New Sensors for Optimized Performance, Control and Monitoring of Turbofan Lubrication Systems

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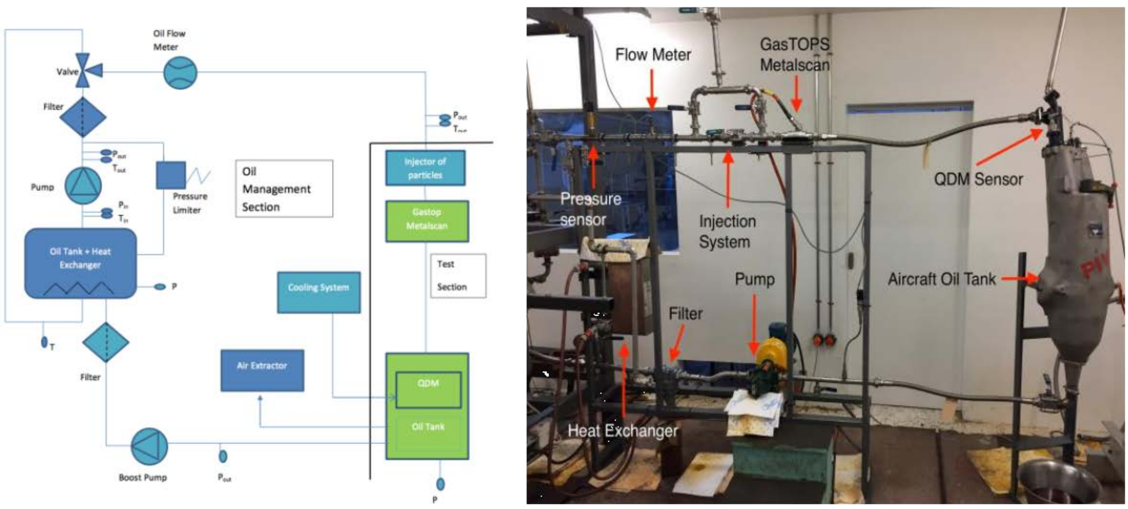
ABSTRACT

To ensure effective, continuous and failsafe operation of aero-engines, a significant number of sensors are used. In particular, in the oil circuit (or lubrication system) of the aero-engine where debris monitoring, oil level and other sensors play a major role. During the complete life of an engine, the contact patches produce oil-insoluble debris. These debris are collected in the lubricating oil of the engine. The debris monitoring sensors function is to detect those particles in the oil and catch them. The analysis of the debris located in the oil allows then to detect the degradation of surfaces, assess the overall health of the engine and detect any abnormal situation.

This paper will show tests done in collaboration with aero-engine manufacturers for the development of these sensors in realistic test set-ups that are representative of real aero-engine working conditions (as the one presented in Figure 1).



(a) (b)

Figure 1 – Schematics and test set-up of ULB for the sensors of oil circuit of aero-engines

A possible sensor is the GasTOPS sensor, which categorizes the particles by size, type and mass. It also counts the total debris detected and estimates the total mass. The sensor can only detect particles whose size *is between 250 and 1000 µm. Another sensor, the QDM sensor from Eaton, only counts the amount of debris detected, and its magnet catches the debris. The sensor does not give any information about the size or mass of the debris detected. The sensor only detects debris whose size lies between 400 and 600 µm.*

EXPERIMENTAL METHOD

The oil is heated to the desired temperature and the mass flow rate is regulated with the rotational speed of the two pumps. The oil used is Mobile Jet Oil II, an oil of type II. The mass and type of particle to inject are prepared. The particles are injected with a special injector in the oil circuit. The results are obtained on the computer. The QDM is removed from the separator to collect all the particles caught.

Tests and Values

Three sizes and two types of particles were tested, and three types of tests were done. They are described in Table 1. For each test condition, each type of test was repeated 10 times. Different test conditions are described in Table 2. The flow rate and temperature of the oil were kept constant, as was the mass injected; only the type and size of debris were changed between the tests.

Table 1. Description of the different test packages

	Type	Size (µm)	Mass Injected (mg)	Number of Tests
Test Package 1	Iron	850–1180	10	10
Test Package 2	Iron	425–600	10	10
Test Package 3	Steel	150–500	10	10

Table 2. Average of the test conditions

	T (°C)	Flow Rate (l/h)	Mass Injected (mg)
Test Package 1	129.1	3521.8	10
Test Package 2	129.2	3521.3	10
Test Package 3	128.8	3521.4	10

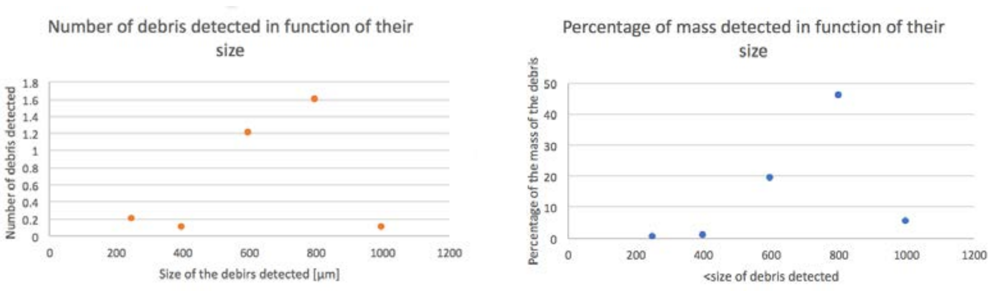
Table 3 gives the test results for each test package. The first two results are the total mass detected and the total number of particles counted by the sensor GasTOPS. The last two are the total mass caught and the total number of particles counted by the sensor QDM. The GasTOPS sensor categorizes the debris detected into five different sizes (250, 400, 600, 800 and 1000 µm).

Table 3. Test results, percentage of the total mass, and amount of total debris detected

	Test Package 1	Test Package 2	Test Package 3
GasTOPS Total Mass (%)	75	63	47
GasTOPS Total Number	3.5	12.5	12.2
QDM Total Mass (%)	66	60	33
QDM Total Number	4.8	10.2	6.4

Test Package 1—Iron 850–1180 µm

The results of the first test package are presented in this section. The size of the chips injected lies between 850 to 1180 µm. It can be seen in Figure 2 that debris of 200, 400 and 1000 µm were detected each only once during the 10 tests. In six tests out of 10, particles of 600 µm have been detected. Most of the debris detected was categorized as 800 µm particles.

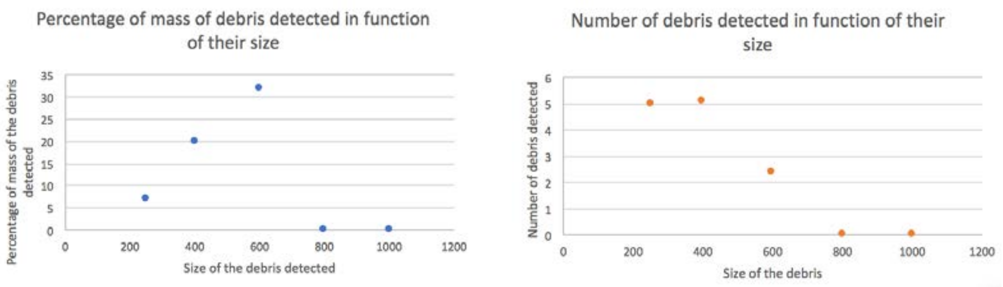


(**a**) (**b**)

Figure 2. Test Package 1: (a) Average amount of debris detected as a function of size by the GasTOPS sensor; (b) percentage of the average mass of debris detected as a function of size by the GasTOPS sensor.

Test Package 2—Iron 425–600 µm

The results of the second test package are presented in this section. The size of the chips injected was between 425 to 600 µm. Figure 3 shows that no debris of 800 and 1000 µm and only 0.7 mg of debris with a size of 250 µm was detected. Those results are logical because the size of the debris injected is smaller. One can say that the GasTOPS sensor detects the right range of particle size. In terms of amount, debris of 400 µm was detected more than debris of 600 µm. The results presented in this section and in Table 3 demonstrate that the two sensors are in accordance with their respective range of detection of the debris specified by the manufacturer of the sensors.

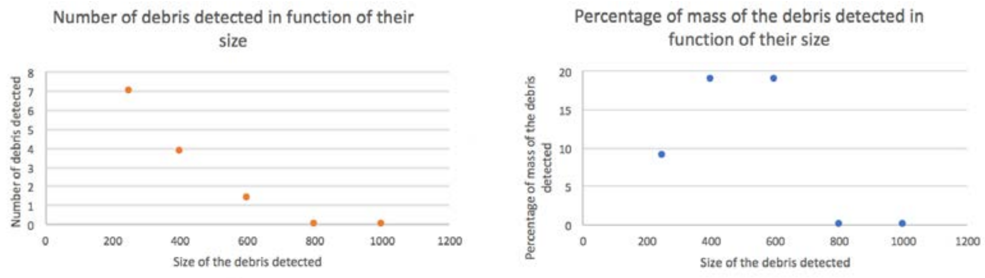


(**a**) (**b**)

Figure 3. Test Package 2: (a) Average amount of debris detected as a function of size by the GasTOPS sensor; (b) percentage of the average mass of debris detected as a function of size by the GasTOPS sensor.

Test Package 3—Iron 150–500 µm

The results of the third test package are presented in this section. The size of the chips injected was between 150 to 500 µm. As can be seen in Figure 4, no particles of 800 and 1000 µm were detected, but some particles of 600 µm, about 20% of the mass, were detected despite the particles injected being smaller. In terms of amount, debris of 250 µm was detected the most, but in terms of mass, particles of 400 µm were detected the most. According to Table 3, QDM only counts half of the debris.



(**a**) (**b**)

Figure 4. Test Package 3: (**a**) Average amount of debris detected as a function of the size by the GasTOPS sensor; (**b**) percentage of the average mass of debris detected as a function of the size by the GasTOPS sensor.

This paper presents tests uisng two debris monitoring sensors (GasTOPS and QDM) on an oil test bench that was built in order to test them in the same conditions as in an aircraft engine. Debris is injected in the oil and GasTOPS determines the size and mass and counts the debris. The QDM counts but also catches the debris. The two sensors exhibit similar behaviour for debris with a size of 425–600 μm or 800–1180 μm. For those ranges, on average 63–70% of the mass of debris injected is detected by the GasTOPS sensor, and the QDM catches 60–66% of the mass injected. Small debris whose size lies outside the range of the two sensors was not detected by the two sensors. This confirms that the sensors only detect the particles for which they were designed. The oil test bench is assembled, and the injection, detection, and capture of debris by the sensor are operational.

Some improvements can still be made to the test bench to improve the injection of debris and test the sensors with better repeatability. To develop a sensor with a wide range of detection complicates its implementation and specifically its integration in the oil and electrical circuit of the aircraft engine.