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SAFETY INVESTIGATION REPORT

Incident to the AIRBUS - A330 - 200 registered **F-GZCJ** operated by Air France on 31 December 2020 en route, FL 380 (Chad)

Time	Around 23:35[1]
Operator	Air France
Type of flight	Passenger commercial air transport
Persons on board	Captain (PM), co-pilot[2] (PF), relief pilot for captain, 8 cabin crew and 136 passengers
Consequences and damage	None

Fuel leak en route, diversion, both engines kept in operation up to taxiing to parking area.

[1] Except where otherwise indicated, the times in this report are in Coordinated Universal Time (UTC). One hour should be added to obtain the legal time applicable in Chad on the day of the event.
[2] In Air France, a co-pilot is designated by the term First Officer (FO).

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August 2022

BEA2021-0001

Safety investigations

The BEA is the French Civil Aviation Safety Investigation Authority. Its investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion blame or liabilities.

BEA investigations are independent, separate and conducted without prejudice to any judicial or administrative action that may be taken to determine blame or liability.

SPECIAL FOREWORD TO ENGLISH EDITION

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

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Contents

Glossary

Abbreviation	English version	French version
A/THR	Auto THRust	
AD	Airworthiness Directive	
AMC	Acceptable Means of Compliance	
AMM	Aircraft Maintenance Manual	
AOL	All Operator Letter	
AP	Auto-Pilot	
CAM	Cockpit Area Microphone	
CAS	Computed Air Speed	
CCA	Cabin Crew Attestation	
CVR	Cockpit Voice Recorder	
DSAC	French civil aviation safety directorate	Direction de la Sécurité de l'Aviation Civile
EASA	European Aviation Safety Agency	
EBT	Evidence Based Training	
ECAM	Electronic Centralized Aircraft Monitoring	
FCMC	Fuel Control and Monitoring Computer	
FCOM	Flight Crew Operating Manual	
FCTM	Flight Crew Techniques Manual	
FDM	Flight Data Monitoring	
FDR	Flight Data Recorder	
FFS	Full Flight Simulator	
FL	Flight Level	
FLD	Factored Landing Distance	
FMS	Flight Management System	
FORDEC	Facts, Options, Risks and benefits, Decision, Execution, Control	
HMU	Hydro Mechanical Unit	
HP	High Pressure	
IATA	International Air Transport Association	
ICAO	International Civil Aviation Organization	
ILS	Instrument Landing System	
IPC	Illustrated Part Catalogue	
LOSA	Line Operations Safety Audit	
LP	Low Pressure	

Abbreviation	English version	French version
MEC	Main Engine Control	
ND	Navigation Display	
NOTAM	NOtice To AirMen	
NTSB	National Transportation Safety Board (USA)	
OCV	Flight control organisation	Organisme du Contrôle en Vol
OCC	Operations Control Centre	
P/N	Part Number	
PAPI	Precision Approach Path Indicator	
PF	Pilot Flying	
PFH	Primary Fuel Hose	
PM	Pilot Monitoring	
PPL	Private Pilot Licence	
QFU	Magnetic heading of runway	
QNH	Altimeter setting for altitude above sea level	
QRH	Quick Reference Handbook	
RA	Radio Altimeter	
RNAV	aRea NAVigation	
RNP	Required Navigation Performance	
ROPS	Runway Overrun Prevention System	
ROW	Runway Overrun Warning	
SFI	Synthetic Flight Instructor	
SOP	Standard Operating Procedures	
SPIB	Spare Parts Introduction Bulletin	
TAF	Terminal Area Forecast	
TEM	Threat and Error Management	
THS	Trimmable Horizontal Stabilizer	
TOGA	Take-Off Go-Around	
TR	Type Rating	
UTC	Coordinated Universal Time	
VAPP	Approach speed	
VMO	Maximum Operating Velocity	

Synopsis

On 31 December 2020, the Airbus A330 operated by Air France carried out scheduled flight AF735V between Brazzaville (Congo) and Paris-Charles de Gaulle (France). Take-off was at 21:13.

On reaching the en-route level FL 380, the crew detected that they were lacking around 1.4 t of fuel in the fuel tanks. They monitored the evolution in the fuel quantities. Before the captain left the cockpit for his rest period a few minutes later, he asked the co-pilots to monitor the changes in the fuel quantities. Around twenty minutes later, the co-pilots called him back as they were now lacking around 2.1 t of fuel.

The crew started the FUEL LEAK procedure, breaking off at the line which specified shutting down the engine on the side of the suspected leak (in this case, the left side), as they chose to keep the engine operating.

The crew diverted to N'Djamena airport (Chad) where they carried out a RNAV approach on runway 23, landing there 1 h 47 min after identifying the leak. The ROPS warning, indicating the risk of a runway excursion was activated on touchdown. The PF braked hard and the temperature of the bakes increased up to 600°C.

The two engines were kept in operation. The crew turned around in the turnaround bay at the end of the runway and then shut down engine 1 (left engine) while taxiing to the parking area. The crew brought the aeroplane to a halt in the parking area and shut down engine 2[3]. The fire fighters who had taken up a position close to the aeroplane on it landing intervened after engine 2 had been shut down by spraying water under engine 1. The passengers disembarked without any further incident.

The flight lasted 2 h 21 min; it was estimated that between the take-off and the shutdown of engine 2 in the parking area, around 5.7 t of fuel, including 5.3 t in flight, were lost. An examination of engine 1 found that the fuel leak was situated in line with the mounting flange of the Primary Fuel Hose (PFH), ensuring the interface between the pylon and the engine.

The BEA has issued a safety recommendation concerning the operator's compliance with procedures.

[3] Engine 2 was shut down around ten minutes after engine 1.

Organization of the investigation

On 1 January 2021, the BEA was informed of the diversion of F-GZCJ the day before, to N'Djamena airport (Chad).

Based on the initial factual elements available and in compliance with the provisions of Annex 13 to the Convention on International Civil Aviation, the BEA asked the Ministry of Civil Aviation and National Meteorology of the Republic of Chad (state of occurrence) to delegate it the investigation. The latter accepted this on 12 January 2021.

Air France and Airbus appointed technical advisers to the BEA. The American safety investigation authority, the NTSB, appointed an Accredited Representative (Accrep); he was assisted by technical advisers from GE aviation and Collins Aerospace. The Chad Republic appointed an Accrep.

1 FACTUAL INFORMATION

1.1 History of the flight

Note: The following information is principally based on the CVR and FDR, statements and video recordings of the aeroplane arriving at N'Djamena airport.

On 31 December 2020, the crew took off at 21:13 from Brazzaville airport, Republic of Congo (refer to Figure 1, point 1) bound for Paris-Charles de Gaulle. The total quantity of fuel on board was 45.5 t. The crew consisted of a captain, a co-pilot, a relief pilot and eight cabin crew. On take-off, the captain was the PM, the co-pilot was the PF and the relief pilot was sat on the observer seat in the cockpit. There were 136 passengers on board. Amongst them, there were two company maintenance technicians with the A330 rating. The take-off and climb were carried out without incident.

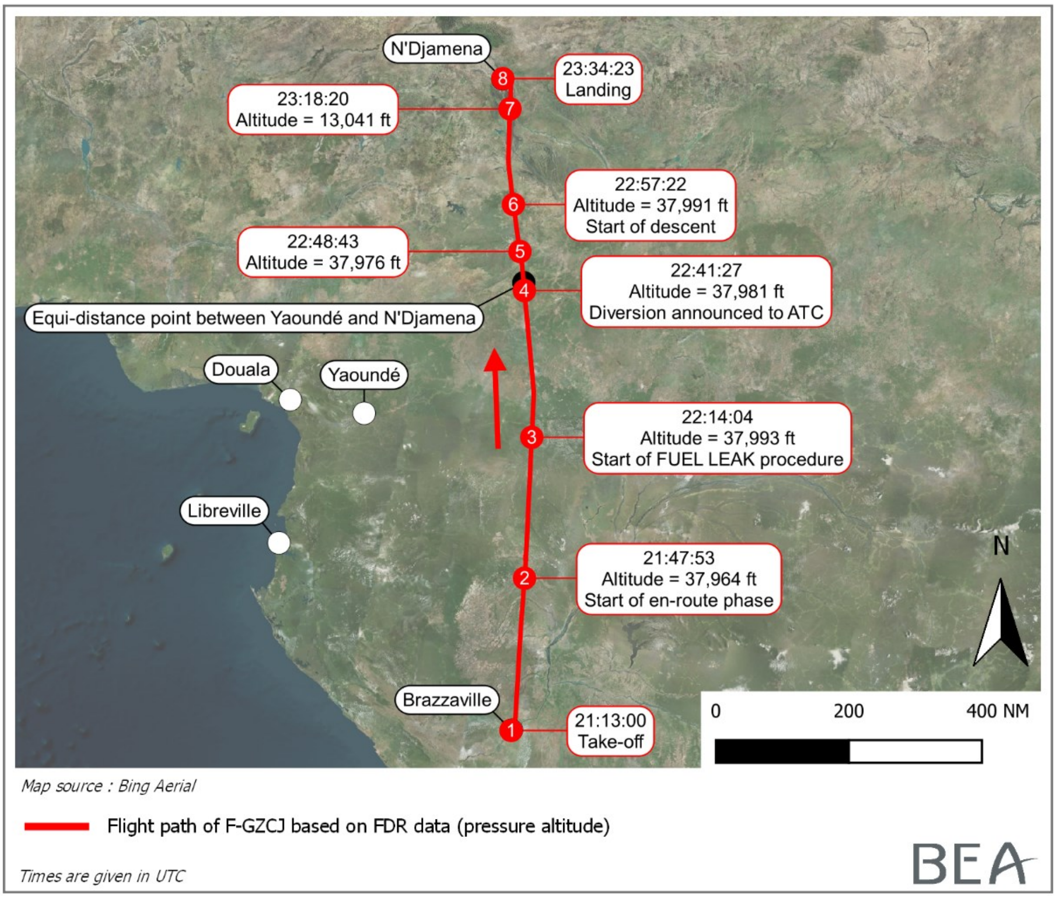

Figure 1: F-GZCJ's flight path

Thirty-five minutes after taking off, at the start of the en-route phase at FL 380, the first checks were carried out (refer to figure 1, point 2). The captain observed that they were lacking 1.4 t of fuel without this creating a visible lateral imbalance between the fuel tanks. He attributed this difference to the fuel transfers that were in progress from the inner wing tanks to the trim tank. He shared this information with the co-pilots and left the cockpit for his rest period a few minutes later, asking the two co-pilots to monitor the evolution of the fuel.

Around twenty minutes after the captain's departure, the co-pilots called him back. At this point, they were lacking around 2.1 t of fuel with a difference in weight of about 400 kg between the two inner tanks. This pointed to a possible leak on the left side, the engine 1 side.

At 22:14 (refer to figure 1, point 3), the crew started carrying out the FUEL LEAK procedure in the QRH. The aeroplane was at around 250 NM east of Yaoundé airport (Cameroon) and 520 NM south of N'Djamena airport. The two airports were accessible. The procedure indicates that the diversion must be considered as soon as possible and asks the crew to shut down the engine associated with the fuel tank where fuel is missing in order to check if this is where the leak is originating from.

At 22:16, the captain hesitated about shutting down the engine, indicating that if they did, this would be the beginning of "something big", "*Alors il faut carrément couper le moteur (…) là ça commence à être gros.*"[4] The crew identified Yaoundé on the left side of the filed flight path. The captain postponed shutting down the engine for the time required to re-evaluate the actual quantity of fuel that had been lost.

At 22:20, the crew updated their information about the meteorological conditions at N'Djamena, Libreville (Gabon) and Yaoundé airports and considered diverting to Yaoundé[5].

The relief pilot and the maintenance technicians on board the aircraft tried to confirm the fuel leak by visually observing the left engine, but without success, due to the low night visibility.

From 22:26, the crew carried out the FORDEC[6] decision method. The captain indicated that factually, there was a fuel leak, "*Au niveau des faits …on est face à une fuite de carburant.*" He then analysed the options and risks, indicating that they had quite a lot of fuel and could fly some time even on one engine. He added that the risk was finding themselves with one engine operative and having to divert.

At 22:30, the crew considered continuing the flight to N'Djamena which they considered to have better facilities. Nevertheless, they continued to debate about the advisability of diverting to Yaoundé which was closer. The captain added that the decision method (FORDEC) was not finished and that they had enough time to fly to N'Djamena, specifying that they had 12 t to 15 t, plus possibly the trim tank, *"Il nous restera… de toute façon douze tonnes… quinze tonnes… plus éventuellement l'arrière… on a le temps d'aller jusqu'à N'Djamena."* He then expressed some reluctance about shutting down the engine, specifying that flying on one engine was not a very comfortable situation, *"Après, on va se retrouver sur un seul moteur …c'est pas non plus une situation super sympa."*

At 22:32, the crew contacted the Operations Control Centre (OCC). During the call, the captain indicated that due to a fuel leak, the crew were hesitating between a diversion to either Yaoundé or N'Djaména, and suggested that N'Djaména was perhaps more suitable from an operational

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[4] The excerpts from the CVR transcript are in italics.

[5] Alternative airfield indicated on flight plan.

[6] Method for making a decision used by the Air France crews (refer to paragraph 1.17.3).

perspective. During the exchange, the co-pilot also expressed his preference for N'Djamena. The OCC then indicated that it would put the aeroplane into contact with the sector manager who confirmed a short time later that there was no problem at N'Djamena.

At 22:33, the captain evoked the FUEL LEAK procedure again and then told the co-pilots that in any case they would have to divert as they had now lost too much fuel to consider flying to Paris, "*De toute façon il faudrait qu'on se déroute, …on a perdu trop de carburant maintenant pour envisager d'aller à Paris*."

At 22:37, the captain informed the chief purser of the situation, specifying that they would have to divert to N'Djamena. He added that it was not necessary to prepare the cabin as the situation was under control and that the crew would try to keep both engines operative up to landing.

At 22:39, the captain proposed keeping engine 1 in operation for as long as possible and to only consider shutting it down when the remaining quantity of fuel in the associated fuel tank was close to five tonnes in order to avoid the engine flaming out spontaneously.

At 22:40, the captain completed the FORDEC and turned to the co-pilots who confirmed the decision to divert to N'Djamena. The decision to divert to N'Djaména was thus formalized.

At 22:43, the captain informed the N'Djaména control of the diversion and announced that they were in an emergency situation with a MAYDAY message (refer to Figure 1, point 4).

The **FUEL F. USED/FOB DISAGREE** alert appeared on the Electronic Centralized Aircraft Monitoring (ECAM) display at 22:48 (refer to Figure 1, point 5). This alert refers the crew to the FUEL LEAK procedure. The captain deleted the ECAM page, and in the absence of a "STATUS" indication, considered that the alert had been processed. The relief pilot then asked that they agree on the moment when the engine would be shut down. The captain indicated that he preferred keeping the engine in operation for as long as there was fuel available.

At 22:52, the crew calculated the landing performance for runway 05 at N'Djamena. The relief pilot then reminded the crew that the thrust reversers must not be used.

During the descent, the controller informed them that ILS 05 was not in service. The captain asked the controller to confirm this information and then the crew modified the route entered in the Flight Management System (FMS) in order to carry out a RNP type approach on runway 05. A few minutes later, the relief pilot read the NOTAMs and confirmed the information provided. He specified that there was also a displaced threshold on runway 05 (landing distance available of 2,410 m) which remained compatible with the required landing distance. The crew contacted the controller who confirmed the displaced threshold and announced a landing distance available of 2,410 m. The relief pilot explained that the RNP 05 approach risked bringing them to the usual 05 threshold and not the displaced threshold and that it would be better to carry out the RNP 23 approach. This proposal was accepted. The captain indicated that there was a risk of a tailwind on final 23 and discussed the taxiing phase, stipulating that they would vacate the runway and shut down the engine, *"Roulage parking (*) en revanche très clairement on libérera la piste on coupera le moteur."*

At 23:07, one of the technicians informed the crew that there was now a visible streak under the cowling of the engine 1 exhaust nozzle. The captain indicated that this information did not change their action plan and asked for the approach briefing to be started.

At the end of the briefing, the crew discussed the threats associated with the approach according to the Threat and Error Management (TEM) method. The co-pilot then verbalized his assessment of the threat as being a fire breaking out on the ground. The captain replied that the first threat was that they would have to shut down the engine before touchdown in which case they might have to fly a holding pattern in the event of a go-around, *"La première menace c'est qu'on soit obligé de couper le moteur avant qu'on soit posé, auquel cas il n'est pas impossible que tu sois obligé d'aller holder quelque part en cas de remise des gaz*." He then indicated that the decision as to when to shut down the engine was the co-pilot's and that he could also shut down the engine before carrying out the final approach. The captain concluded by indicating that they would keep the engine in operation as the remaining quantity of fuel was sufficient to avoid a flame-out. The relief pilot reminded them that unlike usual practices, the thrust reversers must not be used. The co-pilot said that he would like to be reminded of this at the time of landing. The captain then indicated that in the worst case, he could select reverse idle, *"Au pire, tu fais reverse idle."* The relief pilot then replied that in theory this was not even reverse, *"En théorie c'est même pas de reverse."* The captain confirmed this.

At 23:18, the **FUEL IMBALANCE** advisory alert was activated (refer to Figure 1, point 7), referring the crew to the FUEL LEAK procedure which involves shutting down the engine concerned. The captain questioned the danger of keeping the engine operative and concluded that it was not specified in the check-list that it had to be shut down[7] and that there was no notion of a possibility of a fire, *"A priori ce n'est pas écrit dans la check qu'il faut impérativement le couper… il n'y a pas de notion de possibilité de feu."* The relief pilot then intervened, specifying that he thought that shutting down the engine was not a bad idea but that it was a good idea to keep it running for the time being because they were in the air and there was no emergency, *"Je pense que l'idée de couper, ce n'est quand même pas une mauvaise idée… autant c'est bien de le garder pour l'instant, parce qu'on est en l'air et qu'il n'a pas d'urgence… une fois au sol…"* He finished by saying that "once on the ground", without continuing his line of thought.

The captain indicated his intention to shut down the engine on the ground before carrying out the turnaround at the end of the runway. The relief pilot confirmed that they risked spilling fuel on the runway.

The co-pilot replied that he could shut down the engine after the turnaround. The captain then concluded that the decision to shut down the engine, before or after the turnaround, would depend on the information provided by the fire fighters.

At 23:22, the captain mentioned the risk of hot brakes close to the fuel in case of excessive braking due to the length of the runway and asked the co-pilot to modulate the braking, The crew next carried out the approach check-list.

At 23:28, the aeroplane was cleared for the RNP 23 approach. At 3,000 ft, on final, the aeroplane was configured for landing and the landing check-list was carried out.

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7 The FUEL LEAK procedure specifies shutting down the engine on the side of the leak (refer to paragraph 1.6.6).

During the final, the crew were concerned about the tailwind. The captain mentioned a tailwind of 32 kt and referred to the possibility of a go-around. At a radio-altimeter height of 500 ft, the Calibrated AirSpeed (CAS) increased to 147 kt and the tailwind decreased to 21 kt. The AutoPilot (AP) was disconnected.

At 23:34 (refer to Figure 1, point 8), the captain referred to the tailwind, specifying that it was now less than 10 kt. The aeroplane landed 550 m after threshold 23 at a speed of 150 kt (VAPP+8).

Seven seconds after wheel touchdown, the visual and aural warning, **BRAKE MAX BRAKING MAX BRAKING** was activated and in accordance with the briefing, the thrust reversers were not used. The PF applied full braking on the brake pedals. The temperature of the brakes increased and the **BRAKES HOT** alert was activated. During the landing run, fuel spilled onto the runway. The relief pilot asked if the engine shutdown was being considered. The captain replied that the engine would be shut down after the turnaround so that it could be carried out in the correct direction in the turnaround bay, with the left engine on the outside of the turn. During the turn, more thrust (around 40% of N1[8]) was then applied to engine 1, the location of the leak.

After the turnaround, at 23:37, the crew shut down engine 1. The controller informed the crew that the fire fighters positioned near the runway had not seen any signs of fuel on the runway although substantial quantities were running out of the drain mast and nacelle under engine 1[9]. The aeroplane taxied to the parking area and came to a halt. The crew were worried about the high temperature of the brakes given the fuel leak. They waited for confirmation of the gate number before shutting down engine 2 ten minutes after engine 1. A fire fighter started spraying water under engine 1. Once the aeroplane was made safe, the passengers disembarked.

On arrival, a comparison of the fuel used and remaining fuel indicated a fuel leak of 5.3 t in flight and 5.7 t up until engine 2 was shut down in the parking area.

1.2 Injuries to persons

None.

1.3 Damage to aircraft

None.

1.4 Other Damage

None.

[8] Low pressure compressor and turbine rotation speed.

[9] Indicated by the crew in their statements and by what was said and recorded on the CVR.

1.5 Personnel Information

1.5.1 Flight Crew

	Captain (PM)	Co-pilot (PF)	Relief pilot
	Male, aged 54	Male, aged 53	Male, aged 54
ATPL issued on	01 June 2005	04 February 2019	12 April 2005
Type Rating (TR) on A330	7 September 2006 then 29 July 2020	14 February 2020	09 December 2019
TR valid until	31 July 2021	31 March 2021	31 December 2020
Class 1 medical certificate valid until	16 October 2021	28 September 2021	28 August 2021

	Captain	Co-pilot flying	Relief pilot
Total experience	12,399 flight hours including 1,077 hours as captain	5,656 flight hours	4,800 flight hours
Experience on type	3,852 h including 80 h as captain	550 h	803 h
Experience in last 90 days	90 h	105 h	139 h
Experience in last 30 days	33 h	41 h	59 h
Experience in last 72 hours	14 h	14 h	14 h
FUEL LEAK procedure training	20 July 2020 during FFS 08 for A330 TR	02 February 2017 during FFS 07 for A320 TR	25 November 2016 during FFS 05 for A320 TR

Professional experience

The captain joined Air France in 2002 after a career as a military pilot. He had become medium-haul captain on the B737 at Transavia where he flew for four years. He completed his line conversion training on the A330 in February 2020.

The co-pilot joined Air France in December 2016 after a military and then engineer career.

The relief pilot joined Air France in October 2016 after a career as a military pilot and experience as a Simulator Flight Instructor (SFI) at Airbus, notably on the A330.

1.5.2 Chief purser

	Chief purser
	Female, aged 57
Cabin Crew Attestation (CCA) issued on	25 January 1988
A330 TR issued on	10 October 2001
TR valid until	30 November 2021
Medical certificate valid until	30 June 2021

The chief purser joined Air France in May 1988 as a cabin crew member. She became chief purser in 2019. She held the A330, B777, B787 and A350 ratings. Her total experience was 16,400 flight hours.

1.5.3 Fuel leak crew training

The F-GZCJ crew members had followed simulator training in the FUEL LEAK procedure during A320 and A330 TR sessions.
During the simulator session, the FUEL LEAK failure was activated during a flight whose scenario was known to the crews in advance. The procedure was reviewed during the briefing before the session. There was no surprise effect nor operational complexity in the training scenarios, the purpose of the TR being to train the crews in the procedures.

The training suffers from technical limitations inherent in the simulation tools which include the impossibility of simulating a realistic leak during a fuel transfer to the trim tank.

1.6 Aircraft information

1.6.1 Airframe

<table>
<tr><td>Manufacturer</td><td colspan="3">AIRBUS</td></tr>
<tr><td>Type</td><td colspan="3">A330 - 203</td></tr>
<tr><td>Serial number</td><td colspan="3">503</td></tr>
<tr><td>Registration</td><td colspan="3">F-GZCJ</td></tr>
<tr><td>Entry into service</td><td colspan="3">22 November 2002</td></tr>
<tr><td>Certificate of Airworthiness</td><td>122418</td><td colspan="2">from 8 September 2008</td></tr>
<tr><td>Airworthiness review certificate</td><td>2020/122418</td><td>from 26 July 2021</td><td>to 21 August 2022</td></tr>
<tr><td>Operation as on 30 September 2020</td><td colspan="3">71,831 flight hours/11,385 flight cycles</td></tr>
<tr><td>Owner</td><td colspan="3">ILFC</td></tr>
<tr><td>Operator</td><td colspan="3">Air France</td></tr>
</table>

1.6.2 Engines and APU

<table>
<tr><td></td><td>Engine 1</td><td>Engine 2</td></tr>
<tr><td>Manufacturer</td><td>General Electric (GE)</td><td rowspan="8">Not applicable</td></tr>
<tr><td>Type</td><td>CF6-80E1A3</td></tr>
<tr><td>Serial number</td><td>811159</td></tr>
<tr><td>Date of manufacture</td><td>29 January 2002</td></tr>
<tr><td>Date of installation</td><td>24 January 2019</td></tr>
<tr><td>Total operating time (cycles) at date of installation</td><td>58,333 h (9,056)</td></tr>
<tr><td>Total operating time (cycles) since last inspection</td><td>4,691 h (771)</td></tr>
<tr><td>Total operating time (cycles) on 31 December 2020</td><td>63,024 h (9827)</td></tr>
</table>

1.6.3 Flight log book

None.

1.6.4 Weight and Balance

The weight and balance were within the limits specified by the flight manual.
On landing, the aeroplane's centre of gravity was at the aft limit. The crew had isolated the trim fuel tank at the beginning of the FUEL LEAK procedure but had omitted to open it again; they had not completed the procedure.

1.6.5 A330 fuel system

The Airbus A330 has two fuel tanks in each wing (inner and outer), a centre fuel tank and a trim fuel tank located in the tail. Each engine is supplied from its respective inner fuel tank.

A Low Pressure (LP) valve can be used to isolate the corresponding engine from the fuel supply. A crossfeed system can be used to supply either engine from the opposite fuel tank. This system is also used by the flight crew to correct a fuel imbalance between the inner fuel tanks.

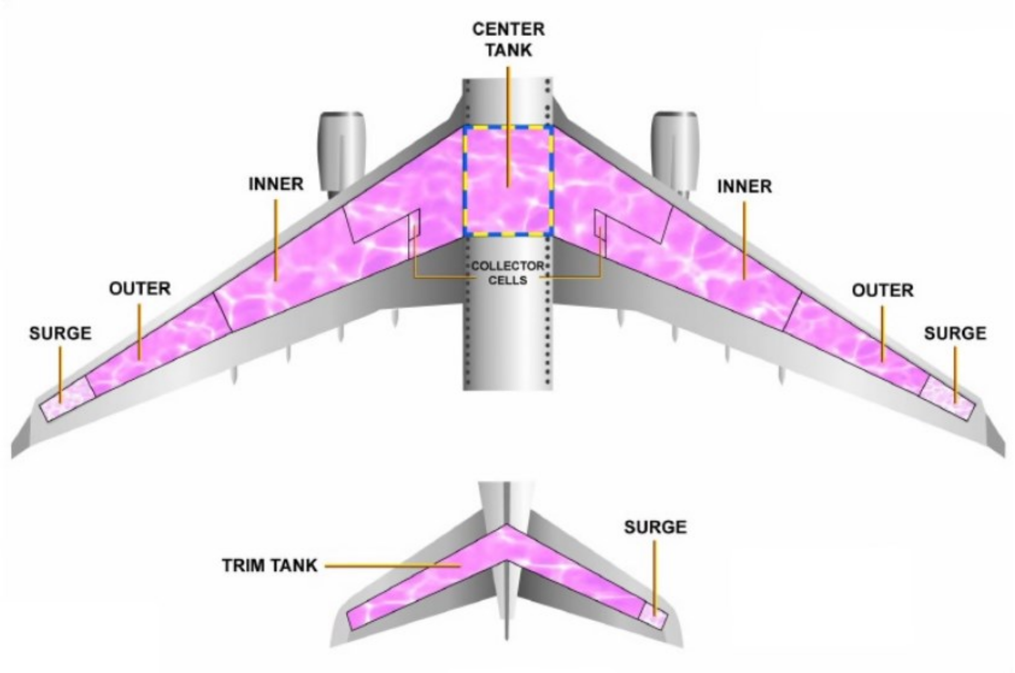

Figure 2: Position of fuel tanks on A330-200
(Source: Airbus)

In flight, fuel is transferred between the wing and trim tanks in order to optimise the centre of gravity position according to the total weight of the aeroplane.
In particular, the Fuel Control and Monitoring Computer (FCMC) automatically starts a fuel transfer from the inner tanks to the trim tank when the aeroplane flies through FL 255 in climb and the centre of gravity is not at its target value. If during the transfer, there is an imbalance of more than 500 kg between the inner tanks, fuel is only transferred from the fullest inner tank to the trim tank until the tanks are balanced.

The quantity of fuel in each fuel tank is measured by fuel gauges and displayed for the crew on the ECAM fuel page. En route, in the flight conditions of the occurrence, the quantity of fuel was given with an accuracy calculated to be around 700 kg. This accuracy depends on the total fuel quantity.

If there is a difference of more than 3.5 t between the fuel used and the fuel available in the fuel tanks, the **FUEL F.USED/FOB DISAGREE** alert appears on the ECAM and directly refers the crew to the FUEL LEAK procedure (refer to paragraph 1.6.6).
In the event of an imbalance of more than three tonnes between the left and right fuel tanks, the **ADVISORY FUEL** alert flashes in green on the automatically displayed FUEL system page. The quantities in the inner and outer fuel tanks are indicated on this FUEL page. It refers the crew to the FUEL LEAK procedure.

The ENGINE MASTER SWITCH situated under the engine power lever simultaneously actions the LP and HP (High Pressure) fuel valves. The LP valve is situated before the fuel tank outlet; closing this valves stops fuel circulating upline of the Hydro Mechanical Unit (HMU). Positioning the ENGINE MASTER SWITCH to OFF, mentioned in the FUEL LEAK procedure, stops the fuel supply to the engine.

Engine fuel supply

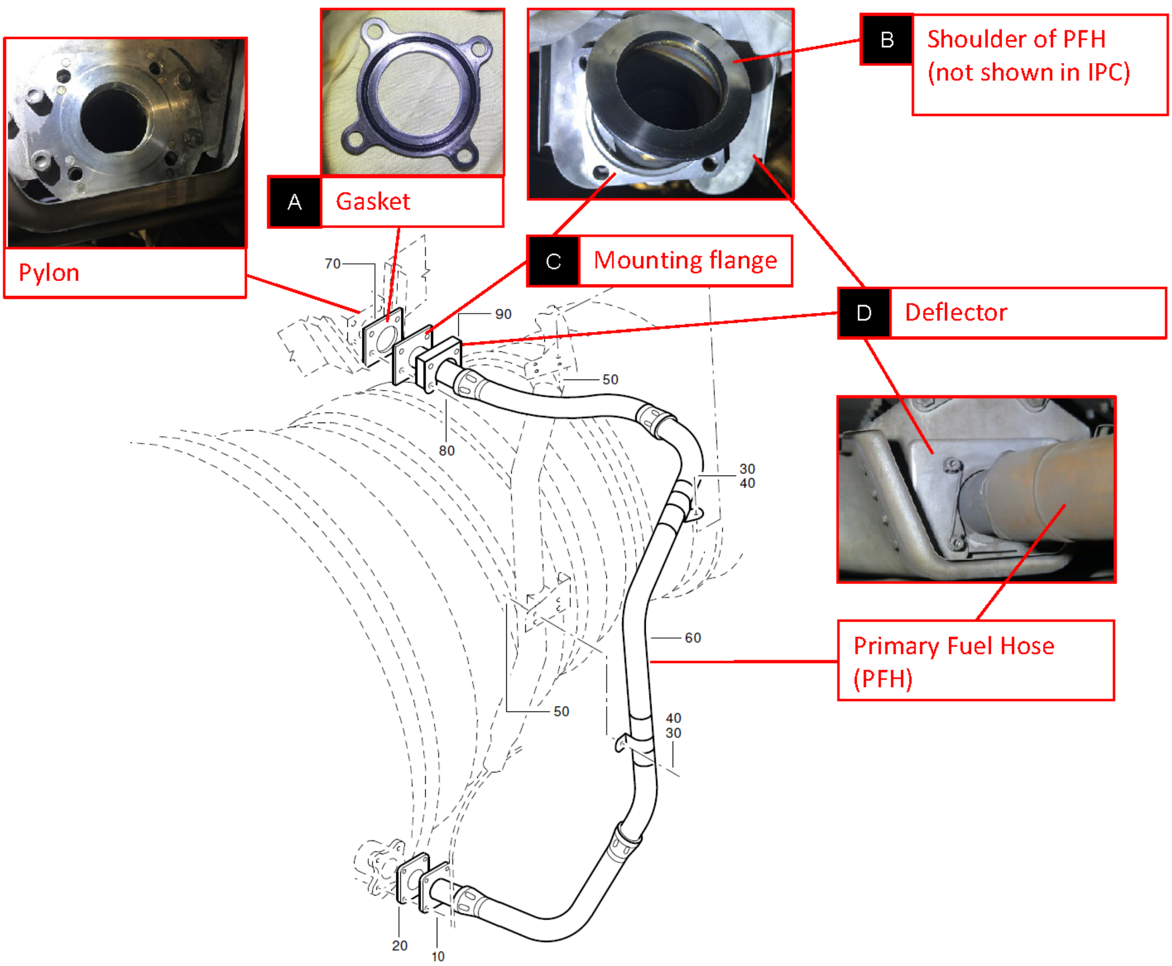

Figure 3: IPC view of PFH
(Source: Airbus IPC Figure 73-11-46-20 and BEA annotations)

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The PFH mounting flange is assembled on the engine pylon by superposing the following components:

- A - gasket with an O-ring on each side
- B - shoulder of PFH
- C - mounting flange
- D - deflector which protects against fuel splashes in the event of a leak at this interface.

1.6.6 Operational procedures

1.6.6.1 En-route checks

Crews are required to check the fuel quantities on board either when overflying the waypoints or at least every 30 minutes. If a leak is suspected, crews must refer to the QRH FUEL LEAK procedure[10].

FLIGHT PROGRESS

FLIGHT PROGRESS .... CHECK | **PF-PM**

Monitor flight progress in the conventional way.

WHEN OVERFLYING A MANUALLY ENTERED WAYPOINT

- Check track and distance to the next waypoint
- Check the wind and update it if the current wind is significantly different.

WHEN OVERFLYING THE WAYPOINT, OR AT LEAST EVERY 30 MIN

Check FUEL:

- Check FOB (ECAM) and fuel prediction (FMGC), and compare with the computerized flight or use the performance application of the EFB
- Check that there is no fuel leak
- Check that the sum of the fuel on board and the fuel used is consistent with the fuel on board at departure:
  - If the value is abnormally negative, suspect a fuel leak
  - If the value is abnormally positive, suspect a fuel quantity overread.

CAUTION	This check must also be performed each time a FUEL IMBALANCE procedure is necessary. Perform the check before applying the FUEL IMBALANCE procedure. If a fuel leak is confirmed, apply the FUEL LEAK procedure.

Figure 4: A330 FCOM Normal procedures
(Source: Air France)

1.6.6.2 FUEL LEAK procedure

Unlike determinate faults, which are linked to an ECAM warning, the detection of a leak initially relies on human vigilance when checking the fuel.

Below the three tonne threshold, a fuel leak does not give rise to an ECAM message. The ECAM **FUEL F. USED/FOB DISAGREE** (difference of 3.5 t) and **FUEL IMBALANCE** (imbalance of more than 3 t) messages refer the crew to the FUEL LEAK procedure.

The FUEL LEAK procedure enables the crew to locate the origin of the fuel leak.

This QRH procedure has multiple sub-steps as there is not one sole condition for a fuel leak.

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10 The FUEL LEAK procedure is described in the paper version of the QRH and in the FCOM. It is not presented on the ECAM.

If the origin of the leak is not confirmed or if the leak has not yet been located, the procedure enables the crew to segregate the fuel zones to try and determine its origin: (left or right) engines, (left or right) wing tanks or trim tank.

In the event of a lateral leak, the shutdown of the engine is systematically required as:

- If the leak is confirmed as coming from the engine, the latter must be shut down.
- If the origin of the leak is not known, shutting down the engine will enable the crew to confirm if the leak is from the engine or from the fuel tank.

In the event of a leak from the engine, shutting it down will conserve the fuel in the associated fuel tank and also prevent fuel from being dispersed in the hot parts of the engine.

If the leak comes from the fuel tank, the procedure indicates that the crew can then consider starting up the engine again.

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FUEL LEAK

LAND ASAP

- **Leak from engine/pylon confirmed by excessive fuel flow indication or visual check:**
  THR LEVER (affected engine)........ IDLE
  ENG MASTER (affected engine)........ OFF
  WING X FEED........ AS RQRD
  DO NOT RESTART AFFECTED ENGINE
- **Leak from engine/pylon not confirmed or leak not located:**
  WING X FEED........ MAINTAIN CLOSED
  L CTR PUMP........ OFF
  R CTR PUMP........ OFF
  T TANK FEED........ ISOL
  INNER TANKS FUEL QUANTITIES........ MONITOR
  - **If one inner tank depletes faster than other by at least 500 kg (1 100 lb) in less than 30 min:**
    THR LEVER (engine of affected inner tank)........ IDLE
    ENG MASTER (engine of affected inner tank)........ OFF
    FUEL LEAK........ MONITOR
    - **If leak stops:**
      ENGINE LEAK CONFIRMED
      L CTR PUMP........ ON
      R CTR PUMP........ ON
      T TANK FEED........ AUTO
      WING X FEED........ AS RQRD
      DO NOT RESTART AFFECTED ENGINE
    - **If leak continues (after engine shutdown):**
      WING LEAK SUSPECTED
      ENGINE RESTART........ CONSIDER
      FUEL LOSS REDUCTION........ CONSIDER
      Refer to ABN-19 Fuel Loss Reduction

CAUTION	Do not apply the FUEL IMBALANCE procedure. Approach and landing can be done, even with one full wing/one empty wing.

  - **If both inner tanks deplete at a similar rate:**
    LEAK FROM CENTER TANK, TRIM TANK OR APU/TRIM FEEDING LINE SUSPECTED
    L CTR PUMP........ ON
    R CTR PUMP........ ON
    - **If fuel smell in cabin:**
      APU........ OFF
      T TANK FEED........ MAINTAIN ISOL

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FUEL LEAK (Cont'd)

- **If no fuel smell in cabin:**
  LEAK FROM CENTER TANK OR TRIM TANK SUSPECTED
  FUEL LOSS REDUCTION........ CONSIDER
  Refer to ABN-19 Fuel Loss Reduction
- **For landing::** DO NOT USE REVERSERS

Figure 5: A330 QRH FUEL LEAK procedure
(Source: Air France)

The fire risk is not explicitly mentioned in the Airbus's FCTM for the A330. It is in the FCTM of other manufacturers of aircraft in the Air France fleet including the B777/B787: "*There are two reasons for the shutdown. The first is to close the spar valve, which stops the leak. This prevents the loss of* *fuel which could result in a low fuel state. The second reason is that the fire potential is increased when fuel is leaking around the engine. The risk of fire increases further when the thrust reverser is used during landing. The thrust reverser significantly changes the flow of air around the engine which can disperse fuel over a wider area."*

1.6.7 Performance

The landing distance was calculated during the investigation taking into account the operational data of the occurrence flight: a QNH value of 1011 hPa, a static temperature of 22°C, a dry runway, all engines operating, a landing weight of 171.7 t, configuration 3, air conditioning set to OFF and A/THR engaged. With the auto-brake set to MED, the Factored Landing Distance (FLD) with a tailwind of 9 kt and a speed of 150 kt was 2,501 m for a landing distance available at N'Djamena[11] of 2,410 m[12], as indicated by the NOTAM.

Runway Overrun Warning - Runway Overrun Prevention System (ROW - ROPS)
The ROW - ROPS is designed to prevent runway excursions on landing. The system compares the required landing distance, taking into account the actual weight and configuration of the aeroplane with the landing distance available and alerts the crew if the stop distance margin is less than 15% by means of:

- An in-flight **RUNWAY TOO SHORT** warning which is both visual and oral to incite the crew to consider a go-around.
- A ground **MAX BRAKING MAX REVERSE** warning which is both visual and oral to incite the crew to increase the braking input.

On the wheels of F-GZCJ touching down at 23:34:27, the ROPS warning, **BRAKE MAX BRAKING MAX BRAKING** was heard two times on the CVR. Two seconds later, the co-pilot manually braked more than 2/3 full deflection for 20 s until reaching maximum braking, deactivating the automatic braking which was engaged.

The runway length taken into consideration by the ROPS on board the aeroplane was 2,800 m as it did not take into account the displaced threshold of the NOTAM (see paragraph).

1.7 Meteorological information

BRAZZAVILLE (FCBB)
METAR FCBB 312300Z 21002KT 8000 NSC 23/23 Q1013 NOSIG
TAF FCBB 311700Z 3118/0124 24006KT 8000 SCT016 BECMG 3121/3123 SCT015 FEW026CB PROB30 3123/0103 -TSRA BECMG 0103/0105 SCT018

YAOUNDE (FKJS)
METAR FKYS 312300Z 24004KT 6000 SCT006 23/23 Q1015 BECMG BKN006
TAF FKYS 311700Z 3118/0118 21005KT 8000 FEW020 BECMG 3121/3123 BKN006 PROB30 0104/0107 4000 BR BECMG 0106/0109 BKN016

N'DJAMENA (FTTJ)

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[11] The crew had taken into account a nominal VAPP and a tailwind of 10 kt. The calculation indicated that the FLD calculated by the crew in flight was less than the runway length of 2410 m.
[12] Refer to paragraph 1.10.

METAR FTTJ 312300Z 31005KT 8000 NSC 22/08 Q1011 NOSIG
TAF FTTJ 311700Z 3118/0124 34008KT CAVOK TEMPO 3118/3120 4000 HZ TEMPO 0116/0119 4000 HZ

The Air France operational supplement to the LIDO C-01 sheets mentions that in the Harmattan period between November and March, there can be a strong wind even at very low levels, with a risk of a strong tailwind on runway 23. The crew are told to be wary of a calm surface wind as in these conditions there can be a northeasterly wind of up to 30 kt between 500 and 2,000 ft. It is indicated that the QFU 23 approach has less aerological problems on short final except for the possible tailwind.

1.8 Aids to navigation

The day of the occurrence, the crew carried out a RNAV 23 approach to N'Djamena. ILS 05 was not available.

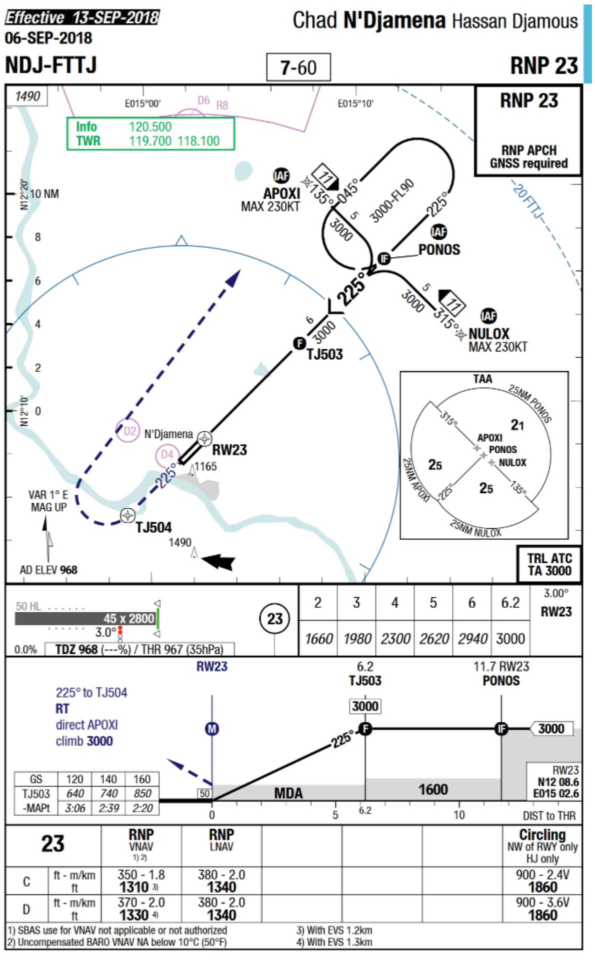

Figure 6 : RNP 23 approach chart
(Source: LIDO)

1.9 Communications

The crew were successively in contact with the following control units:

- Brazzaville en route control centre
- N'Djamena en route control centre
- N'Djamena approach
- N'Djamena airport

1.10 Airport information

N'Djamena airport

N'Djamena-Hassan Djamous international airport has one runway QFU 05/23, measuring 2,800 m long and 45 m wide. QFU 23 is not equipped with approach lights or centreline lights.
Aircraft weighing more than 40 t have to turn around at the end of runways 05/23 in the turnaround bays provided for this and vacate the runway via taxiway B.
The crew used the LIDO RNP 23 approach chart along with the operational supplement provided by the operator.

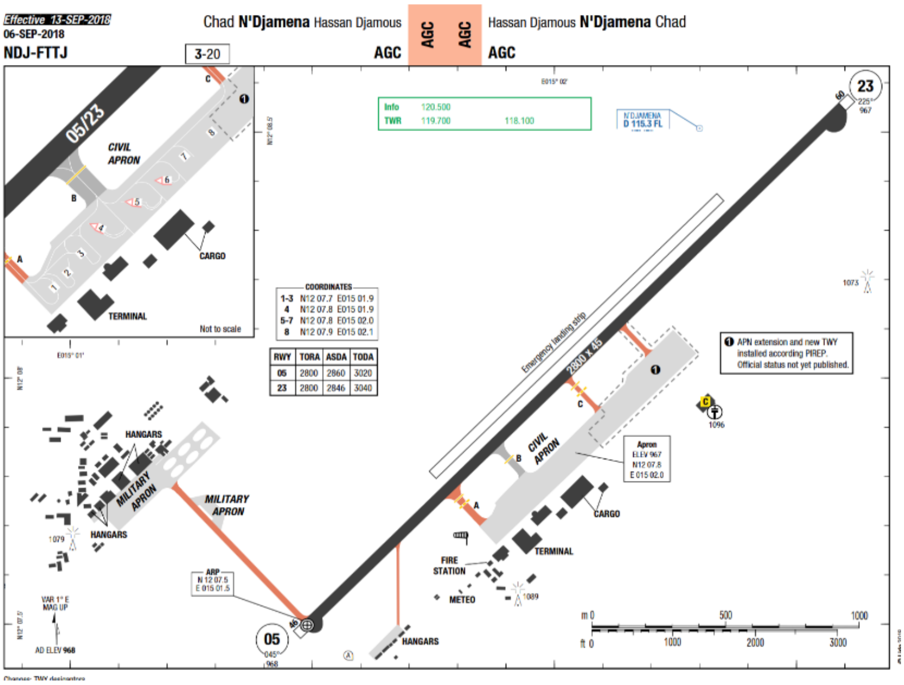

Figure 7 : GND chart
(Source: LIDO)

NOTAM

The day of the occurrence, due to work on and close to threshold 05, a NOTAM mentioned the presence of a displaced threshold for runway 05 which reduced the length of the runway by 390 m on both QFUs, that there was no Precision Approach Path Indicator (PAPI) on this same QFU and that the ILS procedure for runway 05 was suspended.
An Air France NOTAM specified that the 390 m between the displaced threshold and the 05 turnaround bay could be used as a taxiway, and that the turnaround could be carried out in the 05 turnaround bay and power applied from the new displaced threshold.

Airport Rescue and Fire Fighting Service (RFFS)

The airport was equipped with a level 8 RFFS which could take charge of an A330.

Yaoundé airport

Yaoundé-Nsimalen international airport is situated at 2,276 ft. It has one runway measuring 3,402 m long and 45 m wide and is equipped with an ILS for runway 19 (see Appendix 3). No NOTAM affecting performance was in force on the day of the occurrence.

BEA

1.11 Flight Recorders

In accordance with the regulations in force, the aeroplane was equipped with two flight recorders (FDR and CVR).

Flight Data Recorder (FDR)

- Manufacturer: Honeywell
- Model: 4700
- Part number: 980-4700-042

It is a solid state flight data recorder with a recording capacity of at least 25 h. The document to convert binary data into physical values provided by the manufacturer encompasses about 800 parameters.

Cockpit Voice Recorder (CVR)

- Manufacturer: Honeywell
- Model: 6022
- Part number: 980-6022-001

It is a Solid State Cockpit Voice Recorder with a recording capacity of at least 2 h.
The following tracks were recorded:

- Track 1: radio communications and microphone signal of the pilot in the left seat
- Track 2: radio communications and microphone signal of the pilot in the right seat
- Track 3: radio communications and microphone signal of third crew member (rear seat) and the FSK[13] signal
- Track comprised of the above three mixed tracks
- CAM track: cockpit area microphone signal.

Both recorders contained the information relating to the occurrence flight.

The CVR and FDR were synchronized using the landing gear compression parameters, the radio communication activation button and the engagement of the AP.

An audio anomaly was identified on the mixed track and on the CVR CAM track. Blocks of audio data had been duplicated and incorrectly inserted in the recording according to a defined cycle which was identified, enabling the duplicated data to be deleted. The CVR was sent to Honeywell who examined the equipment. It identified an internal fault and repaired this.
This malfunction was not detectable by the CVR built-in monitoring system nor by the daily test carried out by the crew in the cockpit via the CVR TEST control nor during the basic annual verification operation imposed by the European regulations.

The presence of this anomaly substantially slowed down the immediate read-out of the audio content in the scope of the analysis of the occurrence. After deleting the duplicated data, the audio content was analysed in its entirety.

[13] Frequency-Shift Keying.

1.12 Wreckage information

None.

1.13 Medical and pathological information

None.

1.14 Fire

None.

1.15 Survival Aspects

None.

1.16 Tests and Research

1.16.1 Search for fuel leak

While taxiing after landing, the maintenance technicians on board the aeroplane indicated that there was a large fuel leak in line with the drain mast situated under engine 1**Erreur ! Source du renvoi introuvable.** A residual flow continued after engine 1 had been shut down.

The subsequent ground maintenance inspections identified a substantial leak in line with the mounting flange of the PFH of engine 1. The purpose of this hose is to bring fuel from the fuel tanks to the engine (refer to paragraph 1.6.5). The mounting flange of this hose forms the interface between the pylon and the engine. It is disassembled each time the engine is removed.

The PFH had a play of 3 to 5 mm when it was handled after the occurrence. The four nuts were safetied but two of them were insufficiently torqued. As a consequence, when the pressurized fuel supplied the engine, it was ejected from both sides of the hose, inside the engine cowlings.

No deformation was observed on the gasket, flange or PFH shoulder during later disassembly and reassembly actions by the company.

Maintenance actions prior to occurrence
On 30 September 2020, the aeroplane came out of a “Long downtime” inspection. Air France had subcontracted this inspection to the HAECO maintenance workshop in Xiamen (China). It included the removal and reinstallation of the two engines which implied the disassembly and reassembly of the MFH mounting flange.

No leak was observed at this interface during the checks at the end of the maintenance operations, notably when the fuel system was pressurized.

The aeroplane returned to France and did not fly again until 26 December 2020. It then carried out six flights before the occurrence flight. During these flights, the crews did not observe any anomalies. The FDR data from the flight prior to the occurrence did not show a leak.

Difficulties with assembling the fuel hose

The difficulty with assembling the PFH is shown by a note in the Aircraft Maintenance Manual (AMM) (refer to Figure 8), added by Airbus in 2015. It recommends ensuring that the fuel hose shoulder is fully seated on the pylon before torquing the bolts to prevent distortion of the assembly.

(1) Remove the bolts (10) that attach the deflector plate (1) to the pylon. Attach the I PC-CSN(73-11-46-20 ITEM 070) GASKET (11), primary fuel hose (7), and the defl ector plate (1) to the pylon with the bolts (10). Make sure the deflector plate (1) is on the hose (7). TORQUE the bolts (10) **to between 75 and 85 lbf.in (0.85 and 0.96 m.daN)** and safety them with the lockwire (Material Ref. C10-071).

NOTE: Ensure that the fuel hose flange is fully seated before torquing the bolts. Distortion may occur if the fuel hose flange is improperly seated when th e bolts are torqued.

Figure 8: Excerpt from AMM 73-11-46-400-801-A "Installation of the Primary Fuel Hose"

The documentation used by HAECO to re-assemble the assembly (refer to ***Figure 9***) did include this note. The handwritten torque values indicate that the bolts were torqued to the recommended value.

(c) Install a new IPC -CSN (73-11-46-20-070) gasket (129) and attach the primary fuel hose (126) and the deflector plate (128) to the fuel port F1 with the bolts (127). TORQUE the bolts (127) **to between 75 and 85 lbf.in (0.85 and 0.96 m.daN)**. Lockwire the bolts (127) with lockwire (Material No. C10-071). 85 lbf.in. C0L23.65 TA443

NOTE: Ensure that the fuel hose flange is fully seated before torquing the bolts. Distortion may occur if the fuel hose flange is improperly seated when the bolts are torqued.

Figure 9: Excerpt from AMM 71-00-00-400-802-A "Installation of the Engine"
(Reference used by HAECO at XMN when reassembling engine 1)

The assembly of the PFH is tricky for the following reasons:

- The deflector prevents the operator from seeing if the elements of the assembly are aligned. Some technicians indicated that they used an articulated mirror, others checked that the shoulder was correctly seated on the pylon by moving the hose to check that there was no play.
- The hose is not perpendicular to the surface of the pylon (refer to ***Figure 10***) as it has an angle which does not help with seeing the alignment of the assembly elements.

The PFH shoulder is not shown in the IPC (refer to Figure 3), which may result in some misunderstanding as to how the parts are to be assembled. The AMM instructions do not specify how to check that the PFH shoulder is correctly seated in the mounting flange bore.

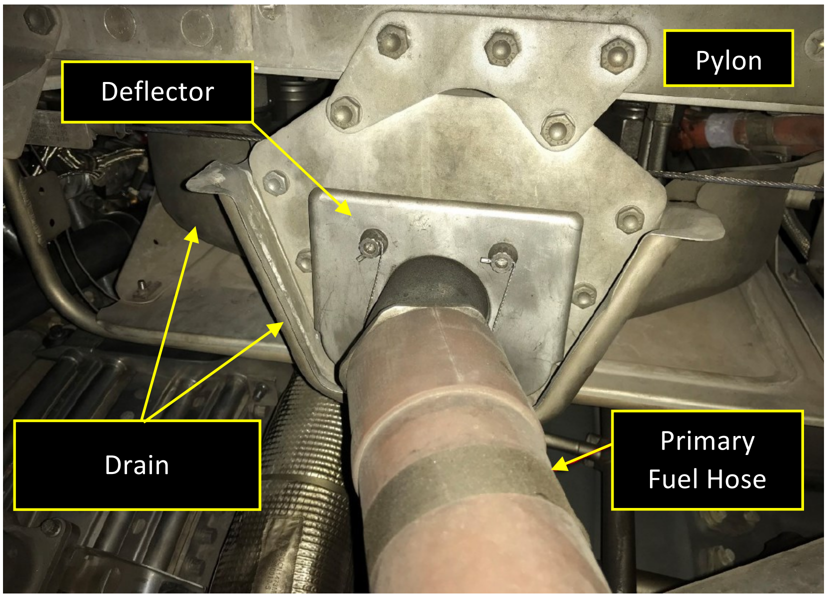

Figure 10: View of mounting flange of PFH
(Source: BEA)

In a Training Newsletter, reference Issue C F680C21005 and dated October 2005, the manufacturer, GE issued recommendations to operators following a leak at the interface between the fuel pump and the Main Engine Control (MEC). This interface is very similar in design to that between the PFH and the engine pylon. GE especially underlined the risk of incorrectly positioning the flange on the tube ferrule (refer to Figure 11). Torquing the bolts after incorrectly positioning the flange can ensure a temporary leaktightness by means of the O-rings. But vibrations can subsequently displace the PFH shoulder in the flange bore (refer to Figure 12), leading to a loss of tightness and as a consequence, to a leak.

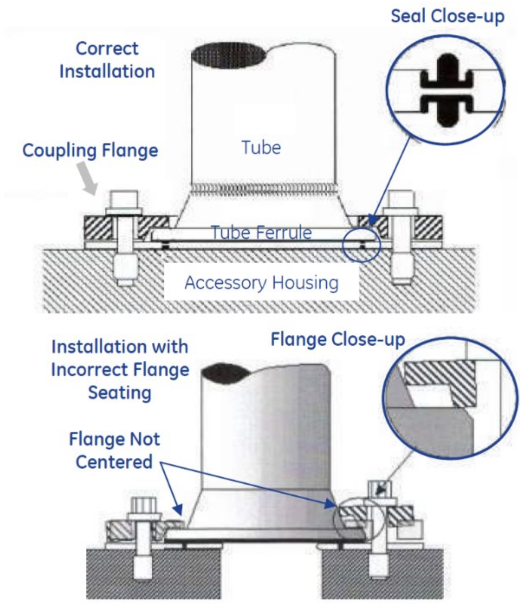

Figure 11: Incorrect position of flange on tube ferrule
(Source: GE Training Newsletter Issue C F680C21005 • October 2005)

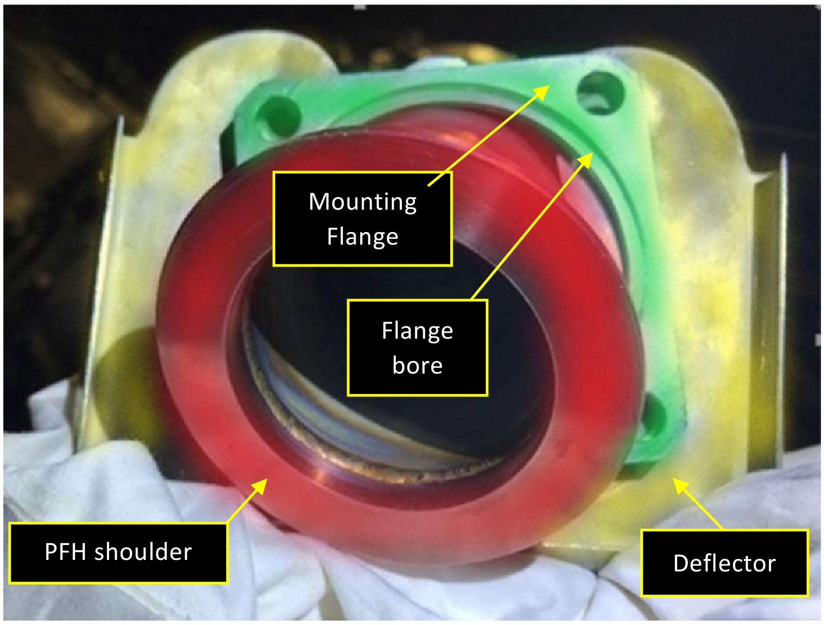

Figure 12: View of flange bore acting as seat for PFH shoulder (Source: HAECO)

Following a fuel leak in 2004 on a Boeing 747 at the junction between the MEC and the fuel flow transmitter, due to the incorrect alignment of the hose mounting flange, Air France highlighted the difficulties with this type of assembly. In particular, it is possible that the assembly ensured sufficient leaktightness at the time of the ground run, but that this degraded substantially during the flight, in particular following the stresses generated during the use of the engine at high thrust. An in-house bulletin asked maintenance teams to be particularly vigilant.

The junction of this hose on the Boeing 747 is similar to the A330 PFH mounting flange.

Special Bulletin SPIB 71-046

In order to reduce the possibility of incorrectly positioning the mounting flange with respect to the PFH shoulder, an SPIB (Spare Parts Introduction Bulletin) No 71-046 was issued on 10 December 2015 by Collins Aerospace[14] who manufactures the interface between the engine and the wing (refer to Appendix 2).

1.16.2 Fire hazard in case of fuel leak

Any fuel leak potentially creates a fire hazard. Consulted independently during the investigation, two engine manufacturers and Airbus assessed in a general way, the fire hazard linked to a fuel leak in the engine area depending on the flight phase.

It seems that when the air pressure increases and the ventilation flow decreases, the risk of spontaneous ignition increases. This is particularly the case:

- On approach, with an air pressure which increases and a low ventilation flow (low aeroplane air speed and engine speed).

[14] Via its subsidiary, Rohr Aircraft.

- On the ground, with a high air pressure and a low ventilation flow (low aeroplane air speed and engine speed), flow which can be modified if thrust reversers are used after landing.
- During a go-around, with a high air pressure and a low aeroplane air speed.

1.17 Organizational and management information

1.17.1 Principle of Airbus documentation

***Flight Crew Operating Manual* (FCOM)**

The FCOM, the primary reference during initial and recurrent training, is a document whose objectives are to:

- provide pilots with information on limitations, procedures, performance and aeroplane systems;
- serve as a basis for operators who wish to develop procedures specific to their operations.

***Flight Crew Techniques Manual* (FCTM)**

The FCTM has been optimised several times since 2016. The manufacturer presented these optimisations at various seminars and symposia.
The objective of the FCTM today is to centralize in a single manual, the techniques that were published in the previous FCOM and FCTM.
As of now:

- the FCTM contains techniques, while the FCOM contains procedures;
- the structures of the FCOM and the FCTM mirror each other.

The FCTM provides additional information to the FCOM and has to be consulted by pilots. It covers the following topics:

- the operational philosophy of Airbus: design and operating principles, "golden rules" for pilots;
- information on FCOM/QRH procedures;
- information on the "why" and "how" of the FCOM procedures;
- information on best practices, certain technical manoeuvres, and the use of systems;
- information likely to improve pilot situational awareness;
- some potential risks and their consequences.

1.17.2 Application of procedures at operator’s

The overriding safety principle when designing a procedure is that it is done at the right time, with rigour and in full.
In Part D of the Operations Manual (training), the “Application of procedures” competency is described in terms of the following expected behaviour:

Définition

Utiliser et adhérer aux procédures en vigueur

Comportements Attendus :

Adhère aux procédures. • Se conforme la règlementation en vigueur
Sait où trouver une procédure dans la documentation opérationnelle. • Sait où trouver une procédure dans la documentation opérationnelle
Applique correctement les procédures avec un bon niveau de conformité et au bon moment. • Identifie et applique les procédures • Utilise les systèmes de l'avion et les équipements associés conformément aux procédures • Surveille les systèmes avion • Démontre une connaissance des procédures
Utilise les procédures pour gérer le vol de manière sûre en considérant la performance opérationnelle et le confort passager.
Sait s'écarter des procédures en concertation équipage lorsque la sécurité l'exige. • S'écarte de la procédure pour raison de sécurité

A difference can be observed between the Air France documentation and the European documentation regarding air operations[15] (refer to Appendix 4), in the definition of one of the observable behaviours of the "Application of procedures" competency:

- The Air France documentation indicates: Know how to deviate from procedures in consultation with the crew when safety requires it. Deviate from the procedure for safety reasons.
- The European documentation indicates: "*Follows SOPs unless a higher degree of safety dictates an appropriate deviation*."

1.17.3 Decision-making process following a failure or anomaly

Air France crews use the FORDEC method, described in Parts A and D of the Operations Manual, to make decisions in the event of a failure or any other irregularity. This is complied with as soon as the procedure for managing the abnormal situation or failure has been completed.

Part A of the Operations Manual describes the FORDEC method which includes:

- Collection of decisive factual information affecting the flight (technical, operational, commercial, economic). It is indicated that the technical and operational assessments will take precedence over the commercial and economic aspects.
- Listing of the options available in relation to the aeroplane's new capabilities, including continuing to destination, turning around or diverting, as well as the examination of the various possible runways and types of approaches at the alternate airport.
- Analysis of the benefits and risks of each option, taking into consideration the essential criteria (limitations, weather conditions, available runways and approaches) and additional criteria (e.g. maintenance and passenger management).

[15] Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations (Version in force on the day of the incident).

- A decision by the captain after asking the co-pilot for his/her opinion.
- Distribution and execution of the tasks.
- Control at each evolution in the situation, to check that the chosen solution is still valid.

Part D of the Operations Manual describes the pilot's expected behaviour as follows:

Définition

Identifier les risques et les opportunités, résoudre les problèmes et prendre des décisions.

Comportements Attendus :

Prend en compte le temps disponible et la possibilité d'un F.O.R.D.E.C. • Temporise à la suite d'un changement ou d'une défaillance • (T) Prend en compte le temps disponible • Emploie le F.O.R.D.E.C.
Collecte, interprète et valide les informations déterminantes de la situation. • (F) Recherche les informations précises et pertinentes auprès des sources appropriées • (F) Identifie les éléments qui ont conduit à la situation rencontrée
Dresse une liste d'options. • (O) Détermine et étudie les options • (O) Improvise face à l'imprévisible pour obtenir le résultat le plus sûr
Évalue les risques et les bénéfices de chaque option. • (R) Détermine et gère les risques/bénéfices et les conséquences des différentes options
Décide d'un plan d'action en concertation. • (D) Sélectionne un plan d'action
Met en œuvre la décision en équipage • (E) Fixe les priorités • (E) Au-delà de "Quoi" et « quand » faire, prévoit « qui » et "Comment" le faire • (E) Adhère au plan d'action
Revalide la décision en fonction de l'évolution du contexte. • (C) Surveille, examine et adapte au besoin les décisions et les projets d'action

A difference can be observed between the Air France documentation and the European documentation in one of the observable behaviours of this competency.
While the European documentation recommends that the pilot "*Adapts when faced with situations where no guidance or procedure exists*", the Air France documentation recommends that the pilot improvises when faced with the unforeseeable to obtain the safest result.

1.17.4 Leadership and crew cooperation at the operator's

The competency, leadership and crew cooperation at Air France is set out in Part D of the Operations Manual and described using the following expected and observable behaviours:

Définition

Instaurer un climat de confiance favorisant la collaboration. S'impliquer dans l'atteinte de l'objectif commun.

Comportements attendus

Apporte son soutien. • Soutient, encadre, délègue ou donne des directives quand nécessaire

Encourage l'expression des avis et des doutes • Implique les autres • Encourage la participation de l'équipe et une communication ouverte • Encourage, donne et reçoit les retours de manière constructive • Tient compte des suggestions • Tient compte des diversités culturelles et linguistiques
Garde son calme et reste factuel dans la gestion des conflits, suggère et suscite des solutions. • Règle les conflits et les désaccords de manière constructive
Défend sa position et intervient avec assurance. • Défend sa position et intervient avec assurance quand la sécurité est en jeu • Intervient efficacement en cas d'écart
Prend ses responsabilités et reconnaît ses erreurs. • Prend des initiatives • Exécute les instructions lorsqu'il en reçoit l'ordre

What is more, Part A of the Operations Manual makes a distinction between the expected behaviour of the captain and the co-pilot:
The captain's expected behaviour is defined by the following points:

- Be exemplary and ensure the exemplarity of his/her crew.
- Develop a team spirit by motivating his/her crew, involving them in the operations and the decision-making process by sharing information.
- Pull all the actors in the same direction in order to ensure safety and security, and to reach the punctuality objective.
- Ensure that the appropriate decisions are made and implemented.
- Encourage a team spirit and create a climate in which crew members can speak and are heard.
- Encourage feedback from the crew and ground personnel.

For the co-pilot, it is indicated:

- Assist the captain in the safe and optimized conduct of the flight.
- Express his/her doubts in a spirit of responsible cooperation.
- Give the captain all information, advice and assistance that contributes to the safe and effective conduct of the flight.

Such a distinction between the captain and co-pilot is not envisaged in the European documentation.

The role of the relief pilot is not detailed in the Air France documentation.

1.18 Additional Information

1.18.1 Captain's statement

As far as he could remember, they were one tonne[16] of fuel short on carrying out the first check at the beginning of the en-route phase. At this point, he thought that a part of the fuel was circulating through the pipes and that the situation was going to stabilise.
He decided not to shut down the engine as indicated in the procedure as he considered that this would generate more risks than keeping it in operation. He also considered that there was no fire hazard in that no fire had immediately broken out. He added that he did not want to worry the cabin crew by shutting down the engine.
In his opinion, the main objective of the FUEL LEAK procedure and in particular, the action of shutting down the engine, was to conserve the fuel, for example when flying over an ocean. In the case of the occurrence, he indicated that if a fire had broken out, he would have carried out the ENGINE FIRE procedure.
Subsequently during the descent, the technician's information that the leaking fuel was running away from the hot parts reinforced his decision not to shut down the left engine.
He indicated that the relief pilot had mentioned, after reading the QRH FUEL LEAK procedure in full, that the thrust reversers must not be used on the ground.
Once on the ground, in the parking area, he was surprised to observe the size of the leak and became aware of the fire hazard as the temperature of the brakes was very high.
In the scope of the training sessions for the A330 TR, he could not remember having shut down an engine during a FUEL LEAK exercise. He did not think that he would have shut it down, even in a simulator.

He indicated that the decision to shut down an engine falls under his prerogative as captain.
He differentiated an ECAM check-list from a QRH check-list. In the case of an ECAM, if the procedure is suspended, the ECAM continues to exist, which is not the case with a QRH procedure. He specified that if the FUEL LEAK procedure had been presented on the ECAM, he thought that he would have shut down the engine.

He considered that during the occurrence, the division of tasks had been satisfactory and that being a crew of three had been particularly useful.

1.18.2 Co-pilot's statement

The co-pilot indicated that when it seemed probable that there was a leak, he had displayed 250 Nm circles on the Navigation Display (ND) and was aware of their position abeam Yaoundé. He felt that if the leak rate had increased, it would have been possible to shut down the engine at any given time. They did not perform the FUEL LEAK procedure in full (no engine shutdown) because they were not flying over an ocean or desert, they had enough fuel, and the leak rate was low. The purpose of the engine shutdown is to conserve fuel.
He believed that if the engine was not damaged, the risk of an in-flight fire was low. He stated that there may be a psychological barrier to shutting down an engine.
He said that the N'Djamena NOTAM had been talked about before the flight but that he did not have it in mind when the decision to divert was taken.

[16] They were in fact lacking 1.4 t.

During the approach briefing, he remembered having suggested shutting down the engine before the approach. He wanted to land with "full configuration"[17] because he felt there was no risk of losing the engine on final and if this had been the case, they would have aborted the approach. He did not insist.
On the activation of the ROPS warning, he immediately braked.
He again mentioned the fire hazard while taxiing, as he thought he would shut down the engine on landing. He sided with the opinion of the other two pilots this time.
He recalled having had FUEL LEAK training in an A320. He did not remember that the thrust reversers should not be extended.
He though they probably would have shut down the engine if the procedure had been displayed on the ECAM.

1.18.3 Relief pilot's statement

In operations, he had already noted differences of the order of 700 or 800 kg at the beginning of certain flights on the A330, which he explained by the presence of fuel in the pipes during transfers and by the inaccuracy of the gauges.
When reading the FUEL LEAK procedure, he was reassured about the decision not to shut down engine 1 by the reaction of the other pilots and "relieved" that the captain had taken this decision. This was supported by the fact that an engine shutdown was only justified if there was an imperative need to stop the leak, in order to conserve the fuel, as is the case when flying over an ocean.
He did not associate the FUEL LEAK procedure with a fire hazard, except when using the thrust reversers after landing, because the procedure allowed for the possibility of starting up the engine in case of a fuel leak in the wing. Lastly, he indicated that if the FUEL LEAK procedure had mentioned a fire hazard, it might have helped shape the discussion about shutting down engine 1.
He mentioned the possibility of shutting down engine 1 before the descent. In hindsight, he felt that it would have been wise to shut it down before the approach.
He indicated that there were not many diversion options. At Yaoundé, the weather was not as good and they did not know the airport which is located at a higher altitude than N'Djamena.
At N'Djamena, the meteorological conditions were better, the airport was known and more reassuring, especially because of the permanent military presence on the other side of the runway.
In his mind, it was not a good solution to consider a night RNP approach to runway 05 with a displaced threshold. He had had a bad experience a few months earlier: an RNP approach to a displaced threshold at Niamey (Niger) had led to the crew uncomfortably intercepting the slope because the approach path was bringing them to the usual threshold, before the displaced threshold.
On final to runway 23, he monitored the tailwind and kept in mind a go-around, which he would have called out without hesitation. Anticipating the increase in brake temperature after landing, he suggested shutting down the engine just after touchdown. He was surprised by the ROPS warning.
Once on the ground, due to a bad experience during a previous flight, he accepted the captain's proposal to keep the two engines operating for the turnaround in the turnaround bay.
He became aware of the fire hazard when he realized that fuel was still running out from under the engine and that the brake temperature was high.
He considered the QRH to be less directive than the ECAM.

[17] The engine failure procedure requires a configuration 3 landing.

He had no particular recollection of FUEL LEAK training during his training.

1.18.4 Chief purser's statement

The chief purser quickly realized that there was a technical problem when she saw the captain return to the cockpit shortly after leaving it for his rest period. About 20 minutes later, the latter asked her to come into the cockpit and briefed her on the diversion, without asking her to prepare the cabin in any particular way for landing. The chief purser then exited the cockpit, feeling that a fire and emergency evacuation were possible. She asked the pursers to prepare the cabin for a "phase 2"[18] and to select the passengers who would be required for an emergency evacuation. She did not return to the cockpit so as not to disturb the pilots. She anticipated an evacuation, but it did not happen. The captain simply told the cabin crew to leave the doors armed, except for the one adjacent to the bridge.

1.18.5 Previous occurrences

The following three occurrences illustrate that fuel leaks which are not managed by the crew can lead to fires in flight or on the ground.

Accident to the Airbus A319 registered G-EUOE operated by British Airways on 24 May 2013 on final to Heathrow airport (United Kingdom)[19]
During the take-off run, the fan cowl doors, which had not been locked, detached from the aircraft, causing damage, in particular to an engine 2 fuel pipe. The crew who had identified the leak, landed at London Heathrow airport without shutting down the engine. On final, when the flaps were extended and the airspeed had been reduced, the fuel ignited and a fire developed. The crew promptly shut down the engine and activated the fire extinguishers without this extinguishing the fire in flight due to the missing fan cowl doors. The fire was brought under control on the ground by the emergency services.

Serious incident to the Boeing B777 registered VN-A146 operated by Vietnam Airlines on 30 July 2008 at Narita (Japan)[20]
A fuel leak occurred in flight without it being possible to determine precisely when it appeared. The crew did not shut down the engine. While taxiing after landing at Narita airport, when the aeroplane was exposed to a tailwind on the taxiway, the airflow in the engine decreased and a fire broke out. It was believed that in flight, the ventilation of the engine had prevented the fire. The source of the leak was identified as being at the junction between the fuel hose and the engine.

Serious incident to the Boeing 767 registered ZK-NCK operated by Air New Zealand on 30 December 2006 at Auckland (New Zealand)[21]
The crew were carrying out a flight from Apia to Auckland. No leak had been detected during the pre-flight inspection. The investigation indicated that it had probably started during the flight but was not identified by the crew. Consequently, the crew did not shut down the engine and used the thrust reversers normally after landing. Three seconds after the thrust reversers were stowed, a fire broke out on engine 1. The fire had been caused by a fuel leak in a manifold.

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[18] A "phase 2" cabin preparation consists of preparing the cabin crew for a potentially complicated landing. It is defined in the document MSS 07-10 "Cabin preparation procedures".

[19] Accident report

[20] Serious incident report

[21] Serious incident report

1.18.6 Checks by oversight authority

The French civil aviation safety directorate (DSAC) and the Flight control organization (OCV) carry out in-flight and on-ground checks to ensure that the regulations and procedures governing the operation of aircraft in commercial transport are complied with. This monitoring mission also covers the training, ratings and medical fitness of the flight crew and cabin crew.

Contacted during the investigation, these organizations told the BEA that their findings were consistent with the observations in this report.

1.19 Useful or effective investigation techniques

None.

2 ANALYSIS

2.1 Introduction

At the beginning of the en-route phase at FL 380, during the first checks to be carried out at this stage of the flight, the captain noticed that they were short of 1.4 t of fuel, without any visible lateral imbalance between the tanks. He attributed this difference to the fuel transfers in progress, shared this information with the co-pilot and the relief pilot and then left the cockpit for his rest period, asking the two co-pilots to monitor the evolution of the fuel.

About 20 min after leaving the cockpit, he was called back by the co-pilots who suspected a leak on the left engine. The crew began to carry out the FUEL LEAK procedure. Although this procedure asks the crew to consider landing at the closest suitable airport[22] and to shut down the engine with the leak, they decided to keep it operating and considered a diversion initially to Yaoundé and then to N'Djamena. Thereafter, the occurrence of the **FUEL F.USED/FOB DISAGREE** alerts and the **FUEL IMBALANCE** advisory message, which referred the crew to the FUEL LEAK procedure, did not lead to a change in the action plan. The crew continued to keep the left engine operating and kept N'Djamena as the alternate airport.

During the descent to N'Djamena, the controller informed them that ILS 05 was not in service, but that the RNP 05 approach was available. The relief pilot then consulted the NOTAMs, which confirmed that the ILS was unavailable and that the runway length was reduced by 390 m due to a displaced threshold on runway 05. After the relief pilot gave his opinion about the aiming point of the RNP 05 approach, the captain confirmed that this risked bringing them to the usual 05 threshold and not the displaced threshold and that it would be better to carry out the RNP 23 approach. This proposal was accepted.
The captain indicated that there might be a tailwind on final 23 and proposed to shut down the engine after landing. Discussions took place among the three crew members as to when exactly they considered shutting down the engine after landing. No joint decision was made at this stage.
The aeroplane landed 550 m after threshold 23 at a speed of 150 kt (VAPP+8). A few seconds later, the ROPS warning, **BRAKE MAX BRAKING MAX BRAKING** was triggered. The PF applied full braking on the brake pedals. The temperature of the brakes increased to more than 300°C. Fuel spilled onto the runway. Despite the crew's initial debate, the decision was taken to turn around in the correct direction in the turnaround bay, with the left engine on the outside of the turn. More thrust (around 40% of N1) was then applied to engine 1, where the leak was located.

After the turnaround, the crew shut down engine 1. The aeroplane taxied to the parking area and engine 2 was shut down. A fire fighter started spraying water under engine 1. Once the aeroplane was made safe, the passengers disembarked.
On arrival, a comparison between the fuel used and the remaining fuel indicated a total fuel leak of 5.7 t for a flight time of 2 h 21 min.

The analysis covers the following points:

- The origin of the fuel leak
- The crew not shutting down the engine
- Leadership and crew cooperation

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22 Excerpt from A330 FCTM, "*If amber LAND ASAP is part of the procedure, consider landing at the nearest suitable airport.*"

- Fire hazard during occurrence
- Crew's perception of fire hazard
- Decision process and diversion.

2.2 Origin of in-flight fuel leak

During a scheduled maintenance operation in September 2020, the aeroplane's two engines were removed. During the reassembly, the Primary Fuel Hose (PFH) shoulder was incorrectly positioned on the left engine, probably due to there being poor visibility and the difficulties with carrying out the assembly operations. The pressurization of the fuel system after the maintenance work did not identify any fuel leak, although the hose was not correctly aligned, probably because the O-ring and the torquing of the bolts ensured leaktightness.
No leaks were detected during the checkout flight, nor during the six following flights. During the occurrence flight, probably as a result of vibrations on the ground and in flight, the PFH shoulder moved in the bore of the mounting flange, which loosened the whole assembly and caused a fuel leak at this flange.

Following a previous leak at the PFH mounting flange, the HAECO maintenance centre had implemented training in 2016, drawing the attention of the maintenance personnel to the possibility of a misalignment (see Appendix 2). This one-off occurrence and training did not prevent the misalignment on F-GZCJ. The note in the engine manufacturer's documentation used for the flange assembly recommends ensuring that the PFH shoulder is fully seated on the pylon before tightening the bolts, to avoid distortion of the assembly. The lack of a clear methodology for checking for correct alignment, the lack of information about the possible consequences of a mounting flange misalignment, and the lack of clarity in the explanatory diagram referenced in the maintenance task probably limited the maintenance technicians' awareness of the risk of an assembling error and the risk of leakage.

A new mounting flange design, with a smaller inner diameter was developed to limit the possibility of a mounting flange alignment error. As early as 2015, a special bulletin issued by Collins Aerospace, the mounting flange manufacturer (refer to paragraph 1.16.1 and Appendix 2) informed operators of the availability of this new mounting flange model, while indicating that the former model could still be used, and this until stocks of the former model were depleted. No service bulletin from the engine manufacturer or aircraft manufacturer was issued with respect to this Collins Aerospace bulletin.
Since 2017, Collins Aerospace only offers the new model to its customers. Nonetheless, it is possible that the former mounting flange model will continue to be installed for several years, depending on maintenance shop stocks. The possibility of a leak at the PFH mounting flange still exists if operators use the former mounting flange design.

2.3 Not shutting down engine

The crew began to carry out the FUEL LEAK procedure after the captain returned to the cockpit. Nevertheless, the engine shutdown was a stopping point in the processing of the failure. The captain immediately decided to keep the engine operating and, from that moment on, introduced a deviation from the procedure. The co-pilots who shared his opinion, in particular for the en-route phase, quickly agreed with his suggestion to keep the engine operating. Any questioning of the decision not to shut down the engine was therefore unlikely in the absence of new elements during this flight phase.

Several reasons may have influenced the crew's initial decision to delay the engine shutdown.
The first reason was probably their shared interpretation of the FUEL LEAK procedure. In their statements, the three pilots spontaneously indicated that the main objective of the engine shutdown en route was to conserve fuel quantities should it be required by the flight path, i.e. when flying over an ocean or desert.
During the event, fuel conservation was not considered necessary, as indicated by the captain's words when he said that they had 12 t to 15 t, plus possibly the trim tank, and that they had enough time to reach N'Djamena. The engine shutdown thus seemed to lose its operational meaning.
Moreover, in this same context, the engine shutdown was perceived as necessary only to avoid an engine flame-out due to fuel starvation, which the captain gave as the main risk during the TEM briefing on the threats related to the approach.
This decision was probably reinforced by the observation of normal parameters, despite the technicians visually confirming the leak during the descent, as well as by the latitude left by the FUEL LEAK procedure to start up the engine again in the event of a wing tank leak.
The second reason was probably a form of shared apprehension about shutting down the engine in flight, especially at night, over the African continent, in a context of health restrictions and a curfew. The pilots' statements as well as their conversations seemed to confirm that shutting down the engine and diverting were consistently perceived as a threatening change of plan. The captain expressed this feeling several times when he said that if they shut down the engine, this would be the beginning of something big, that there was a risk of finding themselves with one engine operative and having to divert, and that flying on one engine was not a very comfortable situation. In his statement, the co-pilot mentioned the existence of a psychological barrier to shutting down an engine in flight and the relief pilot said he was "relieved" by the captain's decision not to shut down the engine.

Thus, each time the decision to shut down the engine was mentioned, the arguments in favour of the initial decision - keeping the engine operating - were privileged:

- En route, shutting down the engine was only useful as an anticipatory measure (to prevent engine flame-out).
- It is not specified in the procedure that it has to be shut down.
- During the approach, shutting it down could lead to a go-around.
- And finally on the ground, the environment is hostile for turning around on a single engine.

It seemed that the engine shutdown was only justifiable insofar as it would prevent an engine flame-out due to fuel starvation, especially since the risk of an in-flight fire was not taken into account, as evidenced when one of the crew said that it did not seem to be specified in the check-list that it had to be shut down and there was no notion of a possibility of a fire.
In his statement, when asked about the management of a fire, the captain indicated that if a fire had broken out, the crew would have carried out the ENGINE FIRE procedure.

The analysis of the CVR showed that in the en-route phase, not one of the flight crew questioned the deviation from the FUEL LEAK procedure, in particular the shutting down of the engine.

It is possible that the expected behaviours, know how to deviate from procedures in consultation with the crew when safety requires it, and improvise when faced with the unforeseeable to obtain the safest result, mentioned in Part D of the Air France Operations Manual reflect a safety culture in part of the flight crew population which esteems crew behaviour capable of easily deviating from

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procedures. The wording of these expected behaviours is notably different from that in the European regulations and in particular in the Acceptable Means of Compliance (AMC) concerning Evidence Based Training. It is possible that these differences in wording in the Air France documents contribute to maintaining a form of tolerance with respect to deviations from procedures by certain crews.

Lastly, several factors could have also contributed to the observed deviation from the FUEL LEAK procedure:

- **Format of documentation**

The paper format of the QRH FUEL LEAK procedure may have contributed to the initial decision not being questioned. Indeed, the crew indicated in their interviews, that they considered the paper format to be "less mandatory" than the ECAM electronic format. In addition, the format with multiple sub-steps, required a certain analysis of the situation by the crew.

- **Limitations of simulator training**

Since flight on one engine does not present any risk during simulator training, it does not allow crews to perceive their own degree of aversion to the risk of single-engine flight in real conditions.

2.4 Leadership and crew cooperation[23]

It can be seen that the crew persevered in their initial decision, the risks associated with the chosen solution being underestimated while those associated with the alternative solution were given more weight.

At first sight, the decision appeared to be collective. However, listening to the CVR, and certain elements of the statements suggest a false consensus, especially during the approach and on the ground, and a possible group effect. During the preparation of the approach, the captain indicated to the co-pilot that the decision to shut down the engine was his, however he concluded the discussion by opting to keep the engine. During the descent, the captain asked whether there was any risk in keeping the engine operating, without giving the co-pilots the time to answer because he immediately replied to himself, saying that it was not specified in the check-list that it had to be shut down and that the possibility of a fire was not mentioned therein.

The captain's propensity to express himself first, in a repetitive way, was not conducive to the co-pilots expressing their opinions and doubts, in particular in their proposal to shut down the engine just after landing and when they evoked the fire hazard.
The discussions thus appeared falsely open insofar as the captain often provided answers to his own questions without taking into account the suggestions made by the co-pilots.
For their part, apart from the use of the thrust reversers, the co-pilots did not manage to assert their point of view, in particular with respect to the fire hazard on the ground, nor did they succeed in getting the captain to take a position on when he considered shutting down the engine.

In this situation, which was considered threatening, the search for consensus within the group, and therefore the search to maintain group cohesion, prevailed over the objective evaluation of alternatives.
Although the QRH procedure must be applied with as a "read and do", as for an ECAM procedure,

[23] In this paragraph, the leadership is analysed by means of the observable behaviours of this competence (refer to paragraph 1.17.4).

it is possible that the paper format of the QRH procedure did not contribute to the decision being questioned. Indeed, an ECAM message may be more easily perceived as a request from an external actor - in this case the plane - thus offering an alternative to group thinking.

2.5 Fire hazard during occurrence

During the occurrence, a significant fire hazard existed, especially since the engine compartment in which the leak occurred is a hot area, where engine surfaces often exceed the spontaneous ignition temperature of the fuel.

The PFH mounting flange is located over a drain pan designed to collect any small leaks and drain them to the engine drain mast at the bottom of the nacelle. This drainage system is not sized for such a large fuel leak. As a result, it is very probable that the drain pan overflowed and that fuel was splashed onto the hot surfaces of the engine. If, in flight, the drain pan overflows, the fuel can be drained under the effect of the airflow through the rear of the nacelle. On the ground, the fuel is drained through pipes at the bottom of the nacelle.

The risk of fuel ignition depends on the rate of leakage, the air pressure and the ventilation flow in the area. These conditions vary depending on the flight phase. The risk of spontaneous ignition increases as the speed and/or altitude decrease. At the end of the flight, the pressure, temperature and ventilation conditions were conducive to the spontaneous ignition of the fuel.
Although it is difficult to formally demonstrate because the level of atomization of the fuel and the air flow in the engine, in particular on approach and on the ground could not be determined with precision, the most probable hypothesis according to the manufacturer, is that the substantial fuel flow and the restricted space of the nacelle resulted in a concentration of fuel which was too high to ignite.

This information was not known to the crew and was out of their hands.

2.6 Crew's perception of fire hazard

In flight
During the en-route phase, the fire hazard was not considered by the crew. The pilots' statements as well as the analysis of the CVR showed that several reasons were put forward to try to justify this point of view: the normality of the engine parameters; the fact that, as the fire had not declared itself immediately, the crew judged that it was unlikely that it would declare itself subsequently; the observation that the fuel was draining from under the engine and away from it, at a distance from the hot parts.
During the descent, the **FUEL IMBALANCE** advisory alert nevertheless caused the captain to ask whether there was any danger in keeping the engine operating, to which he himself replied by verbalising his interpretation of the FUEL LEAK procedure when he said that it was not specified in the check-list that it had to be shut down and there was no notion of a possibility of fire. The two co-pilots agreed with this statement. The crew then continuously adhered to the logic that the remaining quantities of fuel were such that the engine did not have to be shut down to reach the alternate airport.
The crew did not mention the risk of an in-flight fire during the descent and approach phases and did not consider that this risk was different from that of the en-route phase. The risk of fire during the go-around was not mentioned during the approach briefing.

On ground
The risk of an engine fire on the ground was clearly expressed by the co-pilot in descent, during the approach briefing.
The relief pilot suggested shutting down engine 1 before the turnaround. He also persevered in demanding compliance with the "REVERSERSERS DO NOT USE" line in the FUEL LEAK procedure, without however verbalising the fire hazard when the thrust reversers are used, which he was aware of. The clear knowledge of this risk, mentioned during the interview, encouraged him to persevere until he obtained the captain's agreement.
Just after landing, the relief pilot again asked if the engine shutdown was being considered. The captain, for his part, preferred turning around in the turnaround bay with the left engine operating, which indicates that he perceived the risk as low.

The investigation showed a significant gap between the crew's perception of the risk of the fuel igniting and the real risk, when considering the internal route of the leak, and previous events, in particular during the approach and taxiing phases.

This event shows the difference between the individual perception of the risk, based on the professional experience of a crew, and the reality of the facts (see paragraph 1.18.5). The FUEL LEAK operational procedure reflects the manufacturer's in-depth risk analysis and the cumulative in-service experience of manufacturers and operators.

2.7 Decision process and diversion

When the captain left the cockpit for his rest period, although he had a doubt about the gauges, this effectively ruled out any possibility of a discussion about turning back to Brazzaville. Around 30 min then elapsed between the initial detection of the fuel leak and the start of the FUEL LEAK procedure with the full crew. While the captain was absent, the co-pilots had begun to assess the meteorological situation at the alternate airports they were considering (F in the FORDEC decision method).
The crew's discussions about the pertinence of the FUEL LEAK procedure and shutting down the engine then resulted in an additional decision time of 30 min.

The duration and structure of the crew's decision-making process contributed to a significant increase in flight time whereas the situation required them to consider landing at the closest suitable airport, as stipulated in the FUEL LEAK procedure (**LAND ASAP** line). During this phase, the Yaoundé airport was the closest to the flight path.
Furthermore, the FORDEC decision method was started although the failure had not been processed and the technical situation was not stabilized, disrupting the crew's situational awareness.
The insufficient collection of facts, which is the first action in this process, did not allow the crew to exhaustively assess the two diversion options of Yaoundé or N'Djamena.

- Yaoundé airport, which was the regulatory en route alternate airport in the flight plan, had greater operational safety margins than N'Djamena: the meteorological conditions were satisfactory, the approach could be made using an ILS on runway 19, the length of the runway was 3,402 m which did not give rise to any form of landing limitation. The crew considered that it was a disadvantage that none of the pilots knew this airport and that it was a 777 and not an A330 stopover.

- N'Djamena airport had a more restrictive runway, officially 2,410 m long, although the 390 m corresponding to the displaced threshold could be used in order to taxi to the end of the runway to turnaround when landing on runway 23. Moreover, the ILS and the PAPI of runway 05 were not in service.

At the time the decision was made, the aircraft had passed the point where it was at an equal flight time to Yaoundé and N'Djamena, and N'Djamena airport imposed itself as the only possible option. The choice of the latter was then made without knowing the operational and technical conditions of N'Djamena airport. The crew's decision was mainly based on the fact that the pilots were familiar with this airport, and that they considered it safer because of the military presence on the other side of the runway. The crew thus placed themselves in a situation of having to deal with the facts when the descent had already begun.

The crew's only choice was that of the QFU (05 or 23) and the landing configuration.
However, both QFUs had operational risks:

- On runway 23, there were strong tailwind conditions until very short final, increasing the possibility of a go-around.
- On runway 05, the length of the runway would have been highly restrictive (landing at the displaced threshold). In addition, the crew anticipated difficulties related to the fact that the aiming point of the RNAV approach was at the "usual" threshold and not at the displaced threshold.

The crew therefore chose to land on runway 23, operationally the longest runway, but with a strong tailwind component. Although they were aware of and verbalized the tailwind on final, they chose the flaps 3[24] and not full flap configuration, in order to be ready for the possible loss of the engine before landing. The go-around was not "briefed": the crew did not verbalize their strategy in case of a go-around: select TOGA power for both engines or reduce engine 1 because of the leak and follow the single-engine flight profile.

The fire hazard study conducted in the scope of this occurrence indicated that this fire hazard in case of a go-around was very high, which the crew was not aware of.
It is possible that subject to a form of stress, in real operational conditions, the crew tried to simplify the decision-making process, by heading for a known airport considered more reassuring. In this way, they tried to simplify the tasks and limit their workload solely to the diversion, excluding the problems associated with single-engine flights.

[24] Configuration required in case of single engine landing.

3 CONCLUSIONS

3.1 Findings

- The crew held the necessary licenses and ratings to accomplish the flight.
- The composition of the crew complied with the operator's procedures.
- The aeroplane had a valid Certificate of Airworthiness and was maintained in accordance with regulations.
- The aeroplane came out of a “Long downtime” inspection on 30 September 2020. The maintenance work during which the two engines were removed had been carried out in an Air France sub-contractor workshop at Xiamen (China).
- No leakage had been observed after reassembly.
- The aeroplane had performed six flights between the return to service date and the occurrence flight.
- No fuel leak had been detected by the crew during the pre-flight inspection before take-off.
- The crew carried out the en-route checks 35 minutes after take-off and observed that they were short of 1.4 t of fuel.
- The engine parameters showed no anomaly.
- The captain left the cockpit for his rest period after the en-route checks during which a difference of around 1.4 t had been detected and asked the co-pilot and relief pilot to monitor the fuel quantities.
- The crew started to comply with the FUEL LEAK procedure around 30 minutes after it first being detected and after the captain had been called back to the cockpit by the co-pilots.
- The captain decided not to shut down engine 1 contrary to what was required by the FUEL LEAK procedure. This decision was not questioned by the co-pilots.
- The crew considered that the in-flight fire hazard with the engine operating was low.
- The option of turning back to Brazzaville was not considered. The option of diverting to Yaoundé was not chosen by the crew.
- The crew did not consider landing as soon as possible as specified in the FUEL LEAK procedure.
- A NOTAM specified that ILS 05 at N’Djaména was not in service and that due to a displaced threshold on runway 05, the official runway length was 2,410 m for both QFUs, 05 and 23.
- The crew acquainted themselves with the N’Djaména NOTAM after having chosen this as the alternate airport and after starting the descent.
- The crew chose to carry out a RNAV approach to runway 23.
- At 3,000 ft on final, the aeroplane was configured for landing, flaps in position 3 and all the automated systems engaged.
- The maximum tailwind component was 28 kt at a height of 610 ft.
- At a height of 500 ft, the speed exceeded the recommended approach speed (VAPP) by 5 kt and the tailwind component was 21 kt.
- The main gear wheels touched down 550 m after the runway 23 threshold, at VAPP+8 with a tailwind component of 9 kt.
- A Runway Overrun Prevention System (ROPS) warning was activated during the landing.
- This system did not take into account the official landing distance due to it not taking into account the reduction in runway length indicated by the NOTAM.
- The braking input complied with the ROPS warning procedure.
- The temperature of the bakes increased up to 600°C.
- The airport’s level 8 RFFS was in keeping with an A330 type aeroplane.

- The manufacturer indicated that the high fuel saturation of the air in the engine zone probably prevented a fire from breaking out during the approach or on the ground.
- The airport RFFS did not identify a leak while the aeroplane was taxiing on the runway after landing.
- The crew turned around in the turnaround bay of runway 23 with both engines operating. An N1 of 40% on engine 1 was recorded during the turnaround.
- Engine 1 was shut down three minutes after landing.
- Engine 2 was shut down 13 min after landing.
- Once the aeroplane was in the parking area, 13 min after landing, the fire fighters started spraying water under engine 1.
- The fuel leak was located at the PFH mounting flange of engine 1.
- It was determined that the fuel leak amounted to 5.7 t for a flight time of 2 h 21 min.

3.2 Contributing factors

Although the leak was identified and then located in the left engine, the crew decided to keep this engine operating contrary to the requirements of the FUEL LEAK procedure. It was shut down while taxiing after the landing, i.e. more than 1 h and 20 min later. The purpose of shutting down the engine is to both conserve the fuel in the associated fuel tank and prevent the fuel from being dispersed into potentially dangerous areas. The fire hazard was underestimated by the crew in part because it was not clearly indicated in the corresponding procedure or in the supplementary manuals.

The crew’s partial application of the FUEL LEAK procedure contributed to degrading the decision-making process, in particular by excluding alternate options closer to the route, and resulted in the choice of a diversion to N'Djaména, where the infrastructure and the weather conditions were not optimal.

The following factors contributed to the occurrence of the fuel leak

- Design of the mounting flange.
- Intrinsic difficulties in assembling the mounting flange.
- Difficulties in checking that the mounting flange is correctly assembled.
- Use of a former mounting flange model, which made it possible to assemble the flange incorrectly and for a large leak to occur.

The following factors contributed to decreasing the flight’s safety margin, in particular with regard to the fire hazard

- Crew’s partial application of the FUEL LEAK procedure for the management of a fuel leak.
- Insufficient leadership and crew cooperation competency probably due to an excessive search for consensus and a possible group effect.
- No mention of the fire hazard in the manufacturer's documentation.
- Selection of N'Djamena airport for the diversion when other suitable airports were closer to the route.

The following factor contributed to limiting the fire hazard

- Intervention of the relief pilot who reminded the crew that, in accordance with the FUEL LEAK procedure, the thrust reversers should not be extended, even at idle speed.

The following factor contributed to the safety of the flight after the landing

- Chief purser preparing the cabin for a possible evacuation.

4 SAFETY MEASURES TAKEN SINCE THE OCCURRENCE

4.1 Safety measures taken by Airbus

4.1.1 Technical measures

Airbus has undertaken to publish a Service Bulletin recommending the replacement of the PFH mounting flange with a new model at the next disassembly operation. Airbus also worked with Collins Aerospace on the publication of an All Operator Letter (AOL) warning of the possibility of incorrectly installing the former design and its consequences, and explaining the benefits of the new design. This AOL[25] was issued by Collins Aerospace on 20 October 2021. The publication of the Service Bulletin is planned for late 2022.

4.1.2 Measures regarding operational documentation

Airbus updated the information in the FCTM regarding the fire hazards in the event of a fuel leak if it comes from the engine and when using the thrust reversers, in April 2022 for the A350 and A380 fleet and in May 2022 for the A320, A330 and A340 fleets. These updates will be indicated in the Change Summary document, available to all operators on the website, Airbus World.

AIR FRANCE A330/A340 FLIGHT CREW TECHNIQUES MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES FUEL

■ If the fuel leak is not confirmed coming from the engine/pylon or if the leak is not located:

- Isolate each tank: Maintain the cross-feed valve closed and switch off the center pumps. Each wing tank feeds the associated engine.
- If the fuel quantity decreases faster in one wing tank than in the other wing tank, the fuel leak is identified as coming from one wing tank. In this case, the associated engine is shut down in order to confirm if the leak comes from the wing tank or from the engine.
- If the fuel quantity symmetrically decreases in both wing tanks and the fuel quantity in the center tank decreases, the fuel leak comes from the center tank or the APU feed line.

If the flight crew confirms that the fuel leak comes from the engine/pylon, the flight crew must shut down the engine in order to:
- Stop the leak
- Prevent fire hazard due to fuel leaking into the hot surfaces of the engine.

During landing, the thrust reversers significantly modify the air flow around the aircraft. The flight crew must not use the thrust reversers in order to prevent contact between fuel and hot surfaces of engines or brakes.

Lastly, Airbus will develop a specific "FUEL LEAK procedure" video on the WIN website for instructors.

[25] PUB0003606 Rev. 00.

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4.2 Safety measures taken by Air France

4.2.1 Technical measures

Following the occurrence, Air France initiated the replacement of the former mounting flange design during the next hose replacement or disassembly operations, without waiting for the stocks of the former design to run out.
Recurrent practical training with respect to the specific assembly of this hose has been set up for technicians, including those at the HAECO centre in Xiamen.

4.2.2 Operational measures

The operator reported having taken the following measures:

- Issuing of a "Safety First" bulletin on the topic of fuel leaks.
- Recommendation to comply with SOPs
  The Air France internal investigation team recommended to the Training Department that specific messages be developed to improve adherence to procedures, and awareness of the need to adhere in full to the processing of a failure.
- FUEL LEAK exercise
  The investigation team asked Flight Operations and the Training Department to review the fuel leak exercise. It is essential to propose an explicit pedagogical message to all the instructors, on each type of aircraft, regarding the key points of this check-list, as has already been done on the 777, with the aim of giving a meaning, and determining the danger and the associated vital action.
- Teaching the FORDEC decision method
  The investigation team asked Flight Operations and the Training Department to ensure that the FORDEC method is properly deployed for pilots from Air France subsidiaries.

The operator reported having also planned the following measures:

- **LOSA audit**

In 2022, Air France decided to initiate a LOSA audit of various company activities, including flight operations[26].
A LOSA is a safety audit carried out by trained peer observers. It identifies the errors made by operators in their work situation (deviations from procedures), the threats at the origin of the errors as well as the human behaviour of the actors who made these errors. The LOSA maps the areas for improvement in the company's activities while analysing the socio-organizational factors contributing to the errors of the actors.

- **Evolution of flight analysis protocol**

The operator informed the BEA that its flight analysis protocol was being revised with the aim of reinforcing the individualized follow-up of crews.
This revision introduces the notion of "self debriefing" and will provide pilots with tools allowing them to directly access certain data from the flights they have performed.

[26] Air France called on "The LOSA Collaborative", which conducted the first LOSA audits in 2011 and 2015.

5 SAFETY RECOMMENDATIONS

Note: in accordance with the provisions of Article 17.3 of Regulation No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the issuing authority in charge of safety investigations, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

Compliance with procedures

The procedures are the result of an in-depth risk analysis by the manufacturer, and it is assumed that they will be performed by the crew. The overriding safety principle when designing a procedure is based on the assumption that it will be carried out at the right time, with rigour and in full. The expected compliance with the FUEL LEAK procedure would thus both conserve the amount of remaining fuel in the tanks and prevent a fire hazard.

There are many reasons why crews may deviate from procedures in operational conditions, such as the desire to simplify a procedure that is considered too complex in view of the workload, or the idea that the deviation benefits flight safety. These deviations or simplifications are mainly based on the personal experience of the crew and may sometimes be the result of procedures not being completely understood, not always being explicit or not being correctly taught.

The investigation showed that in the case of this occurrence, the engine shutdown, which was specified in the FUEL LEAK procedure and was the subject of simulator training, was omitted by choice, by the crew.

This decision thus created a notable fire hazard and led to a substantial reduction in the flight's safety margin, the fire having been avoided by chance.

As indicated in the *Data Report for Evidence Based Training* produced by the International Air Transport Association (IATA), the intentional non-adherence to procedures remains to this day for all IATA airlines, a source of a large number of errors and unwanted occurrences.

Given the structure of the commercial aviation activity in France, and in particular the volume of operations by Air France compared to other French operators, the BEA is regularly called upon to investigate events that have occurred within this company. In terms of the thousands of flights carried out daily by Air France, the number of flights investigated remains extremely limited and concerns a very small number of crews.
Nevertheless, the BEA has been able to observe, through a certain number of recent investigations presented below, that the crews concerned had not, for various reasons, voluntarily or not, carried out certain procedures in a compliant manner.
These occurrences are of various origins: desire for operational optimization, acceptance of a fortuitous deviation or violation of a procedure. They all have in common the reduction in safety margins without the crew being really aware of it.

- 28 and 30 March 2017: The BEA's Investigation report concerning a double incident involving the Airbus A318 registered F-GUGB (flight with passengers) and the A321 registered F-GTAT (ferry flight without passengers), indicates that the pilots intentionally exited the standard operational flight envelope by a large degree and numerous times in order to test the flight control angle-of-attack and pitch attitude protections. The crew then reached the maximum operating speed of 350 kt (VMO) and applied a nose-up attitude such that a vertical speed of 15,000 ft/mn was recorded, triggering the alert associated with proximity with a potentially converging aircraft. This deliberate violation of procedures resulted in a reduction of the safety margins of the flight as well as within the airspace, with and without passengers on board.

- 12 September 2020: The BEA's Investigation report concerning an incident involving the Airbus A318 registered F-GUGM indicates that the crew partially disregarded operational procedures in order to make a fast approach to runway 25 at Paris- Orly. They thus lined up with the ILS at 6 Nm from the runway threshold in a clean configuration at 250 kt. At a height of about 1,000 ft, a ground proximity warning was activated in the controller position. The approach was destabilized and the crew continued until landing. During the final approach, the crew had very few resources to deal with an unexpected event and the safety margin of the flight was then degraded without the crew being really aware of it.

- 15 February 2022: The BEA opened an investigation into an in-flight incident involving the Airbus A320 registered F-HEPB. The investigation, although still in progress at the time of publication of this report, has brought to light the crew's desire to optimize operations leading to a reduction in safety margins without the crew being really aware of it.

The BEA is aware that certain rare technical or operational situations may require the crew to show discernment and that they must be capable of operating outside of the procedures when they consider that safety requires it.
This is notably the case in a context of serious damage, leading to multiple failures and where the messages from the electronic failure monitoring systems or the procedures may not be adapted or cannot be complied with (for example, the accident while en route to the Airbus A380 registered VH-OQA operated by Qantas on 4 November 2010) or in cases of extreme emergency (uncontrolled on-board fire).
This was not the case for the above-mentioned occurrences, nor for the subject of this report, where the correct compliance with procedures would have contributed to maintaining an adequate level of safety.
In this context, the BEA questioned the current wording of the sentences in Part D of the Operations Manual - know how to deviate from the procedures in consultation with the crew when safety requires it (Application of procedures), and improvise when faced with the unforeseeable to obtain the safest result (Resolution of problem and making decisions) - and how they may reflect or maintain a culture conducive to this type of deviation in a part of the flight crew population, or even lead crews to set aside the procedures.

The review of the above-mentioned occurrences suggests that there is a certain culture among some Air France crews which encourages a propensity to underestimate the extent to which strict compliance with procedures contributes to safety.

The BEA therefore considers that Air France should put compliance with procedures back in the centre of the company's safety culture.

Consequently, the BEA recommends that:

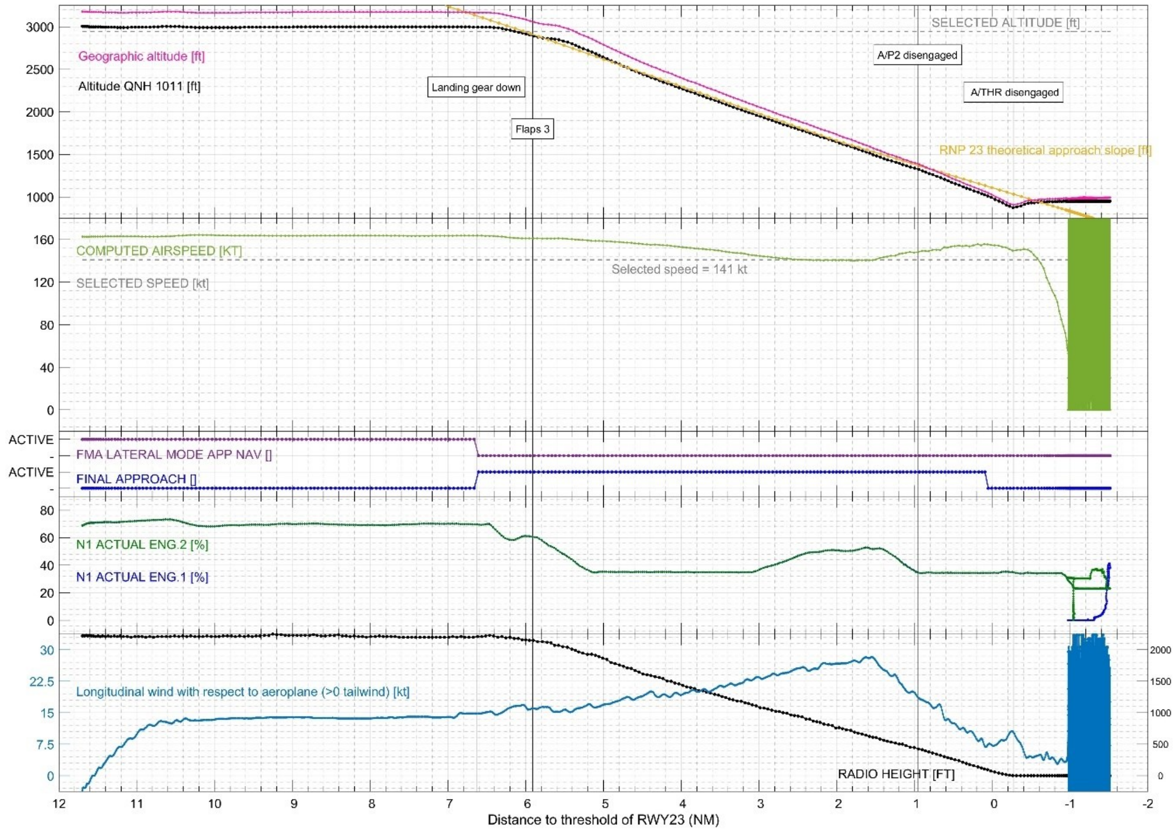
- *Whereas the recurrence of investigations concerning Air France occurrences, recently carried out by the BEA, which show an adaptation of procedures or even a deliberate violation of these leading to a reduction of safety margins;*
- *Whereas the just culture does not accept repeated intentional deviations, serious negligence and deliberate breaches;*
- *Whereas deviations from procedures detected in flight or by means of Flight Data Monitoring (FDM) may require strong global and individual actions;*
- *Whereas the oversight authority told the BEA that its flight checks had given rise to comparable findings;*
- *Whereas the operator told the BEA that its flight analysis protocol was being revised with the aim of reinforcing the individualized monitoring of crews;*
- *Whereas the operator decided to carry out a transversal LOSA audit from the autumn of 2022;*

  Air France continue and extend, if necessary, the internal actions undertaken in order to make the safety culture evolve towards a stricter application of in-flight procedures. This could be based on a global action plan which could include the following topics:
    - *The individual identification and management of deviations from in-flight procedures, in the scope of FDM and within a just culture framework;*
    - *Providing pilots with tools to replay and analyse their flights and promoting the use of these tools;*
    - *An evolution of the Operations Manual to limit the cases of deviations from procedures to exceptional circumstances in which the procedures cannot be applied or are clearly not appropriate;*
    - *The involvement of management, instructors and flight crews in the construction of these cultural changes.*
      [Recommendation FRAN 2022-011]

BEA

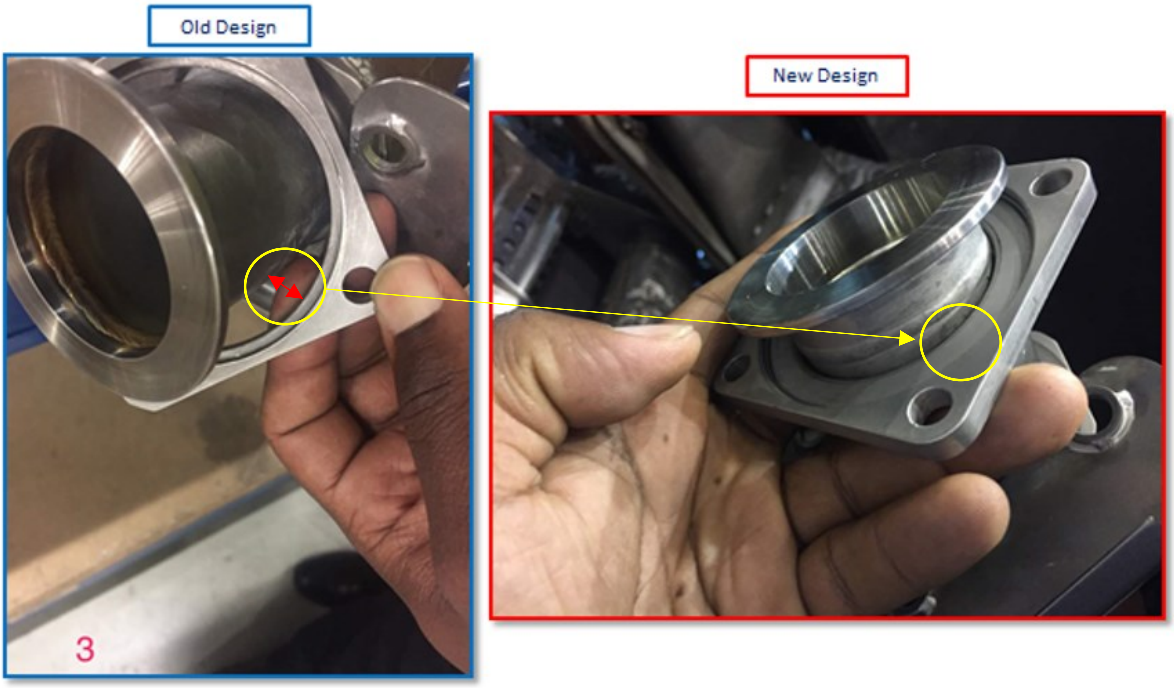
Appendices

Appendix 1: Key parameters during approach



Appendix 2: SPIB 71- 046

This SPIB introduced a new mounting flange design (refer to Figure below). The modification reduces the inner diameter of the mounting flange, thus notably reducing the clearance between this and the outer diameter of the PFH.



Old P/N: AE709962-1 New P/N: AE709962-503

View of former and new mounting flange design
(Source: Airbus)

The mounting flange assembled on F-GZCJ was the old design.

This *SPIB Vendor* is presented as a minor modification. EASA, the certification authority did not make this modification mandatory by publishing an Airworthiness Directive (AD). When a mounting flange has to be replaced during maintenance work, this SPIB authorizes the use of either the old or new mounting flange design, until stocks of the old design are exhausted. The SPIB does not contain any information on the reasons for this design change.
Collins Aerospace indicated that the initial reason for issuing this SPIB was the feedback about PFH alignment errors. It added that the torque values were reduced to prevent mounting flange distortion.

The SPIB was not included in an Airbus or GE Safety Bulletin to inform operators of the availability of this new design and request its replacement under wing or in a workshop.

Collins Aerospace stated that since 2017, only the new design is supplied to their customers, but only 51 were sold between 2017 and 2021. As this part is not often replaced during an aeroplane's life, the proportion of old and new mounting flanges in operator inventories is not well known. As a result, it is possible that the old design will continue to be installed for several years.

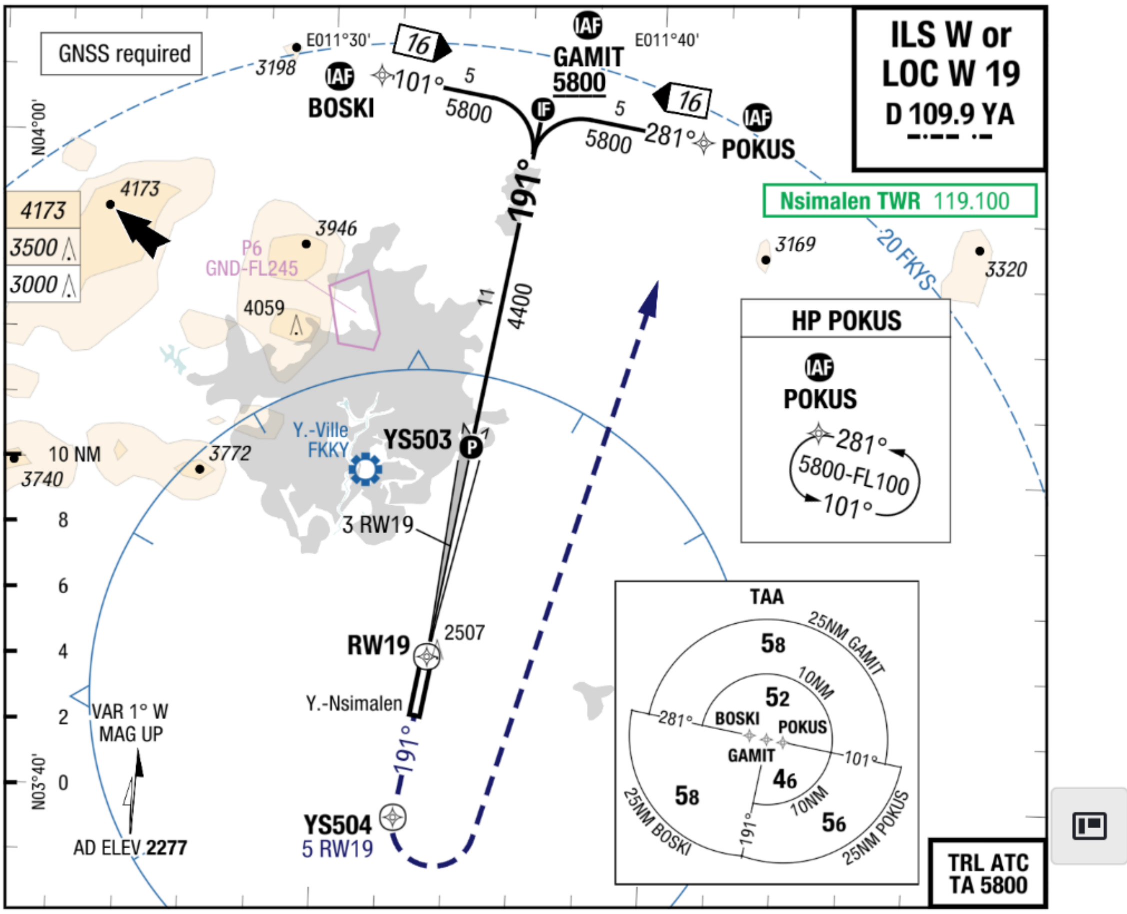
Previous occurrences of localized leaks at the mounting flange

Airbus reported that four cases of leaks at the mounting flange of the PFH on the A330 had been brought to its attention between 2014 and 2017. All of these events involved the old design. At least three of them occurred shortly after reassembly of the flange.

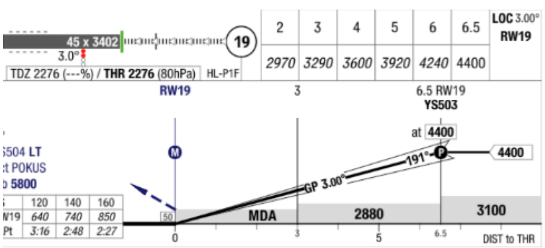
One of these leaks resulted in a commanded in-flight engine shutdown, the others were detected on the ground. Three of the leaks occurred at the same operator's, and the fourth appeared after a maintenance operation at HAECO in December 2015.

After this, HAECO implemented training to draw the attention of the maintenance personnel to the specific difficulty of mounting flange assembly, without this training being recurrent. The maintenance team that reassembled the hose in 2020 during the "Long downtime" inspection of F-GZCJ indicated that they had completed this training in 2016.

Appendix 3: Approach and Yaoundé airport charts



Previous Next Previous Next



19		Cat 1 1)	LOC				Circling 2)
C	ft - m/km ft	320 - 800 **2600**	430 - 1.3 **2700**				690 - 2.4V **2960**
D	ft - m/km ft	330 - 800 **2610**	430 - 1.4 **2700**				710 - 3.6V **2980**

1) With EVS 550m, wo EVS use STD
2) HJ only

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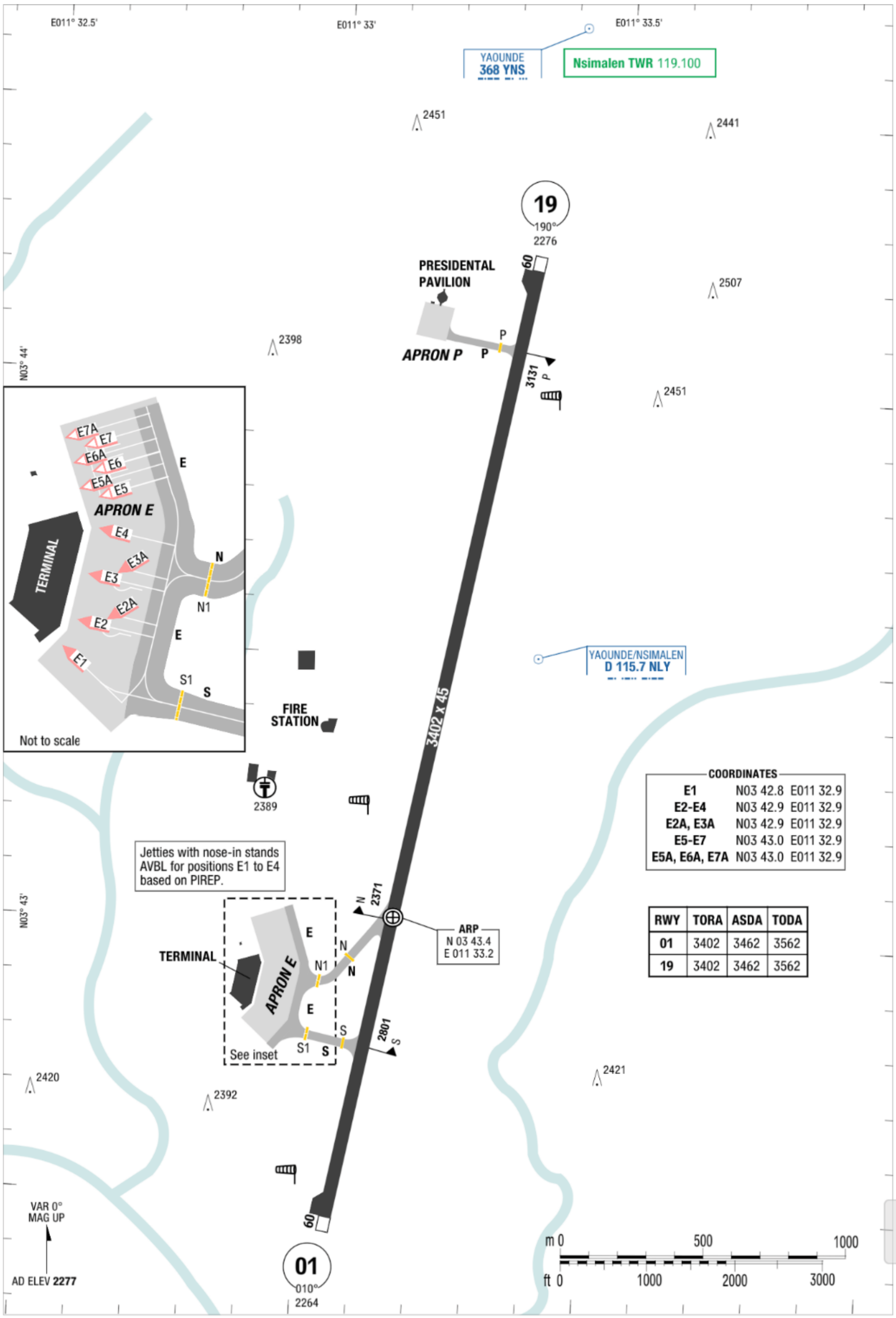

RWY	TORA	ASDA	TODA
01	3402	3462	3562
19	3402	3462	3562

Appendix 4: AMC1.ORO.FC.231(b) *Evidence-based training,* excerpt from Air OPS European regulations

Application of procedures and compliance with regulations (PRO)	
Description:	Identifies and applies appropriate procedures in accordance with published operating instructions and applicable regulations
OB 1.1	Identifies where to find procedures and regulations
OB 1.2	Applies relevant operating instructions, procedures and techniques in a timely manner
OB 1.3	Follows SOPs unless a higher degree of safety dictates an appropriate deviation
OB 1.4	Operates aircraft systems and associated equipment correctly
OB 1.5	Monitors aircraft systems status
OB 1.6	Complies with applicable regulations
OB 1.7	Applies relevant procedural knowledge

Problem-solving — decision-making (PSD)	
Description:	Identifies precursors, mitigates problems, and makes decisions
OB 6.1	Identifies, assesses and manages threats and errors in a timely manner
OB 6.2	Seeks accurate and adequate information from appropriate sources
OB 6.3	Identifies and verifies what and why things have gone wrong, if appropriate
OB 6.4	Perseveres in working through problems whilst prioritising safety
OB 6.5	Identifies and considers appropriate options
OB 6.6	Applies appropriate and timely decision-making techniques
OB 6.7	Monitors, reviews and adapts decisions as required
OB 6.8	Adapts when faced with situations where no guidance or procedure exists
OB 6.9	Demonstrates resilience when encountering an unexpected event

Leadership & teamwork (LTW)	
Description:	Influences others to contribute to a shared purpose. Collaborates to accomplish the goals of the team
OB 5.1	Encourages team participation and open communication
OB 5.2	Demonstrates initiative and provides direction when required
OB 5.3	Engages others in planning
OB 5.4	Considers inputs from others
OB 5.5	Gives and receives feedback constructively
OB 5.6	Addresses and resolves conflicts and disagreements in a constructive manner
OB 5.7	Exercises decisive leadership when required
OB 5.8	Accepts responsibility for decisions and actions
OB 5.9	Carries out instructions when directed
OB 5.10	Applies effective intervention strategies to resolve identified deviations
OB 5.11	Manages cultural and language challenges, as applicable

Appendix 5: Performance in real landing conditions