GLOBAL THERMAL DYNAMIC SIMULATION OF MAIN GEARBOX, AND APPLICATION TO EC225 COOLING SYSTEM

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Abstract: In this paper, we describe a new brand approach to modeling the thermal behavior of a power transmission system of a rotorcraft. This work is part of the continuous research and development strategy of Eurocopter to insure a high level of customer satisfaction. Based on a simple theory, this method uses leading edge mathematical computation tool and brings very good correlation with experimental test results. To conclude, we describe briefly an application on the additional cooling system of the EC225.

1. INTRODUCTION

In order to insure a high level of operator satisfaction especially offshore customers, Eurocopter decided to improve the EC225 cooling system to further extend the capacity to fly at the fallback speed in case of loss of the main cooling unit. This development has been managed using a new global thermal simulation of the main gearbox. The thermal behavior of the main gearbox is dependant of many parameter such as power transmitted, speed, height and outside air temperature and many else. To optimize the design of this additional cooling system Eurocopter has developed this new thermal modeling. The integrity of the main gearbox is fundamental for the safety of the flight.

2. PRINCIPLE OF THE GLOBAL THERMAL MODELLING

The purpose of this modeling is to have a fast access to oil temperature prediction taking into account all the parameters of the flight. The previous modeling needs a complex geometry capture and where not easy to modify. Those models use to perform computation complex nodal network. Each elementary part must be consider as a node of this network and all thermal exchange between parts leads to define a link in this network. For such complex system which is the main gearbox of a helicopter, the result is a system of hundreds of equations. The solution needs a high computation power and a long time to be found. The major issue with those classical approaches was the necessity to calibrate with several experimental tests very high number parameters in each equation.

This new thermal dynamic modeling makes use of quite simple algorithms but uses a brand new approach of thermal simulation leading quickly to a high level of accuracy. The base principle of this method is to have a global view of the system. In this method we consider global elements, the gearbox parts are divided in two classes like it is illustrated by the figure 1.

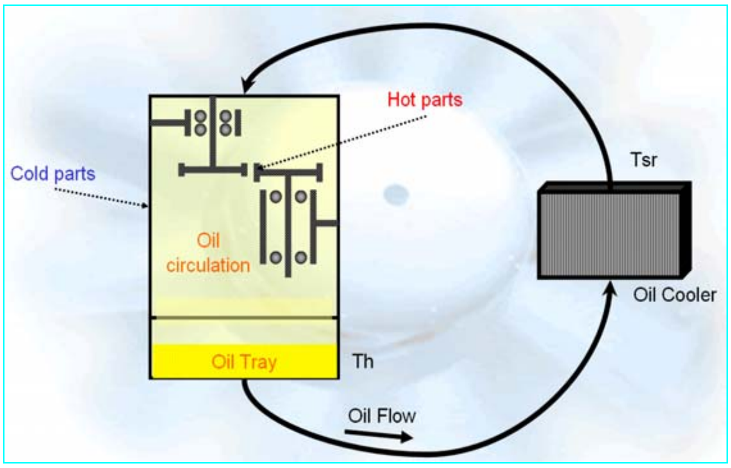

Figure 1: Principle scheme

The first one, the hot parts are the moving parts or parts with direct relation with the moving parts. Those parts are entry point of the thermal flow coming from the power losses in gears, bearing and seals. Typical hot parts are gear, bearing, shaft… The second one: the cold parts receive the thermal flow indirectly by conduction from the hot parts or from oil. Those parts are also the interface with outside environment. Typical cold parts are housings or caps. The third element consider inside the modeling is the most important one. It is the cooling and lubrication fluid: the oil. The oil circulation insure the homogenization of the temperature in the system, it is a thermal carrying fluid. Considering oil thermal action we define the thermal fluid exchange in the global diagram shown in figure 2. Others aspects must be taken into account as oil cooler works, convection with outside air.

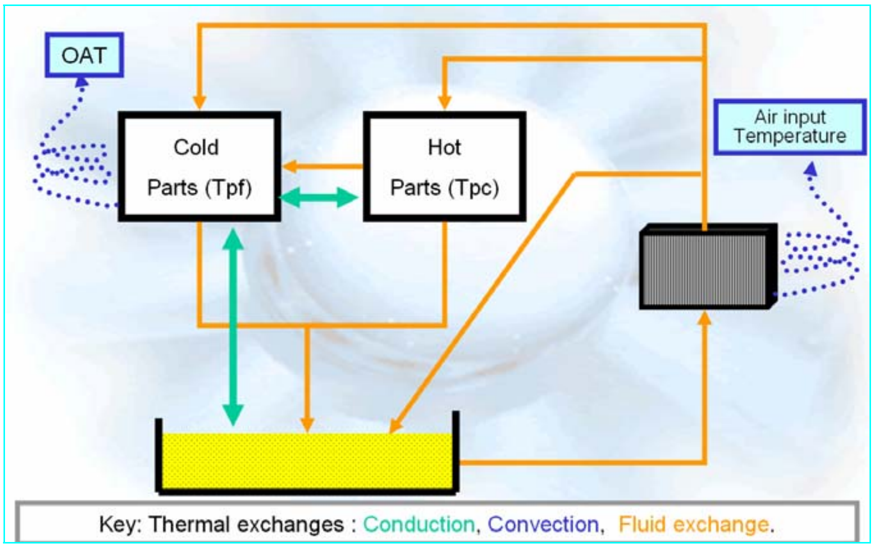

Figure 2: Global diagram of thermal flow

3. FUNDAMENTALS EQUATIONS

As it is previously mentioned, the method is based on simple principles of heat transfer and thermal energy balance. The fundamental equation (1) of the method is the famous first law of the thermodynamic for an open system considering incompressible element.

$$\Sigma\Phi\text{incoming} - \Sigma\Phi\text{outcoming} = M \times Cp \times \frac{d\theta}{dt} \qquad (1)$$

Now, if we written these equation for each element of the global approach. We obtain the following set of three differential equations mutually dependant (2) .The difficulty of computation is increased by the all oil physical characteristics as density, thermal capacity that are varying with the temperature.

$$\begin{cases}
\underline{For\ the\ hot\ parts:} \\
\underbrace{P\cdot(1-\eta)}_{Mechanical\ power\ loss} - \underbrace{\dot{m}_{oil\,HP}\cdot Cp_{oil}\cdot(\theta_{HP}-\theta_{CO})}_{Oil\ conduction\ thermal\ transfert} - \underbrace{\frac{(\theta_{HP}-\theta_{CP})}{Rth_{HP/CP}}}_{Conduction\ to\ cold\ part} = \underbrace{M_{HP}\cdot Cp_{HP}\cdot\frac{d\theta_{HP}}{dt}}_{Hot\ part\ mass\ temperature\ elevation} \\
\underline{For\ the\ cold\ parts:} \\
\underbrace{\frac{(\theta_{HP}-\theta_{CP})}{Rth_{HP/CP}}}_{\substack{Conduction\ from\ hot\ part\\ to\ cold\ part}} + \underbrace{\dot{m}_{oil\,HP/CP}\cdot Cp_{oil}\cdot(\theta_{HP}-\theta_{CP})}_{Oil\ conduction\ thermal\ transfert} + \underbrace{\frac{(\theta_{oil}-\theta_{CP})}{Rth_{oil}}}_{\substack{Conduction\ from\ oil\\ to\ cold\ part}} \\
-\underbrace{\dot{m}_{oil\,CP}\cdot Cp_{oil}\cdot(\theta_{CP}-\theta_{CO})}_{Oil\ conduction\ thermal\ transfert} - \underbrace{H\cdot S\cdot(\theta_{CP}-\theta_{OAT})}_{Convection\ with\ surronding\ atmosphere} = \underbrace{M_{CP}\cdot Cp_{CP}\cdot\frac{d\theta_{CP}}{dt}}_{Cold\ part\ mass\ temperature\ elevation} \\
\underline{For\ the\ oil:} \\
\underbrace{\dot{m}_{oil\,CP}\cdot Cp_{oil}\cdot(\theta_{CP}-\theta_{oil})}_{Oil\ conduction\ thermal\ transfert} + \underbrace{\dot{m}_{oil\,HP}\cdot Cp_{oil}\cdot(\theta_{HP}-\theta_{oil})}_{Oil\ conduction\ thermal\ transfert} - \underbrace{\dot{m}_{oil}\cdot Cp_{oil}\cdot(\theta_{oil}-\theta_{CO})}_{Oil\ conduction\ thermal\ transfert} \\
-\underbrace{\frac{(\theta_{oil}-\theta_{CP})}{Rth_{oil}}}_{\substack{Conduction\ from\ oil\\ to\ cold\ part}} = \underbrace{M_{oil}\cdot Cp_{oil}\cdot\frac{d\theta_{oil}}{dt}}_{oil\ temperature\ rise}
\end{cases} \qquad (2)$$

The heat exchanger action is traduced by an implicit link (3) between the oil temperature at the inlet and at the outlet of the cooler.

$$\theta_{oil\,outlet} = \theta_{oil\,inlet} - \frac{\dot{m}_{air}\times Cp_{air}\times\Delta\theta_{air}}{\dot{m}_{oil}\times Cp_{oil}} \qquad (3)$$

We can notice that the numbers of parameters to fix in those equations are reduced that is an advantage we develop in the following paragraph.

4. NUMERIC RESOLUTION

The numerical resolution of the set of three differential equations is performed with mathematical software using a Newton-Raphson algorithm. We only need one run on the test rig to calibrate all the parameters of the model

The result can be plotted as below as an oil MGB temperature function of time. The graph on the figure 3 represents comparison during a non stabilized phase of run on an EC225 main gearbox between test results and model. This is one of the test results taken into account for the modeling validation; the level of accuracy obtained is very good.

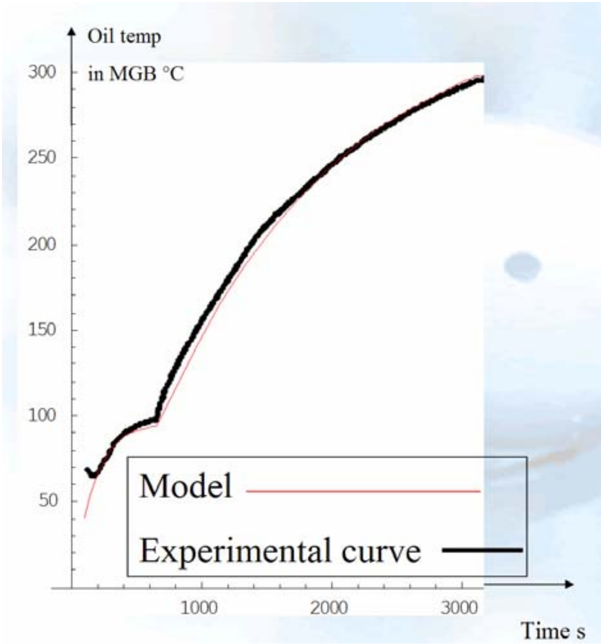

Figure 3: Validation of the thermal modeling by confrontation oil temperature with test results

5. APPLICATION TO EC225 MGB COOLING SYSTEM

The applications of this method are already numerous: simulation of oil temperature variation with various scenarios, extrapolation to extreme temperature condition from flight test results... One of these applications is the improvement of EC225cooling system for off-shore applications. The additional cooling system of the EC 225 (figure 4 and 5) brings an extended time of 2 hours of flight after a loss of the main cooling unit. This feature allows a return to base with a high level of safety.

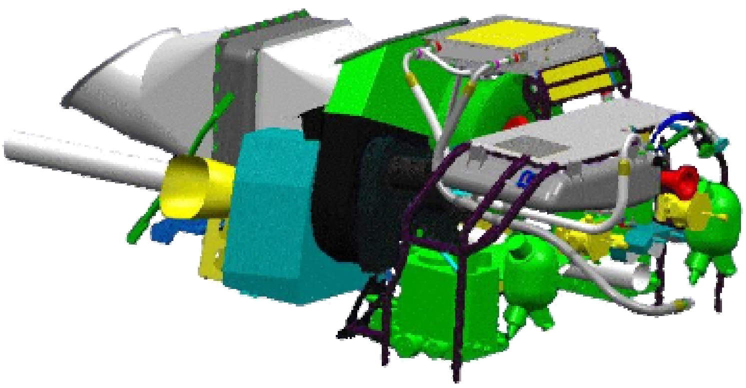

Figure 4: CAD model EC225

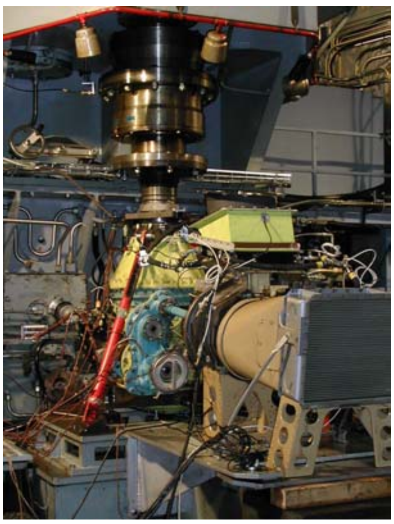

Figure 5: test rig for validation

During the design the global thermal simulation has allowed to predict oil temperature in all thermal conditions. Flight and bench tests have shown a very high accuracy of the model.

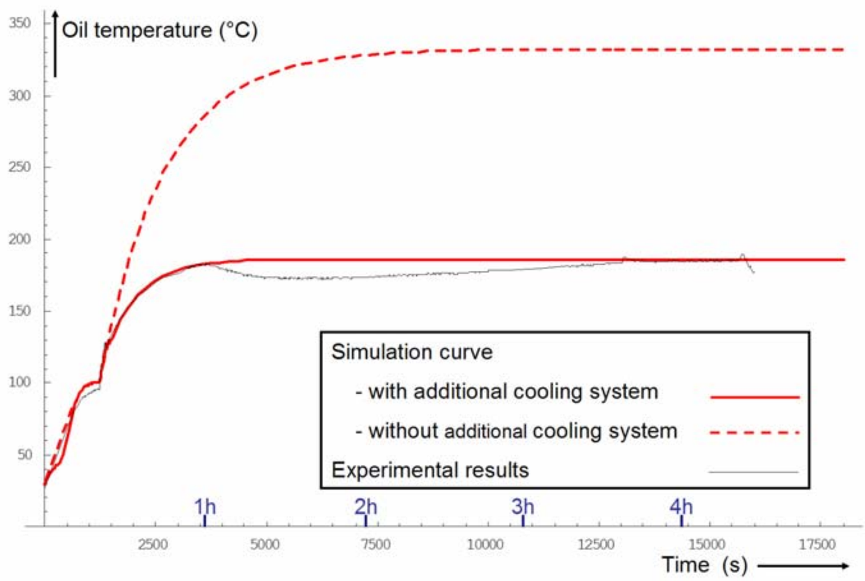

Figure 6: Final simulation versus experimental results benchmark

The global thermal simulation of the main gearbox with the integration of the additional cooling system has taken an important part in the time reduction for the development of this new feature.

6. CONCLUSION

To answer with more and more accuracy to our customer queries we continuously developed new scientific tools. The global thermal simulation of transmission gearbox system is one of them. Built on simple theory using leading edge software technology, the global thermal modeling of a helicopter main gearbox brings a better understanding of the thermal behavior of the system. Many applications have already been found during development stage to optimize the design of the cooling unit of new aircrafts.

7. NOTATIONS

$\dot{m}$: Mass flow (kg/s)

Cp : Specific heat transfer (W/kg/°)

R_{th} : Thermal resistance

θ : Temperature (°C)

P : Power transmitted (W)

H : Convection coefficient (W/m²/°)

S : External surface (m²)

$_{HP}$: Hot parts

$_{CP}$: Cold parts

$_{OAT}$: Outside air temperature

8. REFERENCES

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