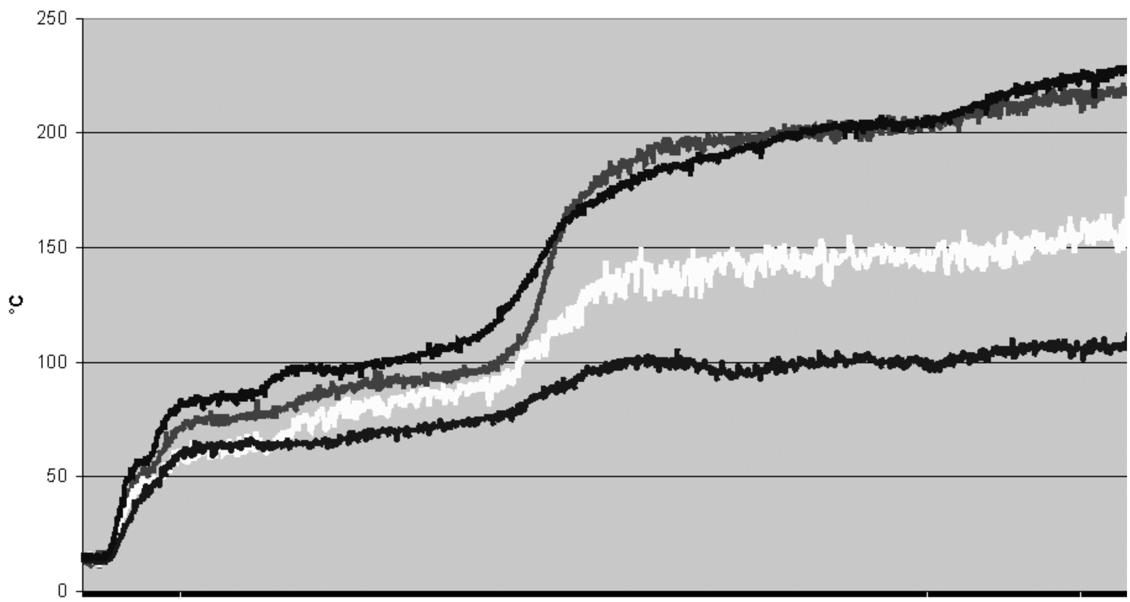
The following array gives a summary of Eurocopter main gearboxes performances in loss of oil situation.

Aircraft	Aircraft weight (ton)	JAR Requirements	Respect of JAR requirement	Additive Time	State of MGB at the end
EC120	1.7	Autorotation	Yes	60 minutes	Good
AS355	2.2	Autorotation	Yes	> 60 minutes	Good
EC155	4.8	30 minutes	Yes	-	Good
TIGER	6.1	30 minutes (customer need)	Yes	35 minutes	Good
AS332L2	9.5	30 minutes	Yes	-	MGB jamming
EC225	11	30 minutes	Yes	21 minutes	MGB jamming

Eurocopter gearboxes always anticipate or respect JAR requirements.

During research activities, on a prototype derived from Tiger MGB fitted with a research external spraying system, the test duration reached 6 hours with 3 hours at maximum continuous power without any damages.

For high power main gearboxes, the temperature reached can be very high (sometimes more than 300°). In fact the gearbox try to find a thermal equilibrium without lubrication and cooling.



Typical example of temperatures curves in loss of oil test

To anticipate MGB behavior early in design process, some research activities are made to obtain make a virtual loss oil test.

7 Loss of oil modeling to improve design

The purpose of this activity is to simulate the temperature map of the gearbox during loss of oil situation to adapt :

- Architecture
- Materials used
- Residual lubrication
- Clearances

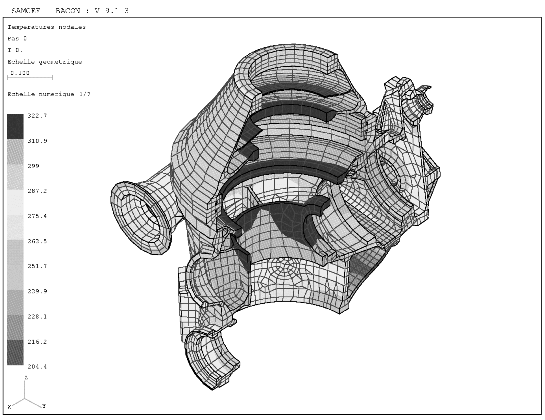
The target is to have a model able to point out excessive temperatures and clearance vanishing.

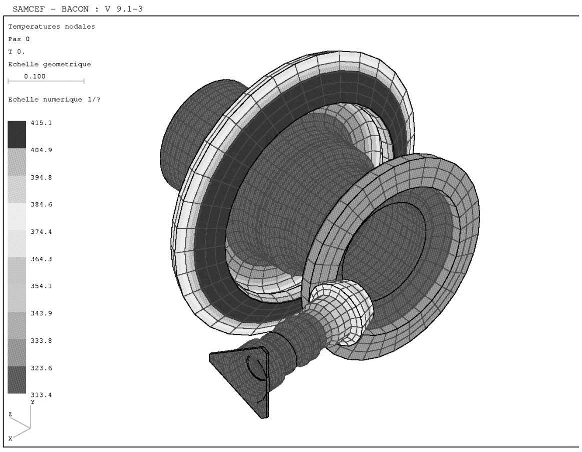
This complex model needs many inputs, a valid CAO 3D mock up and the knowledge of thermal losses generated in all contact areas, by meshing, bearings and seals.

These thermal losses are calculated with dedicated analytical models that are introduced in a 3D finite elements model.

This 3D model needs all thermal characteristics of shafts and housing on the conduction side and the convection side. These values are not easy to obtain and are mainly defined by tests or experience.

This model allows putting in light hot points in gearboxes and performing coupled thermo-mechanical computations to simulate thermal expansions.





Example of 3D mock up map of an Eurocopter MGB housing and bevel pinion

8 Conclusions

For 30 years Eurocopter has always improve the design of its gearboxes towards loss of oil behavior. Many technological innovations realized thanks to important research programs have been developed and applied on Eurocopter serial gearboxes.
Last numerical tools allow having more accurate knowledge of loss of oil behavior, and it is now possible for Eurocopter designers to modify very early the design of gearbox.
But many works have still to be done to control all parameters involved in loss of oil conditions, and Eurocopter will continue its efforts to always propose better design to its customers.