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INVESTIGATION REPORT

Incident to the Airbus A319 registered F-GRHT on 12 March 2014 at Paris - Charles de Gaulle

Time	Approximately 13:42[1]
Operator	Air France
Type of flight	Commercial Air Transport - Passenger
Persons on board	Captain (PF); First Officer (PM); 3 cabin crew; 79 passengers
Consequences and damage	No damage

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in January 2020. As accurate as the translation may be, the original text in French is the work of reference.

[1] Unless otherwise stated, all times given in this report are in Coordinated Universal Time (UTC).

Failure of the fuel quantity indicating computer, insufficient refuelling and shut-down of one engine during descent

1 - HISTORY OF THE FLIGHT

Note: the history of the flight is based on the CVR and FDR recordings and the crew statements.

On the morning of 12 March 2014, a crew was carrying out the first two legs of a four-leg rotation between Marseille and Nantes. In Marseille, while taxiing at the start of the third leg, the crew entered in the ATL[2] that the indicator for the quantity of Fuel On Board (FOB) was showing 300 kg less than expected. In Nantes, a maintenance team carried out a test which revealed that a sensor in the outer left tank had failed. Its replacement was scheduled for a later date and the aircraft was put back into service. The next flight to Marseille proceeded normally.

[2] Aircraft Technical Log.

At Marseille, after the engines had been shut down on the last leg of the rotation, the crew calculated a difference (denoted by **Δ**[3] in the ATL) of 20 kg between:

- the quantity of fuel corresponding to the sum of the fuel used during the leg (information provided by the totalizers, denoted by **T** in the ATL) and the FOB (information provided by the gauges, denoted by **J** in the ATL), and
- the theoretical quantity of fuel on departure (calculated at the start of the leg by the crew and denoted by **D**).

[3] See 2.2.1 ATL fuel on board and refuelling log (in force at the time of the incident).

In reality, the difference was 880 kg.

The next crew was to carry out a four-leg rotation departing from Marseille. During the flight preparation, the crew learnt of the complaint recorded in the ATL by the previous crew regarding the fluctuating fuel . For the first leg, the crew decided to carry 5,000 kg of fuel. Because the ATL and the aircraft's gauges indicated an FOB of 3,780 kg (J), the crew requested an additional 1,200 kg of fuel. The crew checked the fuel uplift and that the fuel was distributed normally in the tanks. The crew reported that the outer tanks were full. The aircraft's gauges indicated an FOB of 5,080 kg.

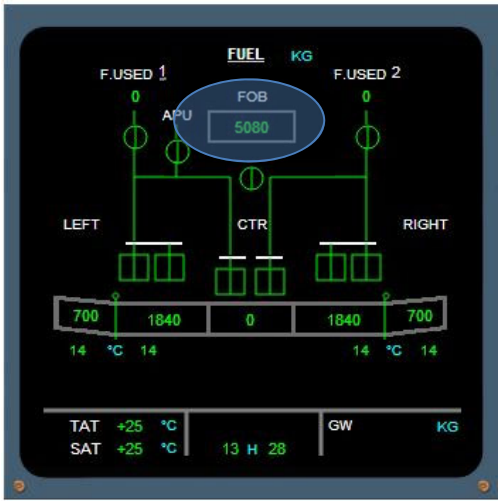


Figure 1: simulation of the FUEL page of the SD[4] after refuelling

[4]System Display.

The crew took off at 12:41 for Paris - Charles de Gaulle. The aircraft's gauges indicated an FOB of 4,950 kg at take-off. The captain (PF) observed during the climb between FL150 and FL200 that both fuel transfer valves (XFR valves) from the outer tanks to the inner tanks were open. According to him, the quantity of fuel indicated in each wing at that time was approximately 1,600 kg.

Fifteen minutes after take-off, while still climbing, the ECAM "*FUEL L WING TK LO LVL*"message appeared on the EWD[5], the Master Caution light lit up, the "*Single Chime*" audible alert sounded, and the FUEL page opened automatically on the SD. The crew announced "*ECAM action*" and explained that, when the associated procedure item "*IF NO FUEL LEAK AND FUEL IMBALANCE*" was announced, the Master Caution light and the audible alert stopped, and the ECAM message and FUEL page on the SD disappeared. They then displayed the FUEL page again and noticed that the fuel quantity s fluctuated and then seemed to become consistent again.

[5]ECAM Warning Display (screen displaying engine parameters and warnings).

The crew deduced from this that it was an untimely warning. They nevertheless decided to regularly check the fuel s. The FUEL page of the SD was therefore displayed by the crew every five to ten minutes during the rest of the flight to check that the FOB, the fuel consumed, and the fuel at departure were consistent.

At 13:35:54, while descending to FL80, a drop in pressure in both left engine fuel pumps triggered the "*Fuel Left Tank Pump 1+2 Low Pressure*" warning. The crew performed the actions of the associated procedure.

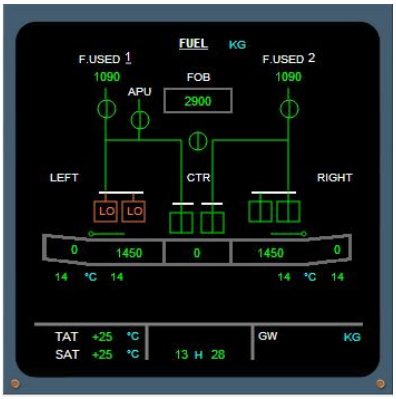


Figure 2: simulation of the FUEL page after the "FUEL L TK PUMP 2 LO PR" warning

At 13:42:22, at the end of the downwind leg, the "*ENG 1 FAIL*" warning was activated and the engine stopped. The crew performed the associated procedure and started the APU[(6)] which stopped a few minutes later. The crew declared an emergency and landed with only one engine operative.

[(6)] Auxiliary Power Unit.

2 - ADDITIONAL INFORMATION

2.1 General information on the fuel system

2.1.1 Description

The fuel for the Airbus A319 is contained in a centre tank with a capacity of 8,250 l (6,476 kg) and four wing tanks. In each wing, an 880 l (691 kg) outer tank communicates with a 6,925 l (5,436 kg) inner tank via two transfer (XFR) valves.

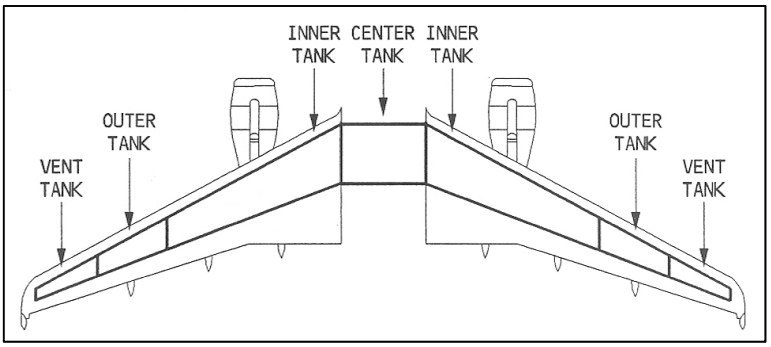


Figure 3: tank distribution

The two inner wing tanks and the centre tank each have two main pumps. In normal use, each engine is supplied by the two pumps which are on its same side and by a centre tank pump. The left and right systems are connected by a cross-feed (X FEED) valve. This valve is closed in normal operation and each engine is supplied solely by the part of the system which is on its side. When the cross-feed valve is opened, both engines can be supplied from a single wing tank.

2.1.2 Fuel Quantity Indicating System (FQIS)

The FQIS measures the quantity of fuel[7] in each tank using:

- a set of capacitive sensors, some of which have a temperature sensor;
- a densimeter installed in the lowest part of the inner tanks and the centre tank;
- a Fuel Quantity Indicating Computer (FQIC).

[7] The accuracy of the FQIS is approximately 1% of the total tank capacity + 1% of the actual quantity contained in the tanks.

The FQIC displays the FOB on the EWD screen. The quantities of fuel in each tank are displayed on the FUEL page of the SD.

Manual magnetic gauges located on the lower face of the wing can also be used to check the fuel quantity. These manual gauges are accurate to approximately 5%.

2.1.3 Fuel Level Sensing Control Unit (FLSCU)

The FLSCU uses different fuel level sensors from those used by the FQIC.

When the fuel weight in an inner tank is approximately 750 kg, the low level sensors are no longer immersed and send a signal to the FLSCU, which commands the XFR valves between the inner and outer tanks to open. The crew is informed of the opening of these transfer valves by the appearance of an "*OUTER TK FUEL XFRD*" memo on the EWD screen and by the information on the SD page.

The FQS and FLSCU systems were detailed in the system description section of the FCOM[8] in force at the time of the incident. This description consisted of two dedicated sections that listed the functions of each system separately.

[8] Flight Crew Operating Manual.

In particular, it was specified that when the low fuel level is reached, an ECAM message, "*FUEL L(R) TK LO LVL*" appears on the EWD. This message is associated with the activation of the "*Master Caution*" indicator light, a "*single chime*" audible alert, and the automatic opening of the FUEL page on the SD.

2.1.4 Fuel consumption during incident flight and quantity remaining on ground after incident

Measurements taken by the ground maintenance teams after the incident indicate that the left tank was empty and that there were 1,100 kg remaining in the right tank (i.e. the final reserve +150 kg).

The calculations of the fuel consumption by the left and right engines from start-up, during the incident flight, are 1,272 kg and 1,525 kg respectively. When the engines were started up, the FOB was therefore 3,800 kg instead of the 5,080 kg displayed by the FQIC at the start of the leg. This 1,270 kg overestimation of the fuel weight by the FQIC is consistent with the fuel weight indicated on the FUEL page of the SD on arrival, namely 2,370 kg (1,360 kg on the left and 1,010 kg on the right).

2.2 Procedures

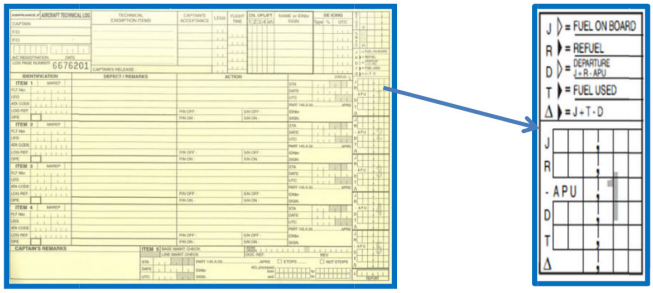
2.2.1 ATL fuel on board and refuelling log (in force at the time of the incident)

The operator set out the manufacturer's fuel management procedure in its Operations Manual. The ATL's fuel log has five sections to cover a rotation with multiple legs performed by the same flight crew. The following fuel monitoring procedure must be performed on each leg and the information must be recorded in the ATL's fuel log. Fuel quantities are expressed in kg.

At the start of a leg:

> *"FOB.....CHECK*
> *- Check that ECAM fuel on board corresponds to the F-PLN.*
> *- Check that fuel imbalance is within limits.*
> *- Crosscheck that the sum of the Fuel On Board (FOB) recorded at the end of the last flight and the fuel uplift (if any) is consistent with the current FOB. If an abnormal discrepancy is found, a maintenance action is due."*

- The theoretical fuel quantity (denoted by **D**) must be compared with the gauge indication. **D** corresponds to the sum of the FOB from the previous leg (denoted by J, which is the sum of the gauges read on the SD FUEL page) and the refuelling (denoted by **R**), minus the quantity of fuel consumed by the APU.
- **D = J + R** – APU consumption.
- The ATL's fuel log is completed to calculate the theoretical fuel at departure.



At the end of the leg, after shut-down of the engines:

> *"FUEL QUANTY.....CHECK*
> *Check that the sum of the fuel on board and the fuel used is consistent with the fuel on board at departure. If an unusual discrepancy is found, maintenance action is due."*

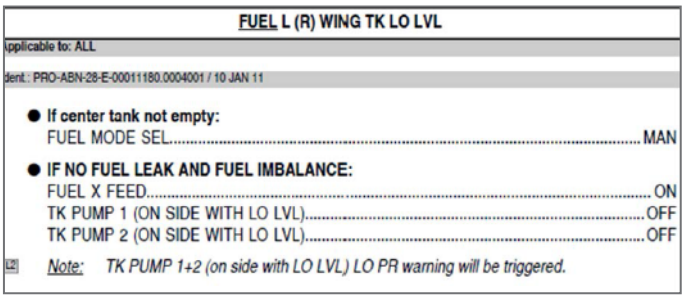
- The sum of the totalizers on arrival (fuel used during the leg, read on the SD FUEL page) is transferred to box **T** of the ATL and the sum of the gauges to box **J**. The result of the sum **T + J** must be compared with the theoretical fuel quantity at departure **D**. This difference is denoted by **Δ** in the ATL, entered by the PF and verified by the PM.
- **Δ = T + J – D**.

The maximum acceptable value of **Δ** is not defined, leaving it up to the crew to decide whether the value is normal or not.

Furthermore, the method of filling in the fuel log of the ATL is not covered by the operational documentation available to pilots. Pilot training includes only a 17-minute module on using the ATL.

A review of the documents related to refuelling and the ATLs of the F-GRHT flights since February revealed calculation errors (sometimes of as much as one tonne), and that the ATL was not completed in accordance with the instructions described above. Crews had entered calculated fuel quantities, not those read from the indicators. These calculation errors suggest that the first officer's verification of the calculation is not systematically carried out. They may also explain why the problem of intermittent FQIC failure had not been identified and resolved despite the occurrence of previous cases.

2.2.2 Procedure associated with "FUEL L WING TK LO LVL" alert at time of incident



FUEL L (R) WING TK LO LVL

Applicable to: ALL

Ident.: PRO-ABN-28-E-00011180.0004001 / 10 JAN 11

- **If center tank not empty:**
  FUEL MODE SEL ..... MAN
- **IF NO FUEL LEAK AND FUEL IMBALANCE:**
  FUEL X FEED ..... ON
  TK PUMP 1 (ON SIDE WITH LO LVL) ..... OFF
  TK PUMP 2 (ON SIDE WITH LO LVL) ..... OFF

L2 *Note: TK PUMP 1+2 (on side with LO LVL) LO PR warning will be triggered.*

Figure 4: "FUEL L(R) WING TK LO LVL" SOP[9]

[9] Standard Operating Procedures.

When a low fuel level alert is triggered, the crew must carry out a fuel transfer (opening of the X-FEED valve) if they detect an imbalance in the fuel quantity and the tanks are not leaking. To do this, the crew has the fuel quantity information provided by the FQIC.

During the incident flight, the fuel quantity calculations show that, at the time the low level warning was triggered, the information provided by the FQIC did not suggest to the crew that there was any leak or imbalance that would require the cross-feed valve to be opened in accordance with procedure. Thus, if an FQIC malfunction occurs, the procedure associated with the low fuel level alert being triggered does not prevent the engine from shutting down due to a fuel supply failure.

2.2.3 Maintenance procedures associated with fuel quantity indication failures

At the time of the incident, the maintenance procedures associated with FQIC failures dealt only with specific cases. No procedures in the Troubleshooting Manual (TSM) addressed a fuel quantity indicator malfunction/fluctuation in a generic situation such as that of the incident, in which the erroneous indications were intermittent.

Airbus asks to be informed by operators in the case of a situation for which no specific task is given, in order to consider the actions to be taken.

2.3 Crew statements

The crew explained that, when preparing the flight, they decided to take on board 5,000 kg of fuel (the software used for flight preparation had calculated that a minimum of 4,710 kg should be carried). When they took charge of the aircraft, they noted:

- an ATL complaint lodged at Nantes by the previous crew, relating to fluctuations in fuel quantity; the complaint was closed by maintenance, with mention of work scheduled on a fuel sensor observed to be faulty;
- an FOB of 3,780 kg entered in box **J** of the ATL, identical to the FOB displayed by the gauges;
- a memo left by the captain of the previous rotation, recording the varying fuel quantity indications according to the different phases of the flight during the last leg from Nantes to Marseille (maximum deviation of 300 kg).

The captain said that he did not inform the first officer that the two fuel transfer valves had been opened because this indication did not raise any particular concerns for him. The first officer did not recall noticing this indication while climbing. The captain explained that this fuel transfer usually occurs at the end of a flight but that he had already seen fuel transfer being activated on other aircraft when the amount of fuel in the inner tanks was more than the theoretical activation value of approximately 750 kg[10].

After the ECAM "*FUEL L WING TK LO LVL*" message disappeared, the crew explained that they manually displayed the FUEL page again to confirm the system status. They found that the fuel quantity indications fluctuated and seemed to become consistent again. The crew added that they then identified this phenomenon as a problem associated with the previously identified gauge (FQIC) failure. They then wondered whether it was necessary to record another complaint in the ATL since a maintenance action related to this problem was already scheduled.

Because the indications on the FUEL page were consistent, the crew said that they did not consider it necessary to conduct a FORDEC[11] but they decided to regularly check the fuel indications and note all the readings on the FUEL page of the SD at regular intervals of about ten minutes[12]. The crew said that they observed an increase in the sum of the fuel quantities displayed by the totalizers and gauges (J + T) while cruising, from 4,900 kg at TOC[13] up to approximately 5,500 kg.

Approaching FL110, the captain said he noticed that the two fuel pumps on the left side were displayed in amber on the SD. The "*ECAM FUEL L TK PUMP 1+2 LO PR*" warning was then triggered. The first officer stated that the fuel quantity displayed by the FQIC in the left wing was approximately 1,400 kg. The crew explained that they handled this warning by applying the associated procedure, which calls for the pumps to be shut down but does not call for the transfer valve (FUEL CROSS-FEED) to be opened below FL110. The PF added that the crew then performed a FORDEC and decided to continue to their destination by "*GRAVITY FEEDING*". The crew then discussed the possibility of leaving for the next leg if two pumps were not operational and talked about the MEL associated with the pumps.

[10] This information was subsequently confirmed by the receipt of several ASRs reporting this phenomenon.

[11] FORDEC is the acronym for Facts - Options - Risks - Decision - Execution - Check. It is a method that helps crews assess a situation, make decisions and check them.

[12] On the day of the event, the flight dossier was not retained. The BEA therefore did not have access to the fuel indication readings for the Nantes - Marseille flights and the occurrence flight.

[13] Top Of Climb.

When the "*ENG 1 FAIL*" warning was activated a few minutes after the ECAM "*FUEL L TK PUMP 1+2 LO PR*" warning, the crew thought that the pumps were faulty. The captain declared an emergency and requested a shortened track. The crew explained that they followed the associated procedure and that, because of doubts as to the condition of the engine and why it had shut down, they triggered the engine's fire extinguishers. They started the APU but it shut down approximately two minutes later. The crew tried unsuccessfully to start it a second time[14].

[14]The APU is supplied by the fuel in the left tank, which was empty.

2.4 Fuel quantity indicating system failure

When the FQIC was tested in aircraft configuration with a fuel quantity set at 5,000 kg and a gradual reduction in quantity (to simulate consumption by the engines), a similar failure to that of the incident occurred. This failure, related to a solder defect, was intermittent and was caused by voltage variations of an oscillator in the FQIC.

2.5 Disappearance of low level alert as reported by crew

The manufacturer's procedures (FCOM and FCTM) for processing an ECAM message require the crew to terminate an ECAM procedure by pressing the CLR button on the ECP[15]. If the alert is considered to be false, the crew is required to press the EMER CANCEL button. Pressing the RCL button for more than three seconds will then list the alerts inhibited by pressing EMER CANCEL.

[15]ECAM Control Panel.

The RCL button was not pressed on the ground following the event and subsequent maintenance actions did not preserve the information displayed by the "*STATUS*" page. Therefore, it could not be determined whether the procedure displayed on the ECAM disappeared as a result of the crew pressing the EMER CANCEL button.

Examinations of the FLSCU and other components of the FQIS did not reveal any failures that could explain this disappearance. After the aircraft had landed, when the maintenance teams powered up the aircraft systems, this warning was triggered again.

2.6 History of maintenance actions carried out on F-GRHT's fuel system

Between 15 February and 2 March 2014, four complaints about refuelling stopping before the pre-selected amount had been taken on board were recorded in the ATL. The FQIC was replaced on 3 March 2014, i.e. nine days before the incident.

On 6 March 2014, the last two digits displayed by the FQIC, indicating the FOB for the left wing were "*inop*". A reset was performed by the crew without success. The display returned to normal after the engine start-up. The crew recorded this in the ATL. At the end of the flights, the maintenance personnel noted that the fuel quantity indicator was functioning correctly and the aircraft was returned to service.

3 - LESSONS LEARNED AND CONCLUSIONS

Scenario

At the end of the leg preceding the incident, in the absence of verification by the first officer, the captain's error in the fuel log calculation was not corrected/identified. It is likely that a result showing a difference of nearly 900 kg would have alerted this crew and the next to a Fuel Quantity Indicating Computer (FQIC) failure.

The crew of the incident flight, trusting the information available to them (the ATL and the FQIC indications), had incorrect awareness at the start of the flight of the actual quantity of fuel on board.

During the flight, the crew associated the activation of the low fuel level warning with an untimely warning related to the FQIC malfunction recorded by the previous crew in the ATL.

Shortly afterwards, when the fuel pumps stopped due to fuel starvation, and then when the left engine shut down after the left tanks emptied, the crew were unable to identify the cause and thought that the two pumps had failed simultaneously. Throughout the flight, the crew retained the impression that the fuel quantity indicated in the ATL was correct and that the FQIC sensors could be malfunctioning. At no time did the crew question whether there was fuel in the left tank until they arrived at the apron.

Technical examinations identified a failure of the fuel quantity indicating system, which provided erroneous information about the amount of fuel in the tanks before departure and during the flight.

Contributing factors

The following factors may have contributed to the shut-down of the left engine in descent:

- The many differences and inconsistencies in the ATL fuel log completed on the ground by crews, probably due to a lack of information in the Operations Manual, insufficient training, and in some cases lack of verification by the first officer of the captain's calculations.
- The difficulty for a crew of questioning information considered to be reliable before departure of a flight (confirmation bias).
- An ECAM low fuel level procedure that requires crew actions based on erroneous fuel quantity information provided by the FQIC and lack of knowledge of the independence of the Fuel Level Sensing Control Unit (FLSCU) from the Fuel Quantity Indicating System (FQIS).

4 - SAFETY ACTIONS TAKEN FOLLOWING THE INCIDENT

4.1 Actions taken by Air France

After the incident, Air France carried out the following actions:

- A manual dipstick measurement campaign carried out on the entire medium-haul fleet. This campaign did not reveal any FQIC faults.
- A memo to crews explaining how to fill in the ATL fuel log and to remind them of the procedural check points (SOPs).

Subsequently, the Operations Manual procedures were amended to include a detailed procedure for filling in the ATL fuel log. The application of these procedures is the subject of training and line checks.

Assessment of the operational criticality of certain failures, especially intermittent and recurring failures, was also the subject of organizational measures to improve the sharing of information between maintenance services and crews.

The term "*avion récurrent*" was introduced to refer to an aircraft with a significant combination of frequent and severe failures (or crew feedback via the ATL or reports). The purpose of this classification is to enable the operator to set up special monitoring in coordination with the manufacturer in order to identify and deal with intermittent failures like the one affecting F-GRHT as quickly as possible.

4.2 Safety actions taken by Airbus

4.2.1 Maintenance and normal pre-flight preparation procedures

A new maintenance task in the TSM was created in May 2016 to deal with more general cases related to fluctuations in fuel quantity indications.

The standard procedure (FCOM SOPs) for pre-flight fuel management, "*Before start clearance*", was updated in June 2015 to clarify the terms "*unusual*" and "*abnormal*" used in the previous version of the FCOM.

FOB..... CHECK

- *Check that ECAM fuel on board corresponds to the F-PLN.*
- *Check that fuel imbalance is within limits.*
- *Crosscheck that the sum of the Fuel On Board (FOB) recorded at the end of the last flight and the fuel uplift (if any) is consistent with the current FOB. If an abnormal discrepancy is found, a maintenance action is due.*

FOB after refuelling:	*Abnormal discrepancy above:*
Up to 6 tons (13200 lb)	*400 kg (900 lb)*
Between 6 tons (13200 lb) and 12 tons (26500 lb)	*500 kg (1100 lb)*
More than 12 tons (26500 lb)	*600 kg (1300 lb)*

Figure 5: excerpt from the FCOM - Normal procedures - "Before start clearance" SOP

4.2.2 Air operations

The FCOM (Aircraft Systems Fuel – Description, - Fuel quantity Indication and level sensing) was amended in March 2015 to remind crews of the independence of the quantity measurement and the low level alert. A sentence (in bold below) was added: "*When fuel quantity in one wing tank goes below 750 kg (1,650 lb), the low-level sensor triggers the LO LVL warning on ECAM.* ***The LO LVL warning is totally independent from the displayed fuel quantity indication of the tank***".

Airbus amended the cruising fuel monitoring procedure in December 2015.

> *When overflying the waypoint, or at least every 30 min:*
> - *Check FUEL : Check FOB (ECAM), and fuel prediction (FMGC), and compare with the computer flight plan or the in-cruise quick-check table (Refer to QRH/PER-G In Cruise Quick Check at a Given Mach Number).*
>
> *Check that the sum of the fuel on board and the fuel used is consistent with the fuel on board at departure. If the sum is unusually greater than the fuel on board at departure, suspect a fuel quantity over read. If the sum is unusually smaller than the fuel on board at departure, or if it decreases, suspect a fuel leak.*

Figure 6: excerpt from the FCOM - Normal procedures - "Before start clearance" SOP

Airbus also published an article in its Safety First magazine[16] (No. 20 July 2015 "*Fuel monitoring on A320 family aircraft*").

Finally, a safety study carried out by Airbus led at the end of 2018, to an update of the "*FUEL L(R) WING TK LO LVL*" procedure, which consisted of deleting the imbalance condition. The new procedure requires the crew to open the cross-feed valve from the moment that there is no leak.

During the investigation, the coordination and exchanges between Airbus, Air France and the BEA enabled adequate safety measures to be put in place to prevent the failures identified.

[16] https://www.airbus.com/content/dam/corporate-topics/publications/safety-first/Airbus_Safety_first_magazine_20.pdf