AIRCRAFT ACCIDENT REPORT 1/2021

Air Accidents Investigation Branch

Report on the serious incident to
Airbus A321-211, **G-POWN**
at London Gatwick Airport
on 26 February 2020

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This investigation has been conducted in accordance with
Annex 13 to the ICAO Convention on International Civil Aviation,
EU Regulation No 996/2010 (as amended) and
The Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018.

The sole objective of the investigation of an accident or incident under these Regulations is the prevention of future accidents and incidents. It is not the purpose of such an investigation to apportion blame or liability.

Accordingly, it is inappropriate that AAIB reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

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Contents

Appendices

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
ACARS	Aircraft Communications Addressing and Reporting System
agl	Above ground level
AMC	Acceptable Means of Compliance
AMM	Aircraft Maintenance Manual
AMO	Approved Maintenance Organisation
APU	Auxiliary power unit
ARFFS	Airport rescue and fire-fighting service
ATA	Air Transport Association
BEA	Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile
CAA	Civil Aviation Authority
CAMO	Continued Airworthiness Management Organisation
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
EASA	European Union Aviation Safety Agency
ECAM	Electronic Centralised Aircraft Monitoring
ECU	Engine Control Unit
EGT	Exhaust Gas Temperature
FAA	Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FDR	Flight Data Recorder
FMV	Flow Metering Valve
HMU	Hydro Mechanical Units
HP	High Pressure
HPC	High Pressure Compressor
HPSOV	High Pressure Shut-off Valve
HPT	High Pressure Turbine
HPTCC	High Pressure Turbine Case Control
LP	Low Pressure
LPTCC	Low Pressure Turbine Case Control
MSDS	Material Safety Data Sheet
MOR	Mandatory Occurrence Report
N_1	Fan, or Low Pressure Compressor speed
N_2	Intermediate or High Pressure Compressor speed
OSD	Operational Suitability Data
PC	Control Pressure
PCR	Control Pressure Return
PFR	Post-flight report
PM	Pilot Monitoring
ppm	Parts per million
PSOV	Pressurising and Shut-off Valve
QRH	Quick Reference Handbook
Rwy	Runway
SB	Service Bulletin
SCCM	Senior cabin crew member
STC	Supplemental Type Certificate
TBV	Transient bleed valve
TC	Type Certificate
TLB	Technical Logbook
TNA	Training Needs Analysis
TSM	Troubleshooting Manual
VBV	Variable Bleed Valve
VSV	Variable Stator Vane

Air Accidents Investigation Branch

Aircraft Accident Report No: 1/2021 (AAIB-26436)

Registered Owner and Operator:	Hagondale Ltd, Titan Airways
Aircraft Type:	Airbus A321-211
Nationality:	UK
Registration:	G-POWN
Place of Serious incident:	London Gatwick Airport, UK
Date and Time:	26 February 2020 at 0009 hrs All times in this report are UTC

Introduction

The Air Accidents Investigation Branch (AAIB) became aware of this serious incident on 26 February 2020. In exercise of his powers, the Chief Inspector of Air Accidents ordered an investigation to be carried out in accordance with the provisions of Regulation (EU) 996/2010 (as amended) and the UK Civil Aviation (Investigation of Air Accidents and Incidents) Regulations 2018.

The sole objective of the investigation of an accident or serious incident under these regulations is the prevention of accidents and serious incidents. It shall not be the purpose of such an investigation to apportion blame or liability.

In accordance with established international arrangements, the following safety investigation authorities appointed Accredited Representatives to the investigation: the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) in France, representing the State of Design and Manufacture of the aircraft; the National Transportation Safety Board (NTSB) in the USA alongside the BEA, representing the State of Design and Manufacture of the engines; and the Aircraft Accident and Incident Investigation Board of Cyprus. The aircraft operator, various maintenance organisations, the European Union Aviation Safety Agency (EASA), and the UK Civil Aviation Authority (CAA) also assisted with the investigation.

Summary

As part of scheduled maintenance overseas, G-POWN underwent a biocide shock treatment on its fuel system, using Kathon biocide, to treat microbial contamination. The aircraft returned to the UK on 24 February 2020, once the maintenance was complete.

In the 24 hours preceding this serious incident, there were abnormalities with the operation of both engines across four flights. On the flight before the fourth (event) flight, the crew reported momentary indications of a No 2 (right) engine stall. After the aircraft landed, this was investigated using an inappropriate procedure obtained from an aircraft troubleshooting manual not applicable to G-POWN, but no fault was found.

The aircraft took off from London Gatwick Airport Runway 26L at 0009 hrs on 26 February 2020 but, at around 500 ft agl, the No 1 (left) engine began to surge. The commander declared a MAYDAY and turned right downwind for an immediate return to the airport but, shortly afterwards, the crew received indications that the No 2 engine had stalled. The crew established that the engines were more stable at low thrust settings and the thrust available at those settings was sufficient to maintain a safe flightpath. They continued the approach and the aircraft landed at 0020 hrs.

The investigation identified the following causal factors:

1. G-POWN's fuel tanks were treated with approximately 38 times the recommended concentration of Kathon.

2. The excessive Kathon level in the aircraft's fuel system caused contamination of the engine Hydro Mechanical Units (HMU) resulting in a loss of correct HMU regulation of the aircraft's engines.

3. A troubleshooting procedure was used for the engine No 2 stall that applied to LEAP-1A32 engines, but G-POWN was fitted with CFM56-5B3/3 engines. The procedure for CFM56-5B3/3 engines required additional steps that would have precluded G-POWN's departure on the incident flight.

The investigation identified the following contributory factors:

1. The Aircraft Maintenance Manual (AMM) procedure did not provide enough information to enable maintenance engineers to reliably calculate the quantity of Kathon required, and the specific gravity value of Kathon was not readily available.

2. There were no independent checking procedures in place at the base maintenance Approved Maintenance Organisation (Base AMO) to prevent, or reduce the likelihood of, calculating and administering an incorrect quantity of biocide.

3. There were organisational factors at the Base AMO that contributed to the incorrect Kathon quantity calculations. In particular, the workload was high for the available facilities and personnel, and there was no internal technical support function for engineers to consult when they were uncertain.

4. The manufacturer's recommended method of searching the troubleshooting manual was not used to find the applicable procedure relating to the engine No 2 stall.

Following this serious incident, Safety Action was taken by regulators, the International Air Transport Association, the manufacturers of the aircraft, engines and biocide, the AMOs involved, and the operator. The specific action taken is detailed in Section 4.2 of this report.

Redundancy in safety critical systems is one of the principles supporting the safety of commercial air transport but fuel contamination undermines that redundancy because it can affect all engines simultaneously. It is essential that maintenance systems are resilient to errors that can lead to fuel system contamination. Therefore, five Safety Recommendations have been made in this report to promote the classification of biocide treatment of aircraft fuel systems as a critical maintenance task, which would ensure that an error-capturing method is included as part of the task.

1 Factual information

1.1 History of the flight

The aircraft had recently undergone base maintenance overseas, including a biocide shock treatment[1] on its fuel system[2], after which it had returned to the UK. Its next flights were in the 24 hours preceding this serious incident, during which it suffered engine abnormalities across four flights and with two sets of flight crew. The serious incident occurred on the final flight.

1.1.1 Base maintenance

G-POWN was scheduled to enter base maintenance at an EASA Part 145 Approved Maintenance Organisation (Base AMO). The operator defined the work package, which consisted of a variety of Aircraft Maintenance Manual (AMM) tasks and modifications. As part of the preparation for this work, the operator tested G-POWN's fuel tanks for microbial contamination and found moderate contamination. In response to the positive test result, the operator added a biocide shock treatment task to the work package.

Maintenance work on G-POWN started on 23 January 2020. Base Engineer 1[3] was assigned to accomplish the biocide shock treatment. The task stated that the aircraft fuel tanks should be treated with Kathon FP1.5 biocide (Kathon) at a concentration of 100 parts per million (ppm) by volume with Jet A1 fuel. On 20 February 2020, Base Engineer 1 treated G-POWN with Kathon-dosed fuel that had a bulk concentration of 3,814 ppm (by volume), which was approximately 38 times the recommended concentration.

The maintenance work package was completed and G-POWN departed to London Stansted Airport (Stansted) on 24 February 2020.

1.1.2 The flights before the incident flight

The flight crew who experienced the serious incident (Crew A) operated the first of the four flights, positioning[4] G-POWN from Stansted to London Gatwick Airport (Gatwick). At around 0520 hrs, they started the No 2[5] engine normally but while starting the No 1 engine the Electronic Centralised Aircraft

1 An AMM procedure to treat microbial contamination in fuel. See 1.6.7, *AMM procedures for biocide treatments*.
2 See 1.6.3, *Fuel System*.
3 During this report, engineers will be identified by the type of maintenance they carried out, Base or Line, and by a number where necessary.
4 Positioning flight – A non-revenue flight to position an aircraft to another airport.
5 The No 1 and No 2 engines are on the left and right respectively (looking forwards). The No 2 engine is usually started first.

Monitoring (ECAM) system[6] displayed the message ENG 1 HP FUEL VALVE[7]. Commander A followed the associated ECAM action to re-select the engine No 1 master switch[8] to OFF – thus stopping the start cycle[9] – and the ECAM message extinguished. Commander A reported that an engineer from within the company, who was assisting with the engine starts via an external headset, advised them to attempt another start on engine No 1, which was successful. There were no further engine abnormalities during that flight.

At Gatwick, Crew A briefed the on-coming flight crew (Crew B) on the engine No 1 starting fault they had experienced. They rested at a hotel while Crew B operated G-POWN on a return charter trip to Krakow International Airport (Krakow), Poland. Crew A were scheduled to re-position the aircraft back to Stansted that night, along with five members of cabin crew.

The engines functioned normally on the outbound flight to Krakow. At around 2000 hrs engine No 2 started successfully for the return flight, but engine No 1 was subject to three start cycles. Recorded data suggested that start cycles one, and possibly two, generated the ECAM alert ENG 1 HP FUEL VALVE – each time resulting in Crew B aborting the start. The third start cycle generated an ENG 1 START FAULT… ENG 1 STALL[10,11] ECAM alert, which resulted in a NEW START IN PROGRESS message[12]. The automatic restart was successful, with no further ECAM alerts.

Both of Crew B subsequently stated that the only things they could recall were the high pressure (HP) fuel valve ECAM alerts, and that engine No 1 started during the third cycle. After departing Krakow, Commander B notified the operator of that alert via the Aircraft Communications Addressing and Reporting System (ACARS)[13] at 2032 hrs.

While level at FL140 during descent towards Gatwick, with around 66% N_1[14] on each engine, Crew B felt slight vibration in the airframe. It disappeared when engine thrust was reduced for further descent and returned when thrust was increased. Co-pilot B reported it seemed worst between 58 and 64% N_1.

6 ECAM – Monitors and displays systems information, including faults and corrective actions to be taken by the pilots.
7 Failure modes with associated procedures are generally accompanied by a master caution or warning aural alert.
8 Also known as 'engine master lever' – when selected ON, the Full Authority Digital Engine Control (FADEC) initiates the relevant engine start sequence. When selected OFF, the FADEC shuts down that engine or aborts its start sequence.
9 One automatic start cycle (initiated by selecting the engine master switch ON) can include up to three start attempts by the FADEC, depending on the nature of the fault.
10 The engine start fault ECAM message is displayed along with one of its six triggering conditions underneath – in this case, ENG 1 STALL.
11 Engine stall – disruption of airflow in a turbine engine.
12 Displayed when the FADEC attempts a re-start.
13 ACARS – a digital datalink system for text messaging between aircraft and ground stations.
14 N_1 – the engine's fan speed, shown on a gauge in the cockpit.

Crew B reported the engine parameters appeared normal, including N_1 and N_2 vibration readings[15] of around 0.4 units. On two occasions when the airframe vibration was present, the ECAM system displayed the message ENG 2 STALL momentarily[16,17]. Co-pilot B reported the messages were so transient that they were uncertain which engine had been specified.

Crew B attempted to maintain the N_1 below 50% and perform a continuous descent approach[18]. They briefed that if the ECAM alert re-occurred, they would reduce thrust on the affected engine, declare a MAYDAY, and continue to Gatwick. Commander B reported that the airframe vibration returned after the landing gear was extended on the approach. No further ECAM alerts were received. The aircraft landed at 2215 hrs and taxied to stand. A number of cabin crew heard a 'pumping' noise during landing, which they reported to Crew B after arrival.

1.1.3 Line maintenance

At around 2230 hrs, after shutting down the engines, Commander B telephoned the operator's Technical Control department to report the No 2 'Engine Stall' ECAM message, and subsequently recorded it in the aircraft's Technical Logbook (TLB). A line engineer was instructed to attend the aircraft by a Technical Control engineer to troubleshoot the No 2 engine stall. The line engineer used AirN@v[19] to search the troubleshooting manual (TSM) and printed the procedure he thought was appropriate. However, this procedure applied to LEAP-1A32 engines whereas G-POWN was fitted with CFM56-5B3/3 engines.

When Crew A returned to the aircraft, Commander A liaised with Crew B, the line engineer, and the Technical Control engineer regarding the engine abnormalities. The line engineer completed the troubleshooting procedure and Commander A observed him as being "meticulous" in doing so. With no fault having been found, the line engineer signed off the engine stall defect and the Certificate of Release to Service in G-POWN's TLB. Commander A had further discussion with the Technical Control engineer and agreed that he would accelerate the engines to 50% N_1[20] for longer than usual before taking off to check the engine control indications.

15 Indicated as numerical units on the ECAM engine system display page - an advisory is generated when $N_1 \geq 6.0$ units and $N_2 \geq 4.3$ units.
16 The first of these occurred at 2158 hrs. The CVR recorded data began at 2140 hrs.
17 Crew B reported the messages were displayed for less than a second each time.
18 Continuous descent approach – an arrival technique using minimum thrust and avoiding level flight, normally for reducing fuel burn and noise.
19 A maintenance data application. See section 1.6.9.
20 A normal procedure used to check engine control indications before applying takeoff thrust.

1.1.4 The incident flight

At 2349 hrs, as the aircraft was pushed back from stand, Crew A started engine No 2 normally but engine No 1 produced an ENG 1 START FAULT… ENG 1 IGNITION FAULT ECAM alert, which was read aloud by Co-pilot A, who was pilot monitoring (PM). This was followed by NEW START IN PROGRESS and a subsequent instruction to re-select the engine No 1 master switch to OFF, which extinguished the ECAM messages.

Commander A, who was pilot flying, attempted a second start cycle which generated the ECAM alert ENG 1 FAIL. The associated ECAM procedure included re-selecting engine No 1's master switch to OFF, then stated IF NO DAMAGE: ENG 1 RELIGHT. CONSIDER. Commander A described the ECAM messages to Technical Control over the telephone, who advised trying again. He reported deciding then that if cycle three was unsuccessful, he would return to stand and re-consider departing. He asked the pushback crew to remain connected to the aircraft.

The third start cycle generated a temporary ENG 1 FAIL ECAM message. However, it extinguished automatically, and Commander A reported that the engine control indications seemed normal. Recorded data showed that soon afterwards both engines' parameters were consistent with one another. Commander A telephoned Technical Control again who advised that the No 1 engine's starting abnormalities probably resulted from an ignition fault, which should be resolved once the engine was running. Commander A released the pushback crew.

Crew A accelerated the engines once at the runway holding point; checked the status of the cabin with the senior cabin crew member (SCCM); and then accelerated the engines again for around 15 seconds on the runway. The related indications looked normal. They commenced the takeoff from Runway 26L (Rwy 26L) at 0009 hrs (the flight is shown in Figure 1).

Crew A reported that at around 500 ft agl the No 1 engine began "banging and surging". Commander A recalled that the engine's control indications were fluctuating, and the aircraft was "yawing… and fishtailing… all over the place". There was no accompanying ECAM alert. Data recorded on the flight data recorder subsequently showed that the No 1 engine N_1 reduced below 40% for a period of approximately 25 seconds despite the thrust levers remaining in the FLEX/MCT[21] detent.

21 The FLEX/MCT detent is a gate into which the thrust levers were moved for takeoff.

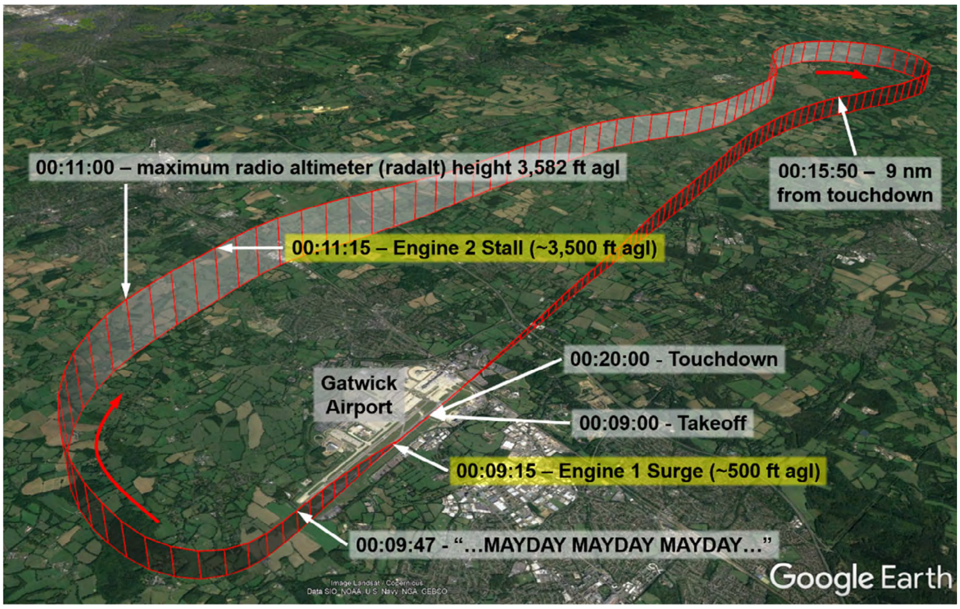


Figure 1

Radar track of G-POWN with timing of significant events highlighted

A number of cabin crew saw flames coming from the No 1 engine's tailpipe and attempted to contact Crew A using the interphone.

Commander A transmitted a MAYDAY call, requesting an immediate return to Rwy 26L and issued an emergency call[22] to the cabin crew. He disengaged the autopilot and turned right, downwind. He moved the No 1 engine's thrust lever to IDLE. At one stage after doing so, he recalled seeing the No 2 engine's control indications begin to fluctuate.

The aircraft levelled at around 3,600 ft agl. Just after commencing descent, the ECAM message ENG 2 STALL was displayed three times in quick succession. This prompted Commander A to move the No 1 engine's thrust lever forward out of IDLE. He commented that both engines appeared more stable when the thrust was reduced while descending, so he aimed to maintain each engine's N_1 at around 49%.

Co-pilot A prepared the aircraft's flight management guidance system for a return to Rwy 26L, and Commander A positioned the aircraft on a 9 nm final approach. He flew slightly above the glidepath to minimise engine thrust, and so he could glide the aircraft to the runway if the engine problems worsened. The aircraft landed at 0020 hrs, with reverse thrust appearing to function normally.

22 A standard procedure to alert the cabin crew that an emergency evacuation may be required.

After stopping, Crew A noted the engine parameters seemed normal; however, the airport rescue and firefighting service (ARFFS) attending the aircraft heard unusual engine noises. Therefore, Crew A shut down both engines on the adjacent taxiway.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor/None	7	0	0

Table 1

Injuries to persons

1.3 Damage to the aircraft

Damage was found on sixteen Stage 3 HP compressor blades and one Stage 7 HP compressor blade on engine No 2. There was no visible damage on engine No 1.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander A

Age:	28 years
Licence:	Airline Transport Pilot's Licence
Licence expiry date:	Valid for life
Ratings:	A320
Operator Proficiency Check:	10 December 2019
Licence Proficiency Check:	10 December 2019
Line check:	15 July 2019
Medical certificate:	14 February 2020
Flying experience:	5,059 hours total; 4,855 hours on type
Previous rest period:	16 hours 17 minutes
Emergency and safety equipment:	10 December 2019
Crew Resource Management training:	11 October 2019

1.5.2 Co-pilot A

Age:	38 years
Licence:	Airline Transport Pilot's Licence
Licence expiry date:	30 November 2020
Ratings:	A320
Operator Proficiency Check:	8 November 2019
Licence Proficiency Check:	8 November 2019
Line check:	14 May 2019
Medical certificate:	22 December 2020
Flying experience:	1,245 hours total; 1,083 hours on type
Previous rest period:	16 hours 17 minutes
Emergency and safety equipment:	10 January 2020
Crew Resource Management training:	10 January 2020

1.5.3 Base Engineer 1

Age:	52 years
Location:	Overseas Base AMO
Licence:	EASA Part-66 Categories B1, B2 and C Aircraft Maintenance Licence, for piston and turbine aeroplanes and helicopters, with no relevant limitations
Licence expiry date:	4 April 2023
Summary of type ratings:	Airbus A320 family, with CFM56 and IAE V2500 engines; various other Airbus and Boeing types; and Bombardier DHC-8-400
Engineering experience:	24 years (B1 licence gained in 2005); with current employer since October 2019
Recent duty pattern:	Alternating between five weekdays on morning shift and five weekdays on afternoon shift with weekends off

Base Engineer 1's first language was not English. He communicated effectively in conversation with the AAIB, though he spoke predominantly in the present tense even when describing events in the past. He reported having no difficulty working with procedures written in English.

1.5.4 Line Engineer

Age:	47 years
Location:	London Gatwick Airport, line maintenance organisation
Licence:	EASA Part-66 Aeroplanes Turbine Categories A and B1, Aircraft Maintenance Licence with no limitations
Licence expiry date:	10 October 2022
Summary of type ratings:	Airbus A320 family, with CFM56, CFM LEAP 1A and IAE V2500 engines; Airbus A330 and A380; various Boeing types; and McDonnell Douglas DC10
Engineering experience:	30 years (B1 licence gained in 2002); with current employer since 2008
Recent duty pattern:	Blocks of four 12-hour shifts consisting of two 12-hour day shifts then two 12-hour night shifts with four days off between blocks. The incident occurred on the engineer's second night shift and last shift within a block

The investigation collected a sleep and work history for the line engineer which did not indicate any sleep or task related risk factors for fatigue.

1.6 Aircraft information

1.6.1 General

Manufacturer:	Airbus
Type:	A321-211
Power plants:	2 CFM56-5B3/3 turbofan engines
Build serial number:	3830
Year of manufacture:	2009
Total airframe hours:	28,586.05 hours
Total landings:	13,404 landings
Certificate of Registration No:	G-POWN/R1
Registered Owner:	Hagondale Ltd, trading as Titan Airways
Date of issue:	30 March 2016

Issuing Authority:	United Kingdom CAA
Certificate of Airworthiness:	EASA Certificate of Airworthiness, issued 30 March 2016
Airworthiness Review Certificate:	EASA ARC expiry date 14 February 2021

1.6.2 Aircraft description

The Airbus A321 is a short to medium range, narrow body passenger aircraft which can carry up to 236 passengers. The aircraft structure is predominantly made from aluminium alloys with a turbofan engine underslung each wing. The A321 can be equipped with either CFM International CFM56 or IAE V2500 engines, whereas the A321neo is equipped with CFM International LEAP-1A or Pratt & Whitney PW1100 engines. It is the largest member of Airbus's A320 family. The operator had a mixed fleet including several A321s with CFM56 engines and an A320 with IAE V2500 engines. The operator had also ordered some A321neo aircraft with CFM LEAP-1A engines. Although these aircraft had not yet been delivered, the maintenance data was available for planning.

1.6.3 Fuel system

Fuel is stored in three separate fuel tanks within the aircraft structure, comprising of one tank in each wing and a centre tank in the fuselage between the wings (Figure 2). On G-POWN there was a refuel coupling in the right wing, used in normal operation, and each wing was fitted with an overwing aperture, allowing direct access to the fuel tanks for gravity refuelling. The aircraft can hold 24,050 litres of fuel and the breakdown of quantities are shown in Table 2.

	Left Wing Tank	Centre Tank	Right Wing Tank
Fuel volume (litres)	7,925	8,200	7,925
Fuel weight (kg – SG=0.785)	6,221	6,437	6,221
Unusable fuel (litres)	19	23	19
Unpumpable fuel (litres)	53	67	53

Table 2

Fuel tank quantities

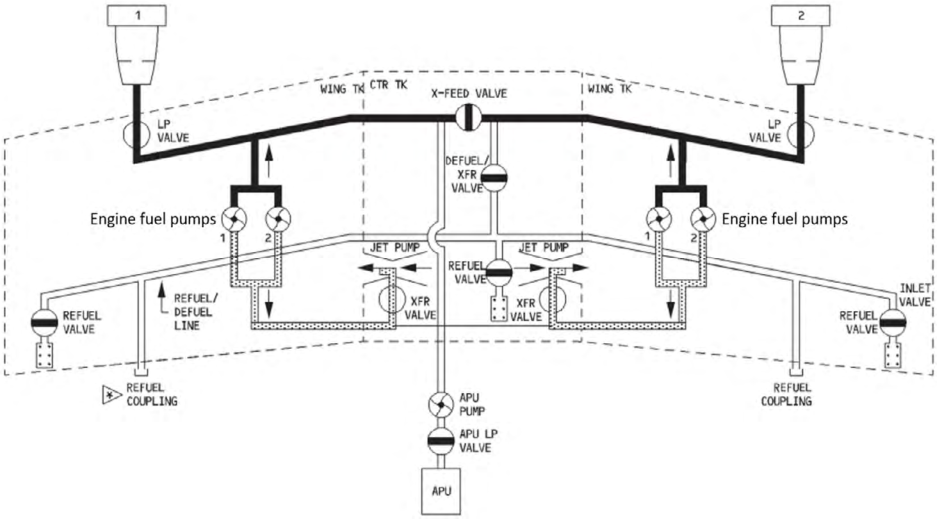


Figure 2

Airbus A321 fuel system diagram

In each wing fuel tank are two electrically powered main fuel pumps which pump fuel from the wing tanks to the engines. They are situated at the wing root end with one pump inlet at the front of the wing and the other at the rear (Figure 3). In the centre fuel tank are two jet pumps which are used to transfer fuel to the wing tanks and will continue to do so until all the fuel is transferred. The main fuel pumps can also be used to transfer fuel between the tanks utilising the refuel line and a cross-feed valve. The fuel pump inlets are positioned to optimise the amount of the fuel that can be used in flight. The unusable fuel is the amount remaining once the tank is drained in the in-flight attitude. The unpumpable quantity is the amount of fuel remaining in the on-ground attitude.

In each fuel tank there are water drains to facilitate removal of any water within the tank during periodic maintenance. The drains are located as close as possible to the lowest points. The amount of accumulated water is dependent on the water content in fuel that is uplifted and the environment through which the aircraft flies. Microbes can enter the fuel tank carried in air or fuel and grow in the interface boundary between the fuel and water. If this growth continues unchecked, it can form a sludge which will ultimately block the fuel filters and restrict fuel flow to the engines. Effective water management is critical to minimise microbial contamination along with effective monitoring and use of biocides.

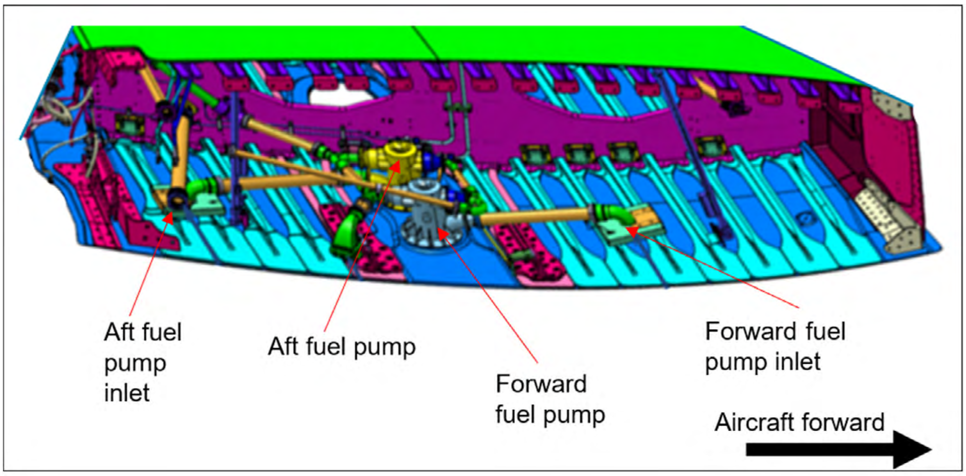


Figure 3

Airbus A321 fuel system. View on left wing root looking outboard (courtesy Airbus)

1.6.4 CFM56-5B3/3 engine

The CFM56-5B3/3 is a high-bypass two-shaft turbofan engine. The low-pressure (LP) shaft consists of a single-stage fan and a four-stage LP compressor, driven by a four-stage turbine. The HP shaft consists of a nine-stage HP compressor, driven by a single-stage turbine.

The data pertaining to the engines fitted to G-POWN are listed in Table 3.

Position	No 1 (left)	No 2 (right)
Type	CFM56-5B3/3	
Serial number	699165	699274
Date of manufacture	19 Nov 2008	29 Jan 2009
Total flight time (hours)	28,979.28	27,804.41
Flight time since last overhaul (hours)	306.19	27,804.41
Total flight cycles	14,185	13,142
Flight cycles since last overhaul	129	13,142

Table 3

Engine data

1.6.5 Engine Control Unit

Each engine is equipped with an Engine Control Unit (ECU), which contains two identical computers, designated Channel A and Channel B. The ECU performs engine control calculations electronically and monitors the engine's condition.

1.6.6 Engine Hydromechanical Units

Each engine is equipped with an HMU, one function of which is to transform electrical signals sent from the ECU into fuel hydraulic pressure to move actuators used to control the engine (Figure 4).

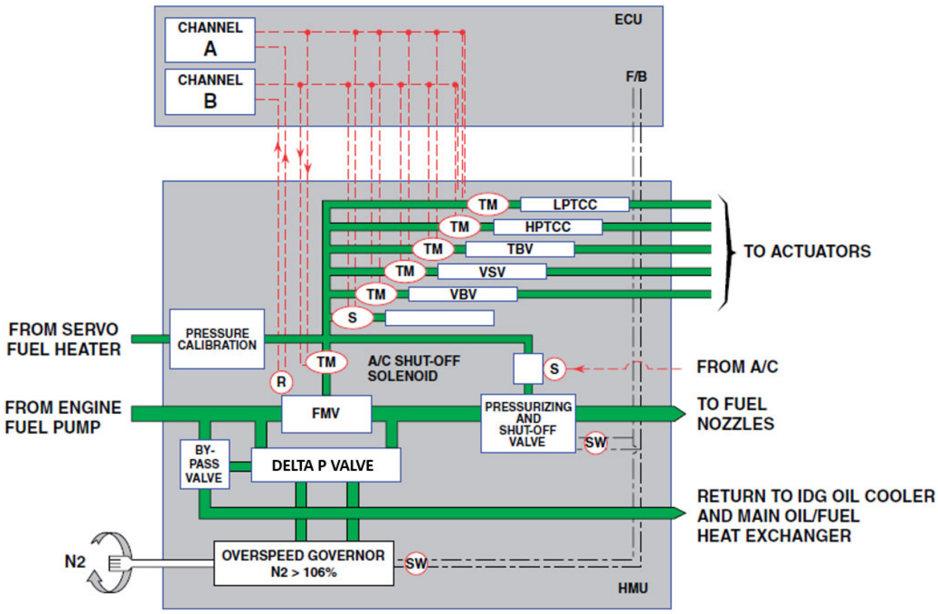


Figure 4

Schematic diagram of the HMU (courtesy CFMI)

Fuel is supplied to the HMU from the engine HP fuel pump, and the Flow Metering Valve (FMV) within the HMU regulates the flow of pressurised fuel to the fuel spray nozzles in the combustion chamber (Figure 5).

The fuel metering system controls the flow of fuel to the engine fuel nozzles through the FMV servo and torque motor, according to commands from the ECU. The ECU commands the FMV to rotate to modify the metered fuel flow. An FMV resolver provides an electrical signal proportional to the FMV position to the ECU, to achieve closed-loop control. The FMV position is not recorded. A pressurising and shut-off valve (PSOV) is located between the FMV and the fuel nozzles. During engine start, the PSOV establishes a minimum fuel pressure to ensure proper operation of the HMU. The PSOV is composed of a piston, a pre-loaded spring and two separate position switches, each indicating if the PSOV is open or closed. The open or closed state of the PSOV, as determined by the switches, is recorded on the aircraft's flight data recorder at a rate of once per second.

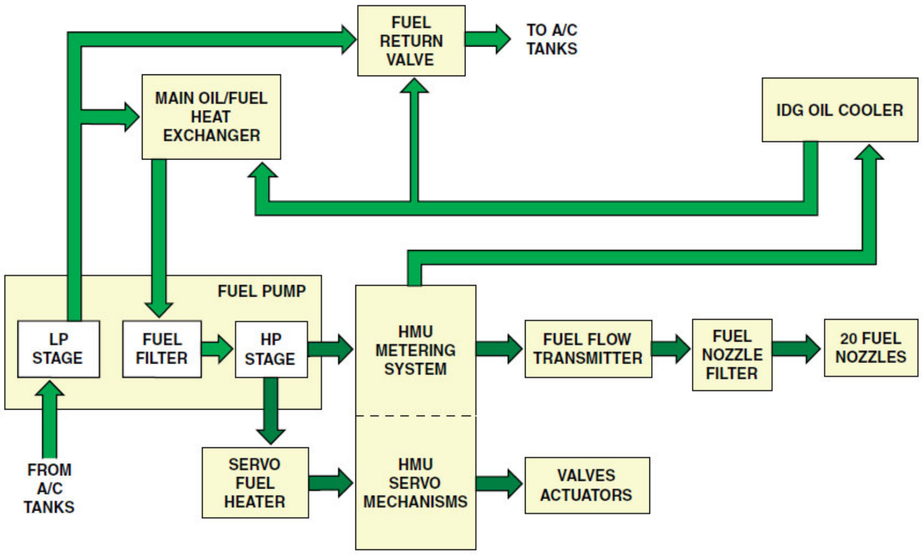


Figure 5

Engine fuel distribution system (courtesy CFMI)

The Delta P and bypass valves ensure that the metered fuel flow is proportional to the FMV area, by maintaining a constant pressure drop across the FMV. The Delta P valve spool and Variable Stator Vane (VSV) and Variable Bleed Valve (VBV) flow control valve spools are rotated around their axes by the HMU drive, each via engagement of a drive pin, to reduce hysteresis. A buffer piston is located between the Delta P and bypass valves to provide compensation to prevent speed overshoot and instability which could occur during operation of the N_2 overspeed governor.

A PC regulator regulates the pressure of fuel used within the HMU control systems to 300 psi above the bypass valve fuel pressure. The PC regulator is comprised of a piston within a ported valve body which moves under the action of fuel pressure against a spring.

A separate control return pressure (PCR) regulator functions identically to the PC regulator but its spring is selected to control the pressure of the return fuel to 150 psi above the bypass fuel pressure.

High pressure fuel is used to provide hydraulic power to the following actuators:

1. VBV actuator – controls the position of the VBV used to bleed air from the compressor to maintain the compressor pressure within the optimal region when the rotational speed of the compressors (LP and HP shafts) changes and a new equilibrium between spool speeds needs to be achieved.

2. Transient Bleed Valve (TBV) actuator – controls the position of the transient bleed valve in the HP compressor (HPC) in response to transient pressure changes in the HPC. The TBV is used to prevent HPC stall during engine start and acceleration.

3. VSV actuator – controls the angle of the stator vanes in the HPC to optimise efficiency and prevent the compressor from stalling during transient engine operations.

4. HP Turbine Case Control (HPTCC) actuator – controls the position of the HPTCC valve to modulate the flow of HPC bleed air to cool the HP turbine (HPT) shroud support structure, to control the tip clearance between the HPT blades and shroud to improve engine efficiency, and to reduce the load on the compressor during transient engine operations.

5. Low-Pressure Turbine Case Control (LPTCC) actuator – controls the position of the LPTCC valve to modulate the flow of fan discharge air to cool the low-pressure turbine (LPT), to control the LPT rotor-to-stator clearances.

The positions of these actuators are not measured or recorded. The fuel pressure supplied to the VSV and VBV actuators is controlled by a second-stage flow control valve, which is itself controlled by a first-stage pilot valve which receives a mechanical input from a torque motor (Figure 6). The torque motors are controlled by signals from the ECU. The radial clearance between the VSV and VBV pilot valve and rotating flow control valve is less than 0.0005 in (12.7 μm).

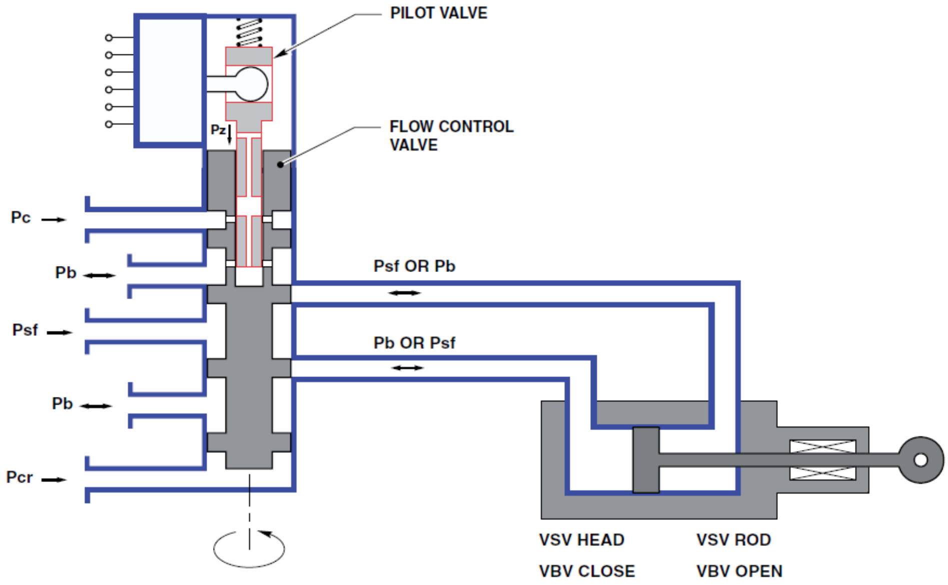


Figure 6

VSV and VBV flow regulator valves, showing the pilot valve and flow control valve design (courtesy CFMI)

The fuel pressure supplied to the TBV, HPTCC and LPTCC valve actuators is controlled by single-stage flow control valve which receives a mechanical input from a torque motor controlled by the ECU (Figure 7). The radial clearance between the HPTCC and LPTCC flow control valve and the valve bore is less than 0.00035 in (8.9 µm).

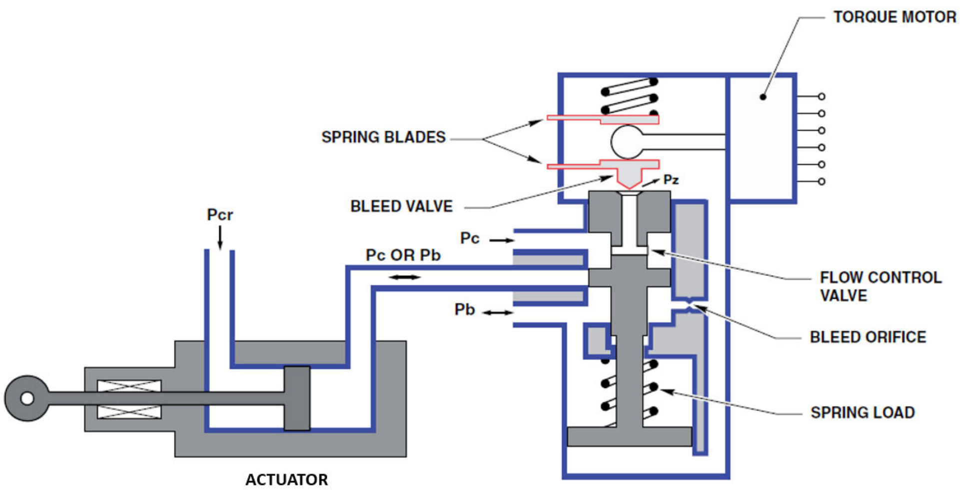


Figure 7

TBV, HPTCC and LPTCC flow control valve design (courtesy CFMI)

1.6.7 Base maintenance

1.6.7.1 Preparation for base maintenance

In preparation for the base maintenance, on 23 November 2019 the operator took fuel samples from the aircraft tanks to be tested for microbial contamination, in accordance with AMM task 12-32-28-281-003-A, *Sample Fuel for Microbiological Contamination Analysis*. The samples were sent to a laboratory and it was determined that there was moderate contamination[23]. The AMM task stated that a second test was required no more than 10 days after the first test and, should this show positive, then biocidal treatment should be applied to the fuel tanks within a further 10 days. In response to the positive test result, the operator added AMM task: '*28-11-00-600-008-A01 Biocide Shock Treatment for Moderate Contamination – With Fuel Mixed with Kathon Biocide'* (pre-mix procedure) to the work package. This was sent to the Base AMO on 8 January 2020 for inclusion in the scheduled base maintenance. No further microbiological testing was performed.

G-POWN arrived at the Base AMO on 20 January 2020 and entered the hangar for work to start on 23 January 2020. Work on G-POWN progressed but there was some difficulty with an in-seat power modification. The maintenance was running behind the agreed schedule and there were representatives from the operator present at the Base AMO throughout the work, who attempted to speed up progress.

1.6.7.2 Preparation for the biocide treatment

The Base AMO had two aircraft that needed to be treated with Kathon biocide, YL-LCQ and G-POWN. YL-LCQ, an Airbus A321, was due to enter long-term storage at the Base AMO and required biocide treatment as part of the storage procedure. An EASA Part-66 licensed engineer (Base Engineer 2) was assigned to the preparation of the aircraft. Base Engineer 2 had worked in aircraft engineering for 13 years and was qualified to work on various aircraft types. He studied the biocide treatment procedure in December 2019 in preparation for the treatment of YL-LCQ. He made an initial calculation to determine how much Kathon to order but did not understand the term 'ppm'. This initial calculation was used as the basis for Kathon orders for YL-LCQ and G-POWN and by the time G-POWN needed to be treated, there was 150 kg of Kathon available in the AMO stores.

23 Moderate contamination is defined as between 1,000 and 10,000 Colony Forming Units (CFU) / ml in water, or between 4,000 and 20,000 CFU / ml in fuel.

The maintenance manager was a Part-66 C-Licensed engineer[24]. He was responsible for the planning and allocation of work to individual engineers, document control, liaison with operators' representatives and answering technical queries from other engineers.

Base Engineer 1 was assigned to the maintenance tasks on the No 1 engine and left wing of G-POWN including the aircraft Kathon biocide treatment. The maintenance manager and Base Engineer 1 discussed how to administer the Kathon to the aircraft's fuel tanks and agreed to add it directly into the tanks through the overwing aperture during refuelling. Base Engineer 1, having referred to the pre-mix AMM procedure for biocide application, thought that using the overwing refuel aperture was an acceptable way to do this procedure.

1.6.7.3 The biocide treatment

The AMM task stated that the aircraft fuel tanks should be treated with Kathon FP1.5 biocide (Kathon) at a concentration of 100 ppm by volume, with Jet A1 fuel.

Base Engineer 1 had not done a biocide treatment before but he expected it to be an "easy job". Base Engineer 1 was not familiar with the term 'ppm' and attempted to find it in the AMM glossary. The term 'ppm' was not defined in the AMM glossary and he could not find another engineer at the Base AMO who knew how to calculate the biocide quantity, so he searched the internet. He found an online calculator and used it to perform the calculation. He could not subsequently recall specifically what website he used or how he performed the calculation. Base Engineer 1 knew that he would be uploading 6,200 kg of fuel into each wing tank. He calculated a quantity of 30 kg of Kathon for each wing tank and made a material requisition for 60 kg of Kathon.

Starting on 20 February 2020, Base Engineer 1 treated G-POWN with 30 kg of Kathon in each wing tank. The biocide was administered directly via the overwing aperture at the same time as each wing tank was filled with fuel. On completion, the Kathon-dosed fuel had a bulk concentration of 3,814 ppm by volume, which was approximately 38 times the recommended concentration. The treatment of the wing tanks took 24 hours after which the Kathon-dosed fuel was transferred to the centre fuel tank for a further 24 hours.

Base Engineer 1 stated he felt sure the calculation was correct when he administered the biocide treatment. Base Engineer 1 reported that when unsure

24 The category C licence permits certification of scheduled base maintenance by the issue of a single Certificate of Release to Service for the complete aircraft after the completion of all such maintenance. The principle function of the category C certifying staff member is to ensure all required maintenance has been called up and signed off by appropriately qualified staff.

how to do something, the options were to look in the maintenance manual or ask colleagues.

1.6.7.4 Completion of the work and departure of G-POWN

The engine and Auxiliary Power Unit (APU) fuel filters where changed, the task card was stamped as complete and a further task was opened to perform a biological contamination check within 10 days but after at least five flights. The maintenance was completed and G-POWN departed to Stansted on 24 February 2020.

1.6.7.5 Other biocide treatments at the Base AMO

The Base AMO had performed one biocide treatment before G-POWN. This was in April 2019 when OE-LOE was treated using one 5 kg container of Kathon. The engineer that did this treatment had a degree in Mechanical Engineering in addition to an EASA Part-66 aircraft maintenance licence. He was not present at the Base AMO when Base Engineer 1 was seeking advice about the task.

On 27 January 2020, it was time for the biocide treatment to be performed on YL-LCQ and Base Engineer 2 was assigned to the task. He was still unsure about the term ppm. He looked for information in the AMM abbreviation list and could not find it, so he searched the internet. He found an internet calculator that offered a ppm to percentage conversion. Base Engineer 2 explained that he mistook the number 0.01 for a factor that he could multiply by fuel quantity to get the required Kathon quantity (Figure 8).

When asked what ‘by volume’ meant in the biocide procedure, Base Engineer 2 stated it meant that if one of the quantities was in kilos, you must calculate the other quantity in kilos.

Figure 8

Extract from internet calculator used by Base Engineer 2

Base Engineer 2 was not confident in the calculation using the internet source and said during interview, “I try ‘till the very last minute to find another thing just to cross-check it.” He looked for further information on the Kathon packaging but did not find anything he felt was useful. He reported that he finally consulted

Base Engineer 1, because he was aware that he had recently treated G-POWN. Base Engineer 1 confirmed he had treated G-POWN with 30 kg in each wing tank and this gave Base Engineer 2 the confidence to proceed. He treated YL-LCQ with 40 kg in the right tank for 6,300 kg of fuel (4,808 ppm by volume) and 20 kg in the left tank for 3,500 kg of fuel (4,396 ppm by volume). The biocide was applied through the overwing apertures.

Following an email from the Base AMO informing their engineers about the G-POWN serious incident, Base Engineer 2 realised that YL-LCQ had also been overdosed with biocide and reported it. YL-LCQ's engines had not been started since the biocide treatment.

Factual Information

1.6.7.6 AMM procedures for biocide treatments

In the operator's A321 AMM there are 12 procedures for biocidal treatment of the aircraft fuel tanks: four relating to the treatment of moderate contamination, four related to heavy contamination, and four to proactively prevent growth during storage. Each group of four similar procedures has two procedures for each of the industry available biocides: Kathon and Biobor. For each of the biocides, there is a procedure using the biocide mixed with fuel, and a procedure to add the biocide during refuel using a metered injection rig. A comparison of all the procedures was undertaken and a variation in terminology and units was observed. A summary of the findings is shown in Appendix A.

1.6.7.7 Biocides - Kathon FP1.5

Kathon FP1.5 is a patented liquid antimicrobial agent that was specifically designed for microbial contamination of hydrocarbon fuels. It can treat a broad range of hydrocarbon fuels, such as diesel fuels, kerosenes, heating oils and aviation fuels. Kathon has two active ingredients, 5-chloro-2-methyl-4-isothiazolin-3-one (1%) and 2-methyl-4-isothiazolin-3-one (0.3%), suspended in dipropylene glycol (90%), water (6%) and magnesium salts (3%). It has a specific gravity[25] of 1,040 kg / m^3 and is available in 5 or 20 kg polythene containers. No concentration or specific gravity data is included on the container label.

Correction May 2023: Amended sentence - see Correction for further details.

1.6.7.8 Biocides - Biobor® JF

Biobor® JF was introduced in 1965 specifically to eliminate microbial growth in aviation fuels. It can be used in jet, turbojet and reciprocating engines and is widely used. It contains two active ingredients, 2,2›-[(1-methylpropane-1,3-diyl)bis(oxy)]bis[4-methyl-1,3,2-dioxaborinane] and 2,2›-oxybis[4,4,6-

25 https://www.oilybits.com/downloads/Dow_Kathon_FP_1.5_Biocide_MSDS.pdf [accessed November 2020].

trimethyl-1,3,2-dioxaborinane], which constitute 95%, with 4.5% Petroleum naptha and 0.5% other inert material. Due to petroleum naptha being classed as carcinogenic and mutagenic, Biobor JF has not been registered for use under EU REACH[26] regulation. It is available in 8 oz (236 ml), 16 oz (473 ml), 32 oz (946 ml), 1 gallon (3.78 l) and 5.5 gallon (20.8 l) containers.

1.6.7.9 Kathon concentration calculation

The AMM task states the Kathon should be mixed with the fuel '*at a concentration of 100 ppm (by volume)*.' To achieve a concentration of 100 ppm by volume, the following calculation should be made:

Fuel uplifted: 6,200 kg (per wing tank)

With a Specific Gravity of 0.808[27] = 7,678 litres

100 ppm = 0.0001

7,678 x 0.0001 = 0.768 litres of Kathon

Using a Kathon Specific Gravity of 1.04 = 0.799 kg (per wing tank)

Some Airbus A320 Family AMM tasks for biocide treatment of fuel included a sample calculation to help the engineers to obtain the correct concentration (Appendix A) but the task selected for G-POWN did not.

At the Base AMO, the specific gravity of the uploaded fuel was available on the fuel receipt. The specific gravity of Kathon was not printed on the container but it was available in the online Material Safety Data Sheet (MSDS).

1.6.7.10 Administering methods - Pre-mix

AMM Task 28-11-00-600-008-A01 - *Biocidal Shock Treatment for Moderate Contamination - With Fuel Mixed with Kathon*, SUBTASK 28-11-00-670-056-A step (4) states to "*refuel all the fuel tanks to the maximum capacity, with fuel mixed with Antimicrobial Agent-Fuel System Liquid Additive*". No instructions are given within the AMM task on how the fuel and biocide should be mixed. The MSDS states "*The biocide should be added in such a manner so as to allow good mixing and distribution across the fuel*".

26 Registration, Evaluation, Authorisation and Restriction of Chemicals. REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry.

27 DEF STAN 91-091 Issue 11 states an allowable range of Jet A-1 density at 15°C of between 775.0 and 840.0 kg/m3. For the purposes of the calculation used in this report, the mean of these allowable density values, 807.5 kg/m3, has been used. This mean value equates to a Specific Gravity of 0.808.

An assessment was made subsequently by the aircraft manufacturer which determined that the process used by the Base AMO would not have mixed the Kathon and fuel effectively. Fuel and Kathon must be agitated to mix effectively, but because they were added to the fuel tank at different locations (refuel coupling and overwing refuel aperture) no direct impingement occurred. As there was no other mechanism available to mix the two fluids, the amount of mixing would have been minimal. The assessment assumed a worse case of no mixing and, as shown in Figure 9, the level of 30 kg of Kathon at the lowest point of the tank was simulated (red surface in Figure 9). This level was then compared to the fuel pump inlet positions in the on-ground and takeoff attitude cases.

Correction May 2023: Updated Figure 9 - see Correction for further details.

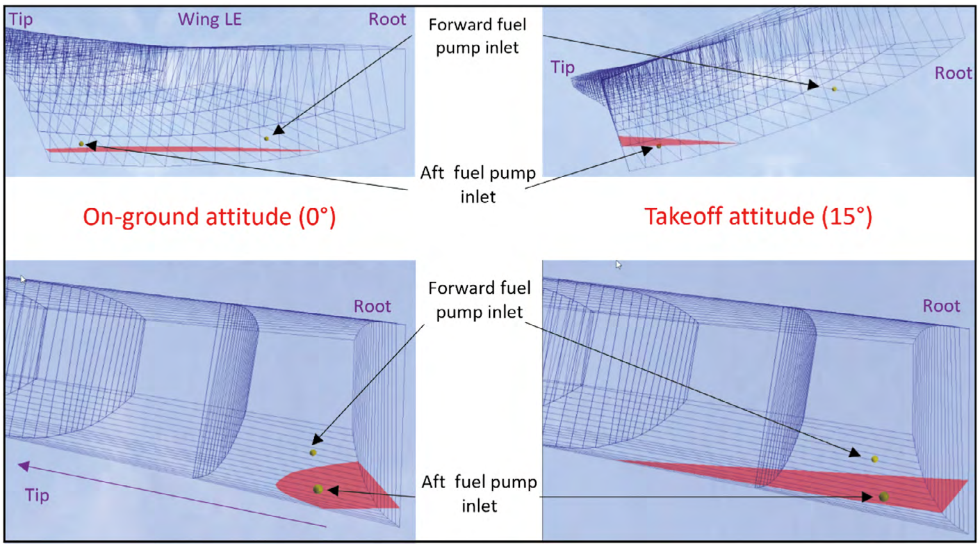


Figure 9

View of the left wing fuel tank at the root showing the fuel pump inlet positions in relation to approximately 30 kg of Kathon (shown in red) (images courtesy of Airbus)

The assessment showed that while the aircraft is on-ground it is unlikely that the pumps would pick up much Kathon and therefore it is probable that the concentration of Kathon in the centre tank would be low. In the takeoff attitude of 15° nose-up, the aft pump inlet would be submerged into the Kathon-rich layer resulting in a high concentration of Kathon in the engine fuel supply.

1.6.7.11 Administering methods – metered injection rig

In the alternative AMM task for moderate contamination, 28-11-00-600-008-A03 - *Biocidal Shock Treatment for Moderate Contamination - Using Kathon Biocide with a Metered Injection Rig*, instructions are given to add the biocide to the aircraft using "metering equipment" although no reference or detail is given.

A metered injection rig is an item of commercially available ground support equipment which enables additives to be added to fluids as they are uplifted into the aircraft storage tanks. They can be used for a variety of additives and fluids including fuel and biocides. The rig has a tank for the additive, an inlet from the fuel bowser and an outlet to the aircraft. A valve controls the amount of additive which is added to the flow of fuel as it comes from the bowser to the aircraft. The valve can be set by the operator to the desired concentration. No metered injection rig equipment was available at the Base AMO.

1.6.8 Line maintenance

The engineer on duty at the operator's Technical Control on the evening of the incident (Technical Control engineer) had over 20 years' experience working as an engineer and maintenance manager on various aircraft types including Airbus types.

The Technical Control engineer reported that Commander B had telephoned to report a "momentary indication of a stall" on engine No 2. The Technical Control engineer passed this information to the line engineer by telephone and asked for troubleshooting on this engine.

The Technical Control engineer was aware of the engine No 1 start problem from the earlier flight and described it as "a start fault, nothing more than that… it was nothing to alert me at the time." The Technical Control engineer did not have access to any more information than was available to the line engineer through the post-flight report (PFR).

At the Line AMO, workload on the evening of the incident was light with three other aircraft apart from G-POWN. The line engineer saw the No 1 engine start problems on the PFR, but this was not highlighted by the operator's Technical Control engineer or by Crew B and there were no entries about it in the aircraft's TLB, ECAM messages or warnings. He stated he was not aware of the recent base maintenance and history of start failures on the flights following the maintenance.

The line engineer demonstrated the process he remembered following to search for the No 2 engine stall troubleshooting procedure. He attempted first to use airnav^{X} [28] but the operator's maintenance data was not available on this application, so he used AirN@v instead. He chose to select all the operator's aircraft in the effectivity filter box. His understanding was that the operator only had aircraft with CFM56 and V2500 engines and he did not see the LEAP 1A engine at the bottom of the list. He stated: "With my PFR, I've

28 A maintenance data application. See Section 1.6.9.

got an ATA[29] Chapter 77 with a stall warning problem, so I know it's a 77." He browsed Chapter 77 using the chapter list and found one titled '*Stall Above Idle on Engine 1(2)*' which he printed to use at the aircraft. The procedure selected was 77-11-00-810-815-A, *Stall Above Idle on Engine 1(2)* which applied to LEAP-1A32 engines. However, G-POWN was fitted with CFM56-5B3/3 engines and the applicable TSM procedure for this engine was 73-00-00-810-866-A, *Stall of engine 1 or 2 in flight.*

The line engineer completed the troubleshooting procedure he had selected and found no fault. He signed off the engine stall defect and released the aircraft to service.

When the line engineer reported that no fault was found, the Technical Control engineer felt that additional assurance was required and agreed with Commander A to do an extra "check of the engines" at the end of the runway. The Technical Control engineer expected that a fault message or indication problems would occur if there was a fault and the pilots would return to stand.

1.6.9 Aircraft maintenance data applications

There are various ways that Airbus maintenance data is provided to AMOs and operators. For G-POWN at the Line AMO, the TSM was provided using the manufacturer's online system *AIRBUS World*. This system included two different applications: AirN@v and airnav^X. Airnav^X has been introduced to replace AirN@v using a gradual transition process. The content of the two applications in terms of maintenance data is identical, they only differ in terms of the graphical interface presented to the user.

Aircraft maintenance data is customised to an operator's fleet and, in some cases, to a specific aircraft. It can also include procedures that an operator has developed. Maintenance engineers who perform maintenance tasks for multiple operators filter the data for the relevant operator each time they access the data. When an operator has multiple aircraft, the maintenance data can also be filtered for the specific aircraft registration or fleet serial number[30] to ensure that only the relevant data is presented.

1.6.9.1 Maintenance data applications interface design

To consider if the design of the maintenance data applications was contributory in this incident, the AAIB performed a task-based heuristic assessment[31] to

29 ATA: Air Transport Association. ATA chapters (or System Codes) categorise systems found on aircraft.
30 Also known as 'effectivity'.
31 Nielsen, J. (1994b). Heuristic evaluation. In Nielsen, J., and Mack, R.L. (Eds.), Usability Inspection Methods, John Wiley & Sons, New York, NY. Also see: https://www.nngroup.com/articles/ten-usability-heuristics/ [accessed October 2020].

evaluate the usability of AirN@v and airnav^{X}. The AAIB evaluated the task of searching for the troubleshooting procedure appropriate for G-POWN based on the PFR and TLB entry that was made after the Krakow to Gatwick flight.

Figure 10 shows the filtering interfaces for AirN@v and airnav^{X}. In AirN@v, the filtering interface is accessed by clicking on the button highlighted in Figure 11. In airnav^{X}, the '*Context*' interface is presented continuously and occupies a prominent position on the left of the screen. Figure 10 shows how the filtering box appeared in AirN@v on the computer that the line engineer used on the evening of the incident when it was examined during the investigation. The size of the box and the width of the columns are adjustable so that more, or less information is visible. Therefore, this image may not exactly represent what the line engineer saw at the time.

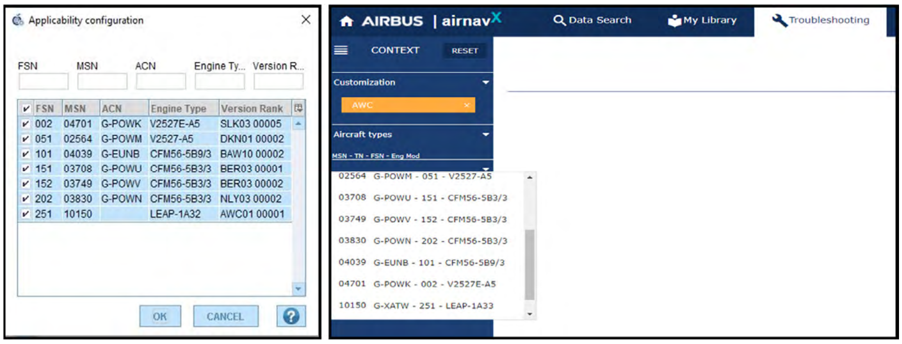


Figure 10

Filtering interface in AirN@v (left) and airnav^{X} (right) (courtesy Airbus)

AirN@v and airnav^{X} offer various ways to search the TSM. The method to reach the appropriate task, described by the manufacturer in the TSM introduction, is to use the '*Start Troubleshooting*' function in AirN@v and the '*Troubleshooting*' tab in airnav^{X} (Figure 11). These both offer an intelligent search function where the engineer can input any fault codes generated by the aircraft in conjunction with other information such as crew observations. The applications then lead the engineer to the appropriate troubleshooting procedure(s). In airnav^{X}, the application forces the user to filter the data to the individual aircraft level before the '*Troubleshooting'* function can be used.

Another method, possible in both applications, is to browse the table of contents which is organised according to ATA codes (Figure 12). In AirN@v, the TSM table of contents is visible by default after accessing the TSM from the initial catalogue page. In airnav^{X}, two clicks are required to access this view. Figure 12 left shows how the table of contents appeared to the line engineer in AirN@v. Chapter 77 – (CFMI) relates to the CFM56 engines fitted to G-POWN. Chapter 77 – (CFML) relates to the LEAP engine and

Chapter 77 – (IAE) relates to the V2500 engine. Figure 12 right shows the equivalent part of the interface in airnav^X.

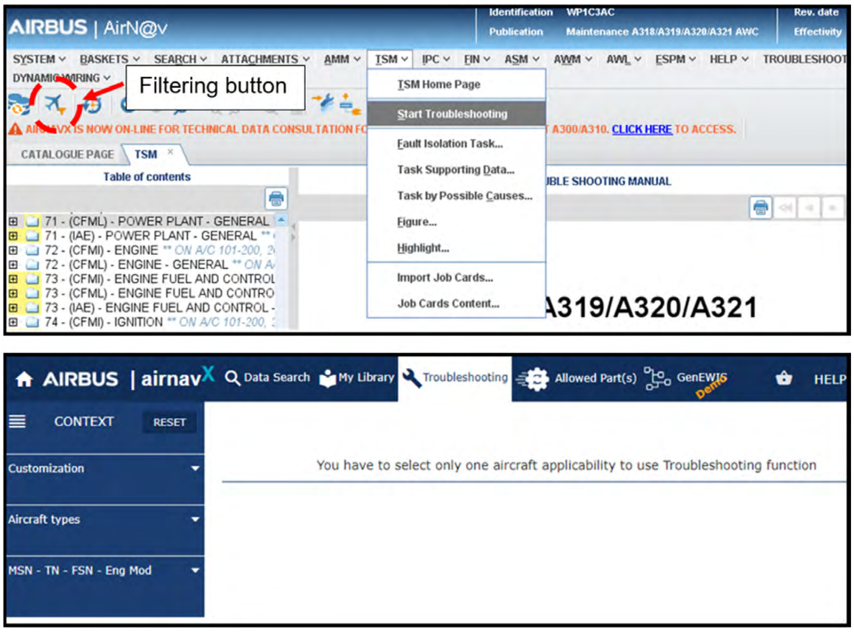


Figure 11

Intelligent search functions – '*Start Troubleshooting'* in AirN@v (above) and '*Troubleshooting'* tab in airnav^X (below) (courtesy Airbus)

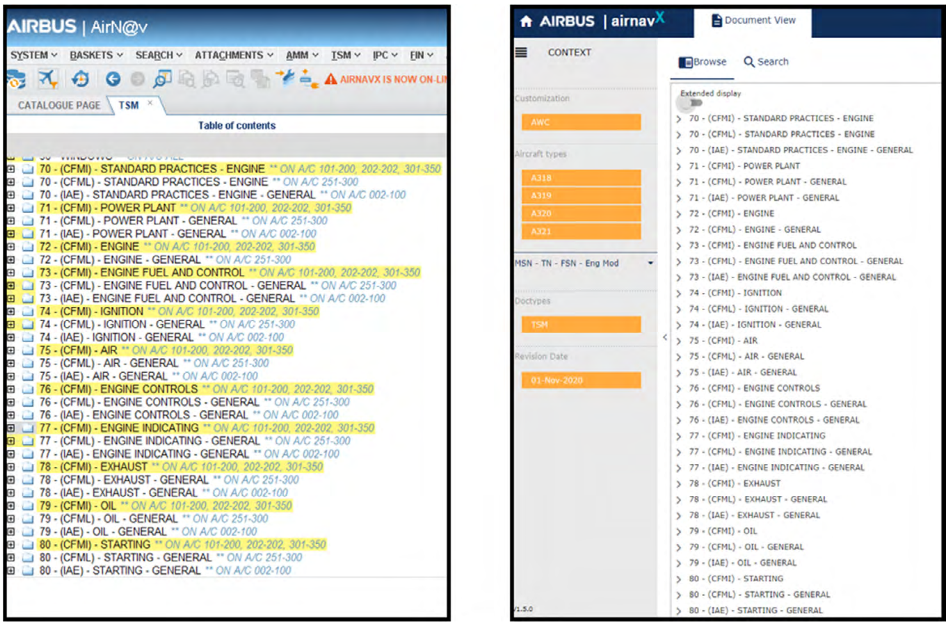


Figure 12

Table of contents in AirN@v (left) and airnav^X (right) showing options for Chapter 77 when data for the operator was not filtered for fleet serial number (courtesy Airbus)

There is also a standard search function in both applications where a user can enter key words or a specific procedure number. The output from the standard search does not take into account the fault codes or other information that the intelligent search function does. These latter two methods are not recommended or taught by the manufacturer.

1.6.9.2 Transition between AirN@v and airnav^{X} and the delegation of access

The Line AMO did not have access to the G-POWN maintenance data in airnav^{X} because it had not been delegated by the operator. The operator reported that they did not intend this and believed that they had delegated access to airnav^{X} to the Line AMO. Figure 13 shows extracts from the operator's delegation screen as it was at the time of the incident. It shows that the operator had delegated access to RNM[32] and SB (Service Bulletin). The text highlighted by the red circle says: '*The access rights delegated are applicable for the following applications: airnav^{X}'.* After the incident, the manufacturer instructed that to provide the Line AMO with access to airnav^{X} they also needed to delegate access to *RNMC – Maintenance data set consult*. Several engineers at the Line AMO stated that they did not question their lack of access to airnav^{X} because they assumed that it was a manufacturer service that the operator had decided not to purchase.

The manufacturer explained that the transition from AirN@v to airnav^{X} was taking place in phases over a period of years and due to be completed in June 2021. The ability to start using airnav^{X} and stop using AirN@v depended on the capability of an operator's IT systems, security requirements and the level of operator customisation of maintenance data.

1.6.9.3 Appearance of the troubleshooting procedure

When a procedure was displayed on the screen within the AirN@v application, the fleet serial number was highlighted in red near the top (Figure 14). The custom at the Line AMO was to print a black and white PDF export of the procedure to use during the maintenance task. When printed, the first page of the procedure appeared as shown in Figure 15. The fleet serial number was grey and there was no identification on any page of the engine type the procedure applied to.

32 This represents the maintenance data set including all the documents of the Maintenance & Engineering domain (such as AMM, TSM and Illustrated Parts Catalogue) to download for consultation with AirN@v.

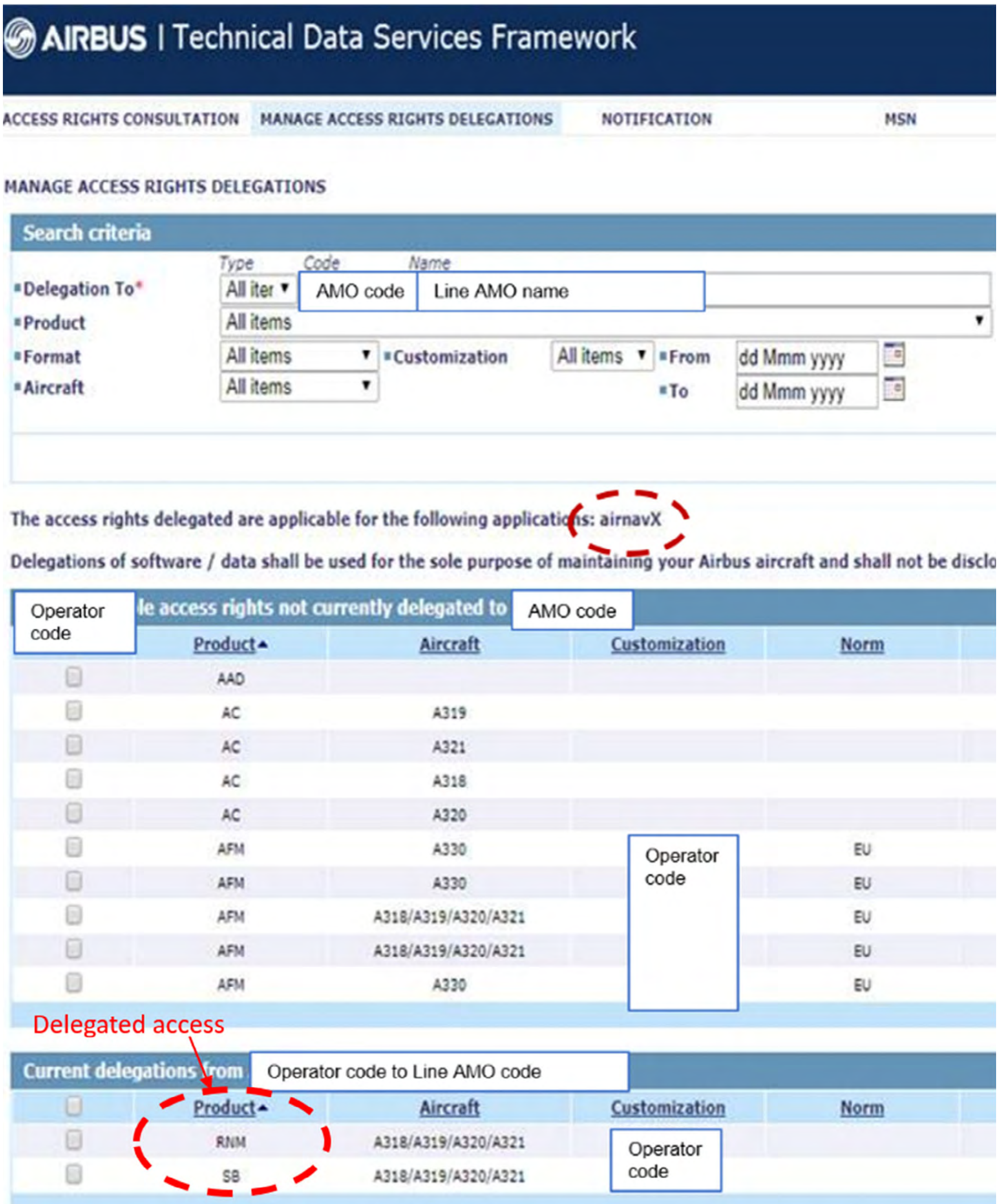
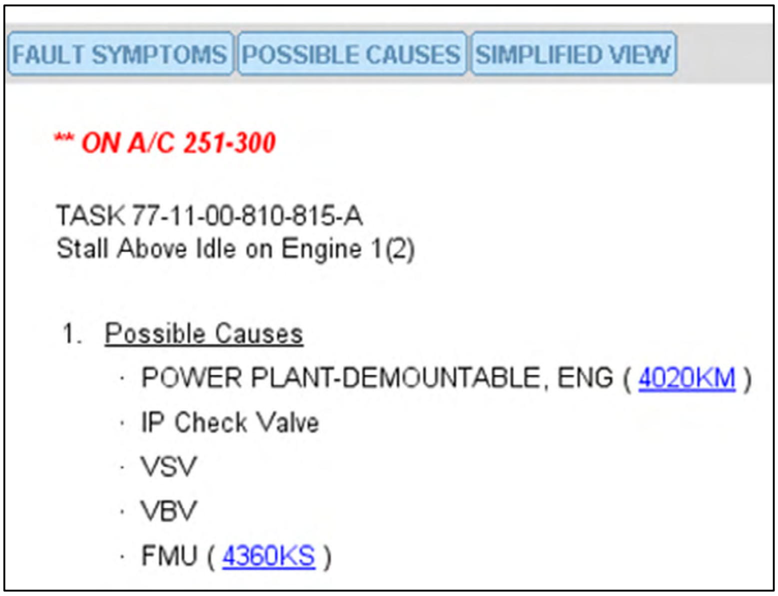


Figure 13

Operator Airbus maintenance data delegation screen at the time of the incident. Codes and names that would identify the organisations have been redacted (courtesy Airbus)



FAULT SYMPTOMS | POSSIBLE CAUSES | SIMPLIFIED VIEW

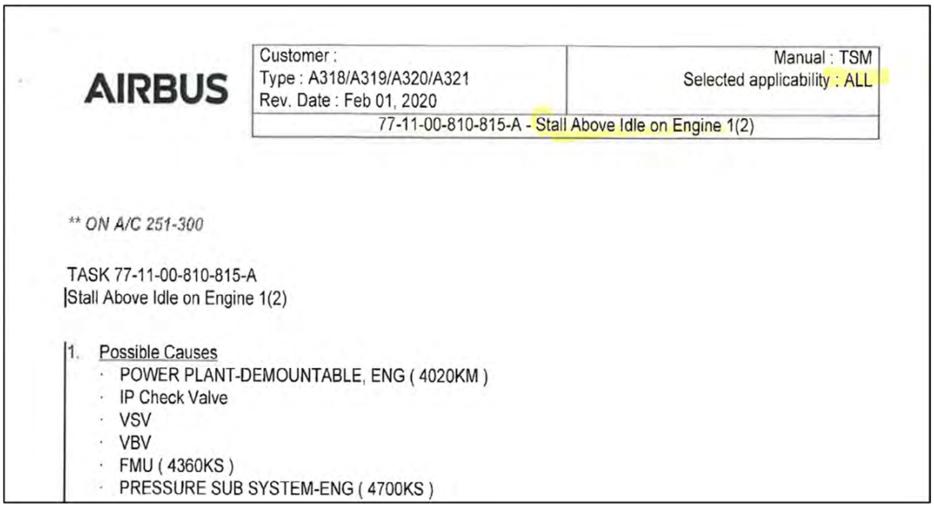
** ON A/C 251-300

TASK 77-11-00-810-815-A
Stall Above Idle on Engine 1(2)

1. Possible Causes
   - POWER PLANT-DEMOUNTABLE, ENG (4020KM)
   - IP Check Valve
   - VSV
   - VBV
   - FMU (4360KS)

Figure 14

Appearance of procedure 77-11-00-810-815-A
Stall Above Idle on Engine 1(2) within the AirN@v application
(courtesy Airbus)



AIRBUS

Customer :
Type : A318/A319/A320/A321
Rev. Date : Feb 01, 2020

Manual : TSM
Selected applicability : ALL

77-11-00-810-815-A - Stall Above Idle on Engine 1(2)

** ON A/C 251-300

TASK 77-11-00-810-815-A
Stall Above Idle on Engine 1(2)

1. Possible Causes
   - POWER PLANT-DEMOUNTABLE, ENG (4020KM)
   - IP Check Valve
   - VSV
   - VBV
   - FMU (4360KS)
   - PRESSURE SUB SYSTEM-ENG (4700KS)

Figure 15

Scan of the procedure used by the Line AMO
(courtesy Airbus)

1.6.10 Troubleshooting procedures for the engine stall message

1.6.10.1 77-11-00-810-815-A - Stall Above Idle on Engine 1(2)

The troubleshooting task is sub-divided into two sections depending on whether additional observations were noted. The TLB entry 53289, made after the

Krakow to Gatwick flight, only referenced the brief ECAM message and the PFR. Some vibration was noted but this was linked to N_1 speed and landing gear extension. This would have led the line engineer to follow the abbreviated troubleshooting which consisted of:

> *'Perform the following abbreviated troubleshooting:*
>
> *a) Check for concurrent fault in the PFR, EEC LAST LEG REPORT, SMR Report, Class 3 report.*
>
> *b) Inspect the tailpipe for indications of metal, damage or defects.*
>
> *c) Inspect the engine inlet, fan blades, fan abradable material, booster Inlet Guide Vane (IGV) for indications of damage, abnormalities or signs of bird strike.*
>
> *d) Turn the fan rotor (N1) by hand to ensure that it turns freely.'*

The line engineer noted in the TLB response that no abnormalities were found during the general visual inspection (GVI) and there were no reports of further faults in any of the other reports. This leads to the following conclusion of the TSM task:

> *'If no damage or abnormalities are found, an engine borescope inspection is NOT required, and the engine can be considered serviceable.'*

The task was subsequently closed and signed for by the line engineer.

1.6.10.2 73-00-00-810-866-A - Stall of Engine 1 or 2 in Flight

Using the TSM '*Start troubleshooting*' interface in either AirN@v or airnav^x and inputting '*Eng 2 Stall*' along with the crew observation in flight, returns the same result of 73-00-00-810-866-A - *Stall of Engine 1 or 2 in Flight*. AirN@v does not require effectivity to be filtered to airframe level to achieve this result. However, airnav^X will not allow the '*Start Troubleshooting*' to start until the effectivity is filtered to a single aircraft.

The procedure for the CFM56-5B3/3 engines fitted to G-POWN requires a GVI of the inlet and exhaust of the engine and a borescope inspection of various booster, compressor and turbine stages in accordance with '*Do a borescope inspection of the HPT Blades Ref. AMM 72-52-00-290-001 and Stage 1 LPT Blades Ref. AMM 72-54-00-20-005*'.

Based upon borescope inspections carried out by the AAIB after the incident flight, these additional borescope inspections would have shown an abnormal covering of the turbine blades with a light white deposit[33]. Borescope inspection experts were consulted to determine what actions would have been taken when presented with these findings and it was stated that images would have been taken and passed to the engine manufacturer for comment. The engine manufacturer confirmed that if presented with these images they would have recommended the engine be removed for further inspection. No further flights would have been permitted.

1.6.11 Operational procedures

1.6.11.1 Engine starting

The operator's Flight Crew Operating Manual (FCOM)[34] described the protection for automatic engine starting. It explained the engines' Full Authority Digital Engine Control (FADEC) detects a hot start, a hung start, or no light up; identifies the fault in an ECAM message; and runs an abort sequence if the start has aborted on the ground, which may result in additional start attempts.

Under starter limitations, the FCOM stated one automatic start cycle includes up to three start attempts, and a 15 minute cooling period is required after four failed cycles.

While abnormal and emergency procedures are often presented by the ECAM system when required, some are also published in the FCOM. The FCOM *'ENG*[INE] *1* [or] *2 HP FUEL VALVE'* procedure stated: *'This alert triggers when HP fuel valve is failed in closed or open position'*. If it has failed in the closed position, with the associated engine running below idle, the ECAM system will display the accompanying message HP FUEL VALVE NOT OPEN, and an instruction to select the engine master switch OFF.

The FCOM procedure for an *'ENG*[INE] *1* [or] *2 START FAULT'* triggered by *'ENG*[INE] *1* [or] *2 IGNITION FAULT'*[35] stated for an automatic start cycle on the ground *'If the engine does not start, the FADEC can attempt an additional engine restart. After any start attempt that is not successful, a dry crank*[36] *phase automatically occurs'*, and the ECAM message NEW START IN PROGRESS will be displayed. When the final dry cranking process has finished, the flight crew are required to select the relevant engine master

33 The high- and low-pressure turbine blades were coated in a thin layer of white material that was observed on the turbine blades' convex surfaces. See Section 1.12.2.
34 Published by the aircraft manufacturer.
35 Occurs when the engine fails to start within 18 seconds following ignition start being selected by the flight crew
36 Dry cranking – pre-start motoring for up to 60 s, to limit the engine core speed.

switch to OFF. Then *'Following starter cooldown, the pilot must decide whether to attempt auto or manual start, or to report the no start condition for appropriate maintenance action.'*

The FCOM procedure for an *'ENG*[INE] *1* [or] *2 START FAULT'* triggered by an *'ENG*[INE] *1* [or] *2 STALL'*, during an automatic start on the ground, stated *'If the FADEC detects a stall…* [it] *will reduce the fuel schedule in stages, if necessary, to achieve a normal condition'.* The ECAM message NEW START IN PROGRESS will be displayed. If a restart is not possible the procedure stated: *'If normal conditions cannot be achieved, the FADEC shuts off fuel and turn*[s] *off ignition'.* Thereafter the procedure required the relevant engine master switch to be selected OFF, which *'confirms automatic start abort'*. The procedure notes stated: *'In case of ENG STALL, consider making XBLEED start if pressure is low'.* The associated procedure for a manual start on the ground was subsequently listed. It stated: *'After the starter cools, and for any subsequent attempt to start the engine, the flight crew must perform a manual start, or must report the "no start condition" to maintenance for appropriate action'.*

The FCOM stated the ECAM message *'ENG*[INE] *1* [or] *2 IGN*[ITION] *FAULT'* on its own is presented for *'crew awareness'* when ignition circuit A or B is failed, thus had no associated procedure actions.

1.6.11.2 Engine vibration

The procedure for *'HIGH ENGINE VIBRATION'* in the operator's quick reference handbook (QRH)[37] explained:

> *'The VIB advisory[38] on ECAM (N1 ≥ 6 units, N2 ≥ 4.3 units) is mainly a guideline for the flight crew to monitor engine parameters more closely … The ECAM advisory alone does not require engine shut down … High N1 vibration [is] generally accompanied by perceivable airframe vibrations' while 'High N2 vibration can occur without …'.*

The procedure instructed flight crew to check engine parameters, especially the exhaust gas temperature (EGT), and cross-check them with the other engine. Then, if icing is not a suspected cause, reduce thrust on the affected engine below the advisory threshold. If vibrations continue after landing, shut down the engine when possible.

37 Published by the aircraft manufacturer.
38 Advisory – affected parameter pulses green, and does not generate a separate ECAM message or aural alert.

The operator's Flight Crew Techniques Manual (FCTM)[39] stated:

> *'High engine vibration alone does not require an engine in-flight shutdown. If the engine needs to be shutdown, other symptoms and certainly an ECAM alert will warn the flight crew, and request them to shut down the engine.'*

1.6.11.3 Engine stall

The QRH procedure for an engine stall is shown in Figure 16.

ENG 1(2) STALL

- **On Ground:**
  THR LEVER (affected engine)........................ IDLE
  ENG MASTER (affected engine)........................ OFF
- **In Flight:**
  THR LEVER (affected engine)........................ IDLE
  ENG PARAMETERS (affected engine)........................ CHECK
  - **If abnormal ENG parameters:**
    ENG MASTER (affected engine)........................ OFF

    ENG 1(2) SHUT DOWN
  - **If normal ENG parameters:**
    ENG ANTI-ICE (affected engine)........................ON
    THR LEVER (affected engine)........................ SLOWLY MOVE FORWARD
    - **If stall recurs:**
      THR LEVER (affected engine)........................MOVE BACKWARD
      Reduce thrust and operate below the thrust threshold where stall recurs.
    - **If stall does not recur:**
      CONTINUE NORMAL ENGINE OPERATION

Figure 16

QRH procedure for an engine stall

The manufacturer's *'ECAM System Logic Data'* page indicated that the ECAM 'ENG 1 [or] 2 STALL' alert in flight would instruct the crew to select the affected thrust lever to idle, check the engine parameters, then apply the QRH procedure.

The FCOM's guidance on engine stalls included:

> *'Indications of an engine stall include varying degrees of abnormal engine noises/bangs, accompanied by flame from the engine exhaust (and possibly from the engine inlet in severe cases), fluctuating performance parameters, vibration, sluggish or no thrust lever response, high EGT and/or rapid EGT rise when thrust lever is advanced'.*

39 Published by the aircraft manufacturer.

The FCTM described other symptoms: *'The engine may give the impression to pump'* and *'Acrid smell in the cockpit'*. It stated:

> *'An engine stall can be due to any of the following reasons:*
>
> - *An engine degradation (e.g. compressor blade rupture, or high wear)*
> - *Ingestion of foreign objects (e.g. birds), or ice*
> - *A malfunction of the bleed system*
> - *fuel scheduling, or stall protection devices)*
>
> *…The FADEC is not able to detect an engine stall in all cases. Therefore, if the flight crew detects one or a combination of the engine stall symptoms, the flight crew should suspect an engine stall, and apply the QRH Engine Stall procedure.*
>
> *The Engine Stall procedure is not a memory item[40]. Therefore, if a stall occurs during the cruise phase, the flight crew shall take the time to assess the situation before applying the procedure, as most of the times FADEC will self-recover from the stall before any flight crew action.*
>
> *…The flight crew should not shut down the engine if the stall can be avoided... The flight crew must report any engine stall for maintenance action.'*

1.6.11.4 Engine fail

The FCOM *'ENG 1* [or] *2 FAIL'* procedure explained that the alert triggers when the engine core speed is below idle, with the engine master switch set to ON and the engine fire push button not pushed. It stated:

> *'The flight crew can suspect engine damage if [they] observe two or more of the following symptoms:*
>
> - *Rapid increase of EGT above the red line*
> - *Important mismatch of the rotor speeds, or absence of rotation*
> - *Significant increase of aircraft vibrations and/or buffeting*
> - *Hydraulic systems loss*
> - *Repeated or uncontrollable engine stalls*
>
> *…if no damage, a new start sequence may be initiated.'*

40 The FCTM defined abnormal or emergency procedures as being either 'memory items' or 'read and do'.

1.6.11.5 Fuel contamination – procedures and training

The only reference to fuel contamination in the pilots' operating manuals was contained in the FCOM *'ENG*[INE] *1* [or] *2 FUEL FILTER CLOG'* procedure. It stated: *'Dual fuel filter clog is likely an indication of fuel contamination'.*

Commander A recalled undertaking some simulator training with his previous operator whereby fuel contamination produced symptoms like high engine EGT and loss of fuel-related indications. It affected both engines in the same way and caused the APU to shut down.

1.6.11.6 ECAM

The operator's head of pilot training summarised the sequence of applying the procedures, relevant to this incident, as follows: *'…before pushback… Action the ECAM…* [After] *the aircraft moves under its own power… Stop and apply park brake… Action the ECAM… Refer to QRH'.*[41]

The FCTM guidance on *'ECAM Tasksharing'* explained that the first pilot who notices the alert resets the master warning/caution. Then for each ECAM procedure, PM announces the *'Title of the failure'*, confirms it by checking the overhead panel and associated systems display.

The QRH section relating to task sharing for abnormal and emergency procedures stated that PM is responsible for *'Monitoring and reading aloud the ECAM and checklists'.*

The FCTM advised *'If an ECAM warning*[42] *disappears while a procedure is being applied, the warning can be considered no longer applicable. Application of the procedure can be stopped'.*

1.7 Meteorological information

Gatwick airport's weather report on 26 February 2020 at 0020 hrs was: wind from 260° at 13 kt, CAVOK[43], temperature 2°C, dewpoint 0°C and QNH 998 hPa.

1.8 Aids to navigation

Not applicable.

41 This was based upon the sequence quoted in the FCTM: Memory items or Operations Engineering Bulletin (OEB) immediate actions; ECAM; QRH.
42 The terms ECAM alert or ECAM warning may be used interchangeably.
43 Visibility ≥ 10 km; No cloud < 5,000 ft, and no cumulonimbus (CB) or towering cumulus (TCU) cloud at any level; no significant weather in the vicinity of the aerodrome.

1.9 Communications

The aircraft remained tuned to the 'Gatwick Tower' VHF frequency for the flight, during which a MAYDAY call was transmitted. After landing, Crew A communicated with the ARFFS on 121.6 MHz. Cockpit Voice Recorder (CVR) data showed those communications were effective.

1.10 Airport information

Gatwick has built-up areas in its vicinity. It has two parallel runways but uses single runway operations, preferring the longer one, Rwy 08R/26L.

Rwy 26L's takeoff run available[44] is declared as 3,041 m and its landing distance available[45] is declared as 2,830 m. It has high intensity runway lighting at the threshold, runway edge, centreline and stop end.

Gatwick has an ARFFS category of 'A10' which is the highest ICAO standard, allowing operation of the largest aircraft in commercial service.

1.11 Recorded information

G-POWN was equipped with an L3 FA2100 solid state CVR, which recorded two hours of audio, and an L3 FA2100 solid state flight data recorder (FDR), which recorded over 177 hours of data. The audio recordings included communications between the pilots, radio transmissions, and audio from the cockpit area microphone. Reports from the aircraft's ECAM that displayed engine and aircraft system information to the crew were analysed. Radar and CCTV from Gatwick Airport were also reviewed to corroborate with other evidence and data sources.

1.11.1 Radar data

An overview of the event flight is shown in Figure 1 in Section 1.1. The figure highlights key points in the incident flight relative to the flightpath based on the recorded secondary surveillance radar Mode S radar returns. The data showed that the aircraft took off from Gatwick at 0009 hrs and landed 11 minutes later at 0020 hrs.

1.11.2 Flight data

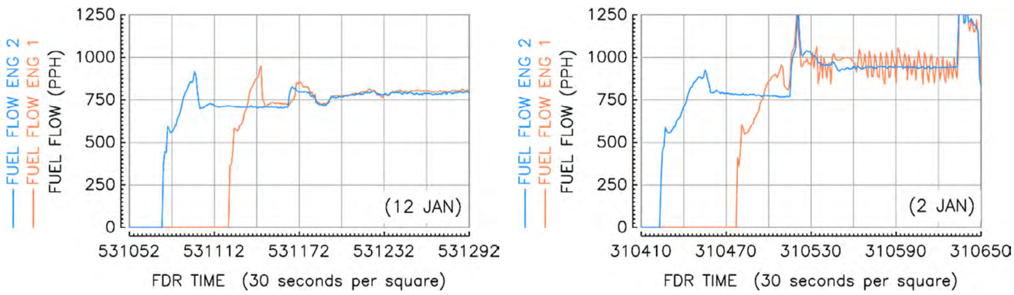
Data from the FDR for the event flight and the previous flights post biocidal treatment are presented in the following subparagraphs. Note that the data for the engines is recorded once per second so transient engine behaviour is

44 The runway length declared available and suitable for the ground run of an aeroplane taking off.
45 The runway length declared *available* and suitable for the ground run of an aircraft when *landing*.

not always captured and visible in the data. Fuel data such as fuel flow and the open or closed position of the fuel HP shut-off valves were recorded but not the position of the fuel metering valves inside the HMU.[46] Also, master warnings and cautions recorded by the FDR are sampled once per second and show if the warning and caution indicator lights are on. The associated chimes (a single chime for a caution and three chimes for a warning) are recorded on the CVR; therefore, the exact timing of these can be determined. It also means that while the indicator lights remain on (ie not cancelled by the crew) any additional alerts are also detected. However, as the CVR recording was two hours with only the event flight recorded in its entirety[47], any multiple master warning and caution alerts for the earlier flights would go undetected.

1.11.2.1 Typical fuel flow characteristics for engine starts

Prior to the biocidal treatment, the FDR recording included the data for 48 flights. The fuel flow during engine starts for each of these flights was examined. Of these 48 flights, 37 had similar fuel flow characteristics to those in Figure 17(a). The other 11 had at least one engine exhibiting an oscillation in the fuel flow immediately after engine start, like the one for Engine 1 in Figure 17(b), which would support that there are likely different fuel regulation methods or control feedback loops that can be active. The fuel flow characteristics shown in Figures 17(a) & 17(b) are therefore considered to represent those for normal engine starts.



(a) (b)

Figure 17

Fuel flow for typical engine start pre-biocidal treatment

46 Fuel metering valves positions are recorded on more recent variants of the A320 family including the new engine option (NEO) versions.

47 The beginning of CVR recording was during the Krakow-Gatwick flight as the aircraft descended through FL300.

1.11.2.2 Larnaca-Stansted (24 February) - first flight post biocidal treatment

Two days prior to the first flight post biocidal treatment, ground runs were conducted twice on the engines at Larnaca. No faults were reported and there was no evidence in the engine data to suggest any problems with the engines. For the subsequent flight to Stansted, the fuel flow for each engine start looked normal. There was no evidence of engine problems in the data and no engine faults reported for the flight.

1.11.2.3 Stansted-Gatwick (25 February) - second flight post biocidal treatment

Figure 18 plots data for the engine starts for the flight from Stansted to Gatwick. The key points are labelled [A] through [E], the details of which are described in the following bullet points:

1. Engine No 2 started successfully [A]; however, the fuel flow exhibited unusual behaviour (highlighted) following the start, compared to the normal behaviour.
2. Once engine No 2 had started, an engine No 1 start [B] was initiated by the crew (first cycle).
3. As the engine No 1 HP shut-off valve (HPSOV) started to open [C] a master caution was issued corresponding to an ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN[48] message alert on the ECAM (§1.11.3.3); however, the engine N_1, N_2 and EGT continued to increase and the engine ignited.
4. After about two and a half minutes of ignition as the engine reached idle speed, a second master caution was issued corresponding to an ENG 1 HP FUEL VALVE > HP FUEL POS SWT FAULT[49] message alert on the ECAM (§1.11.3.3) [D], after which the engine No 1 master switch was moved to the OFF position. Throughout the time engine No 1 had been running, the fuel flow exhibited unusual behaviour (highlighted).
5. Engine No 1 start initiated by the crew [E] (second cycle) several minutes later. The engine started successfully; however, the fuel flow exhibited unusual behaviour (highlighted) following the start compared to the normal behaviour.

48 The aircraft manufacturer determined the nature of the alert from its analysis of the data. The alert indicates that the HP fuel valve failed to open within a defined period.

49 The aircraft manufacturer determined the nature of the alert from its analysis of the data. The alert is generated if the FADEC detects a switch position that is not consistent with the engine state: failed open with the engine below idle (ie N_2 < about 60%) or failed closed with the engine at or above idle.

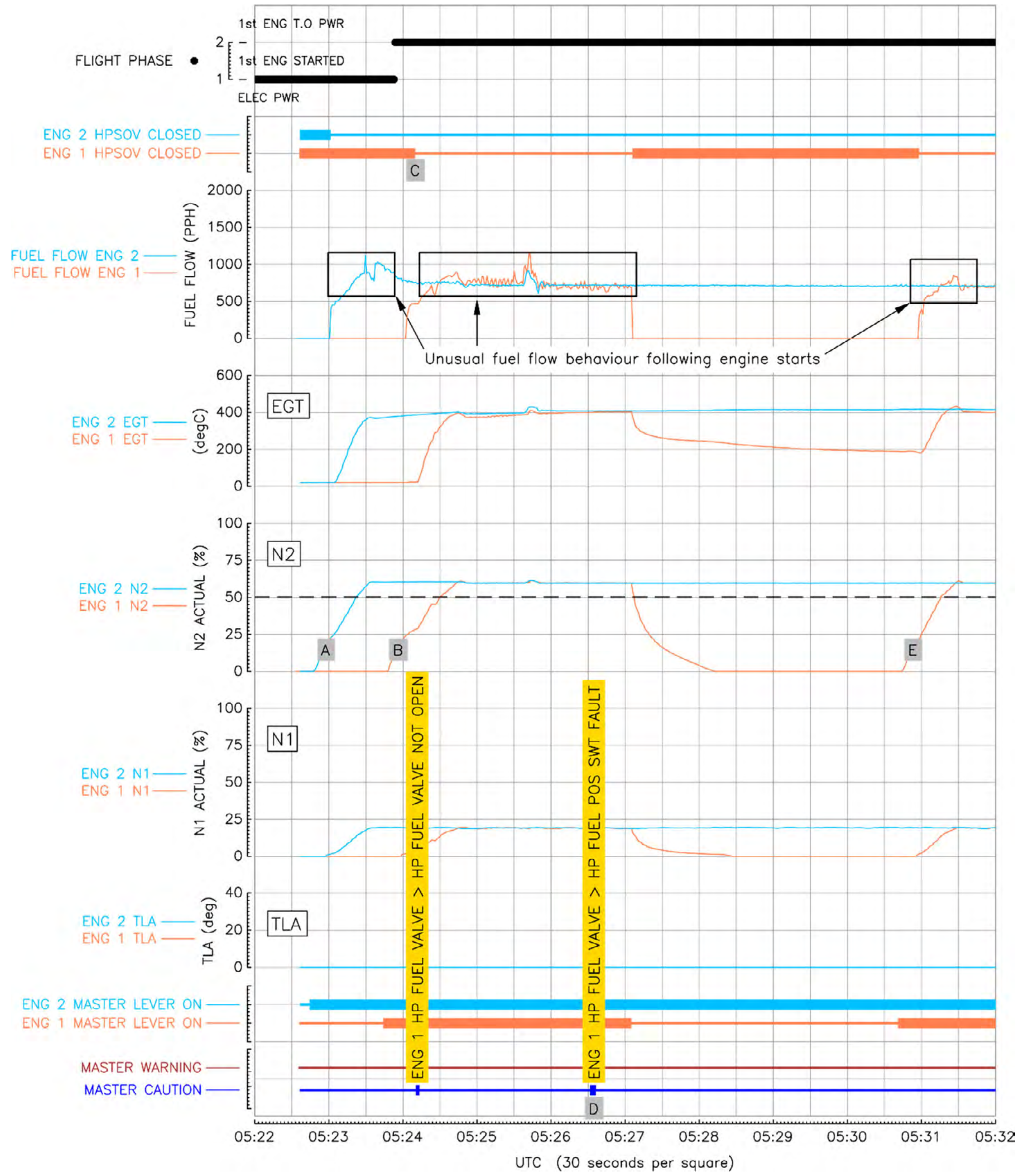


Figure 18

Stansted to Gatwick flight engine starts

1.11.2.4 Gatwick-Krakow (25 February) - third flight post biocidal treatment

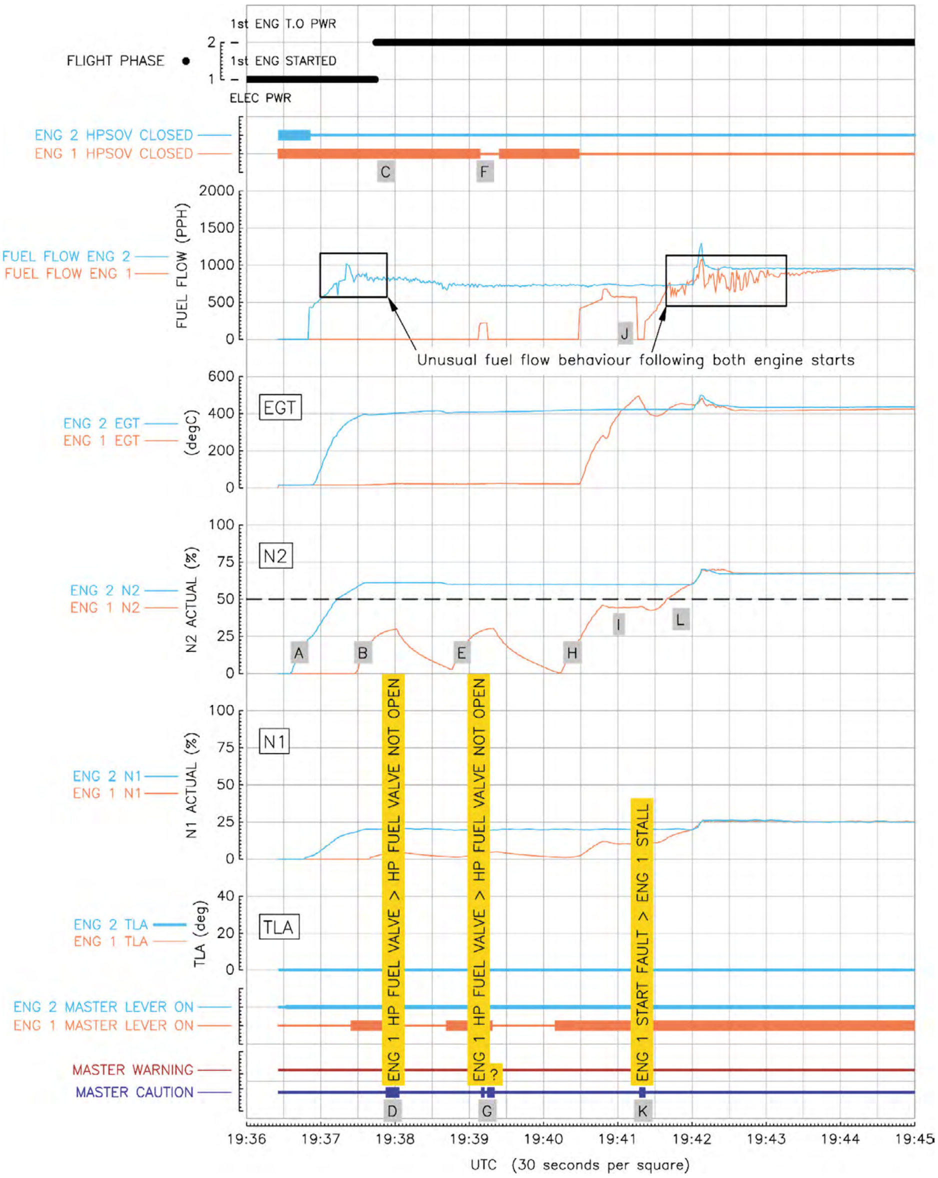
Fuel flow for each engine starts looked normal. There was no evidence of engine problems in the data. No engine faults were reported for the flight.

1.11.2.5 Krakow-Gatwick (25 February) - fourth flight post biocidal treatment

Figure 19 plots data for the engine starts for the flight from Krakow to Gatwick (the penultimate flight before the event flight). The key points are labelled [A] through [L] the details of which are described in the following bullet points:

1. Engine No 2 started successfully [A]; however, the fuel flow exhibited unusual behaviour (highlighted) following the start compared to the normal behaviour.
2. Once engine No 2 had started, an engine No 1 start [B] was initiated by the crew (first cycle).
3. The N_1 and N_2 for engine No 1 started to increase; however, the fuel HPSOV for engine No 1 remained in closed position [C].
4. About 28 seconds after the engine start was initiated (and 11 seconds after the HPSOV was commanded to open), a master caution was triggered corresponding to an ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN message alert on the ECAM (§1.11.3.4) [D] after which the crew moved the engine master switch to OFF.
5. After about 40 seconds, by which time the N_1 and N_2 had dropped to zero, the engine No 1 master switch was moved to ON for another start attempt (second cycle) [E].
6. After about 30 seconds, as the N_1 and N_2 for engine No 1 increased, the fuel HPSOV for engine No 1 opened for about 15 seconds [F] and fuel started to flow. However, the opening of the valve was coincident with the first of two master cautions the first of which corresponded to an ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN message alert on the ECAM (the reason for the second is unknown – §1.11.3.4) [G] after which the crew moved the engine master switch to OFF.
7. 50 seconds later, by which time the N_1 and N_2 had again dropped to zero, the engine No 1 master switch was moved to ON for another start attempt (third cycle) [H].
8. As N_1 and N_2 increased, the fuel HPSOV opened and fuel began to flow. As the EGT passed about 280°C, the N_1 at about 10% and N_2 at about 46% stopped increasing [I]; however, the EGT continued to rise.

Factual Information



Correction May 2023: Corrected Figure 19 - see Correction for further details.

Figure 19

Krakow to Gatwick flight engine starts

9. As the EGT of engine No 1 reached about 490°C (70°C above the EGT of engine No 2) the fuel flow dropped to zero for approximately four seconds [J], during which a master caution was issued corresponding to an ENG 1 START FAULT > ENG 1 STALL[50] message alert on the ECAM (§1.11.3.4) [K]. This message would have been followed by NEW START IN PROGRESS as the FADEC automatically initiated another start attempt.

50 This was confirmed by the aircraft manufacturer who also confirmed that this ECAM message would have disappeared once the N_2 went above 50% following a successful automatic start attempt.

10. The EGT immediately began to fall and as it dropped below about 450°C the fuel started to flow again. The N_1 and N_2 then started to increase [L] and the engine started successfully. The fuel flow, however, exhibited unusual behaviour (highlighted) following the start compared to the normal behaviour.

11. The engine No 1 N_2 reached 50% 22 seconds after the master caution was issued, at which point the ENG 1 STALL message alert on the ECAM disappeared.

For the flight, there was no evidence of engine surges in the recorded engine data. Throughout, the N_1, N_2 and EGT for both engines were matched; however, N_1 and N_2 vibrations for the No 1 engine were more varied when compared to the No 2 engine. During the descent, transitioning from FL130 (time 21:58:25) and passing through FL122 (time 21:59:59), master cautions were issued corresponding to an ENG 2 STALL message alert on the ECAM. The No 2 engine N_1 vibration ranged from 0.0 to 0.2, and the N_2 vibration ranged from 0.1 to 0.4 during the 1 min 34 seconds between and during the two No 2 engine stall alerts.

1.11.2.6 Gatwick-Gatwick (25/26 February) – event flight

The event flight has been broken down into four data plots covering: (1) engine starts; (2) the climb during which engine No 1 surged; (3) downwind during which engine No 2 stalled; and (4) engine shutdown. Key points in data are highlighted on the plots.

Engine starts

Figure 20 plots data for the engine starts for the event flight. The key points are labelled [A] through [F] the details of which are described in the following bullet points:

1. Engine No 2 start initiated [A] with the engine reaching an N_2 > 50% at about time 23:50:00. The engine started successfully; however, the fuel flow exhibited unusual behaviour (highlighted) following the start compared to the normal behaviour.

2. Engine No 1 start initiated by the crew [B] (first cycle) during which the fuel HPSOV exhibited erratic behaviour (highlighted). The HPSOV started to open (three seconds after being commanded to with the N_1 and N_2 rising) but closed after a second before reopening five seconds later.

The fuel started to flow as soon as the valve initially opened and continued to flow until seven seconds after it opened for the second time. A master caution was issued coincident with the fuel flow stopping. The reason for the master caution is unknown; however, the crew referred to some kind of "IGNITION … FAULT" (the speech on the CVR recording is unclear).

There was a second master caution 17 seconds after the first which the crew identified as an ENG 1 start fault > ENG 1 IGNITION FAULT ECAM message alert. The crew were also aware that a new start was in progress. The HPSOV, however, continued to behave erratically before closing.

A third master caution (reason unknown) was issued 26 seconds after the second as the engine was attempting to start while the HPSOV remained closed (§1.11.3.5). The engine failed to start, and the crew moved the master switch to OFF.

3. Engine No 1 start initiated by the crew [C] (second cycle) during which the N_2 reached just over 50% for at least three seconds before dropping below 50%. This generated an ENG 1 FAIL message alert on the ECAM that prompted the crew to move the master switch to OFF.

4. Engine No 1 start initiated by the crew [D] (third cycle) during which the N_2 reached just over 50% for at least three seconds before dropping below 50%. This again generated an ENG 1 FAIL message alert on the ECAM, and just as the crew were about to move the master switch to OFF, the N_2 began to increase. The engine started successfully; however, the fuel flow exhibited unusual behaviour (highlighted) following the start compared to the normal behaviour.

5. Engine run ups were made to about 40% N_1 [E] at the runway holding point and to about 50% N_1 [F] just before takeoff.

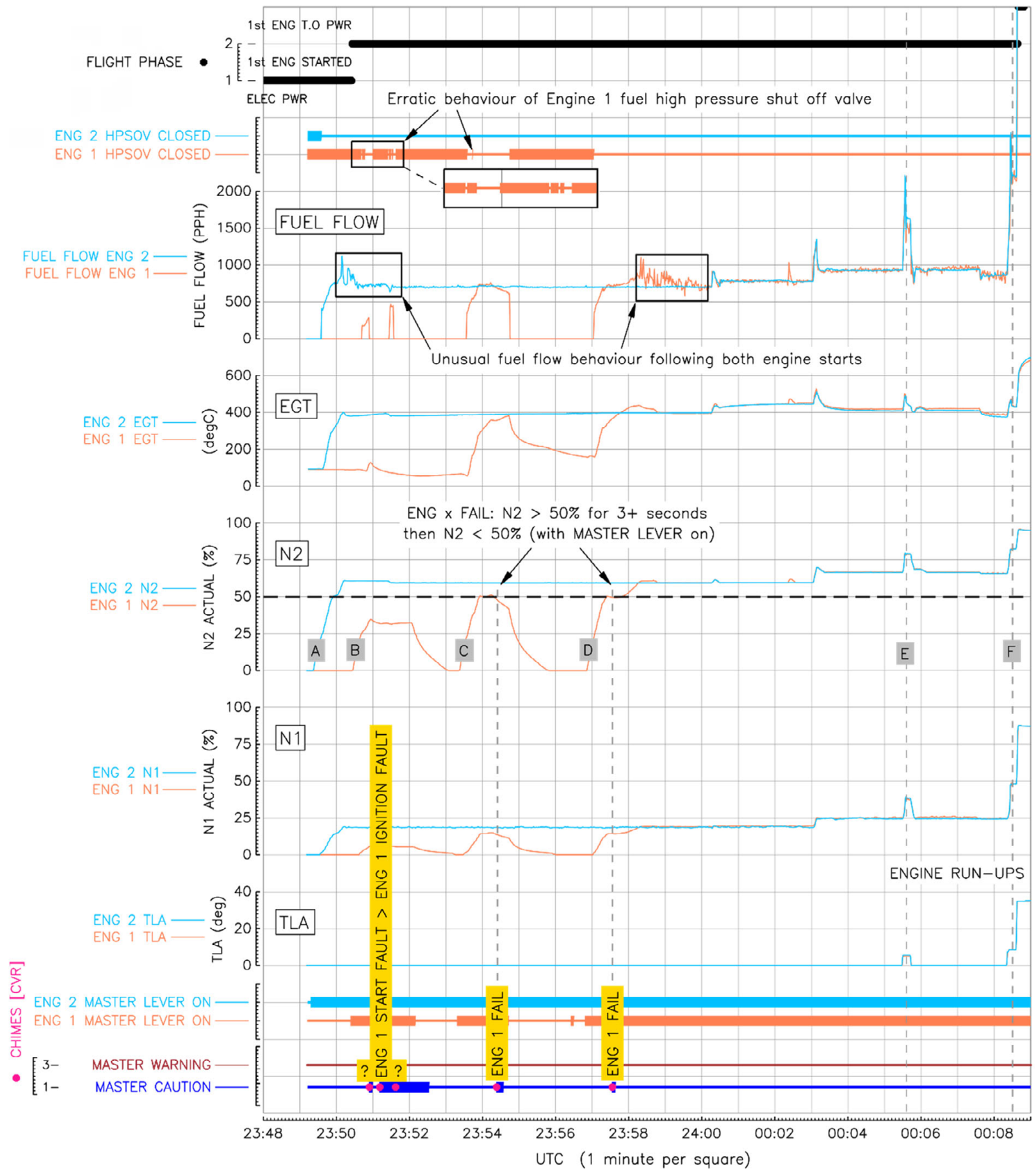


Figure 20

Incident flight engine starts

Event flight

Figures 21 and 22 are an overview of the engine No 1 surge and the engine No 2 stall events during the incident flight. Again, note that the engine parameters are recorded once per second so transient behaviour of the engines is not captured. Also, during the downwind leg of the flight (Figure 22), of the 11 master cautions that were issued and heard on the CVR, only those relating to ECAM fault alerts are highlighted. The other master cautions relate to ECAM alerts providing operational information to the crew which are not recorded (§1.11.3). There were no master cautions issued during the climb phase (Figure 21) when the No 1 engine surged. This was because not all stall types (of which surging is one) can be detected by the FADEC. To detect a stall, the FADEC monitors changes of the PS3 static pressure[51] within a 45 millisecond period; however, not all stall types have sufficient changes in PS3 for them to be detected. The once-per-second sampling rate of PS3 on the FDR also means only much slower changes in PS3 can be observed, and PS3 is, therefore, not shown in these figures.

The main points from Figures 21 and 22 are:

Figure 21:

1. Once the aircraft was airborne, the N_1 and N_2 for engine No 1 became unsteady in comparison to engine No 2 [G].
2. At about 350 ft agl, there was an uncommanded drop in the N_1 of engine No 1 (and correspondingly N_2) over five seconds from about 87% to 35% [H].
3. At time 00:09:16 as the aircraft climbed through 550 ft agl, a thud sound was recorded on the CVR [I] that corresponded with the flash of flames seen coming out of the engine on the airport's CCTV. This was followed by another thud sound one second later, and then for a period of 30 seconds a further 100-plus thuds (between two and four per second). Again, these thuds corresponded to flashes seen on the CCTV footage.
4. The lateral acceleration (sampled four times per second) shows lateral oscillations during this period [J]; however, the sample rate would need be higher to accurately capture the yaw oscillations that the crew reported. A negative shift in the overall lateral acceleration during this period indicates that the aircraft was sideslipping to the right. Right rudder was applied countering the yaw from the thrust asymmetry with the loss of No 1 engine thrust.
5. With the drop in the engine No 1 thrust there was a corresponding increase in N_2 vibration on that engine [K].
6. At time 00:09:43, the engine No 1 throttle lever was pulled back to 25° [L]. About five seconds later, the engine No 1 N_1 (and N_2) responded by increasing back toward the commanded position [M].

51 PS3 is the HP compressor discharge static air pressure – one of several pressures used for engine control.

7. The engine No 1 N_2 vibration remained high compared to the engine No 2 N_2 vibration [N].

8. At time 00:10:15, the N_1 and N_2 for engine No 1 became unsteady again when compared to engine No 2 [O].

9. At time 00:10:28, there was another uncommanded drop in the N_1 (and N_2) of No 1 engine [P].

10. At time 00:10:32, a thud sound was recorded on the CVR [Q].

11. Six seconds later the crew moved the engine No 1 throttle lever to the IDLE position [R].

Figure 22:

12. About 15 seconds later the engine No 1 N_1 (and N_2) started to increase [S].

13. At time 00:10:53 there was an increase in the engine No 2 N_1 vibration that exceeded 1.0 for about five seconds [T]. During these five seconds autopilot 1 disengaged.

14. As the engine No 2 N_1 vibration started to decrease back below 1.0, the first of three master cautions were issued corresponding to ENG 2 STALL message alerts on the ECAM [U]. The three alerts all happened within six seconds of each other. Autopilot 2 engaged shortly after the first engine stall alert and disengaged about three seconds after the third engine stall alert.

15. The engine No 1 throttle lever was returned to the position of the No 2 engine throttle lever [V]. The engine No 1 responded within a couple of seconds to match the N_1 and N_2 of engine No 2. No further engine events were recorded for the airborne portion of the flight.

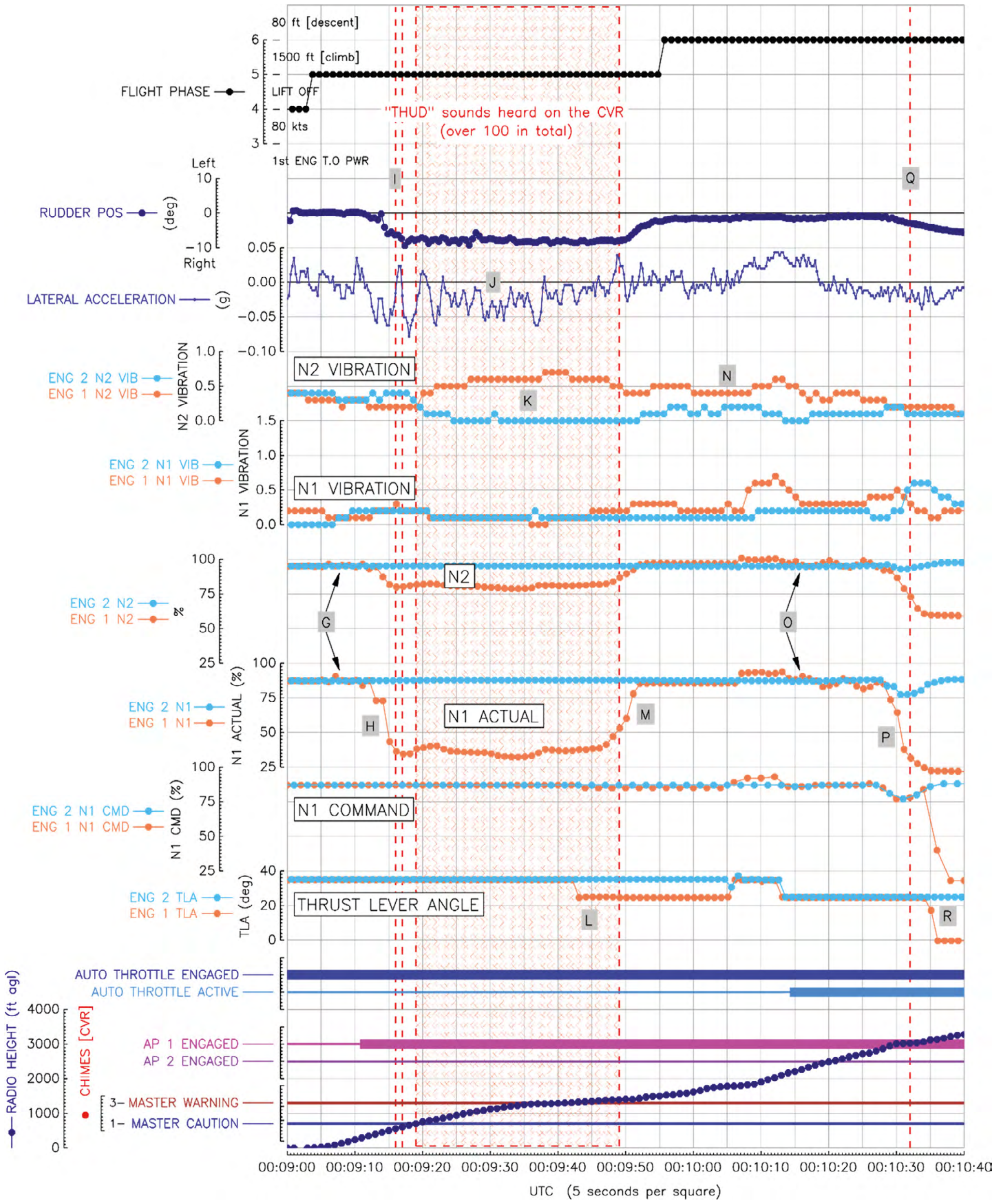


Figure 21

Overview of flight data from the incident (plot 1 of 2)

Correction May 2023:
Corrected Figure 21
- see Correction for further details.

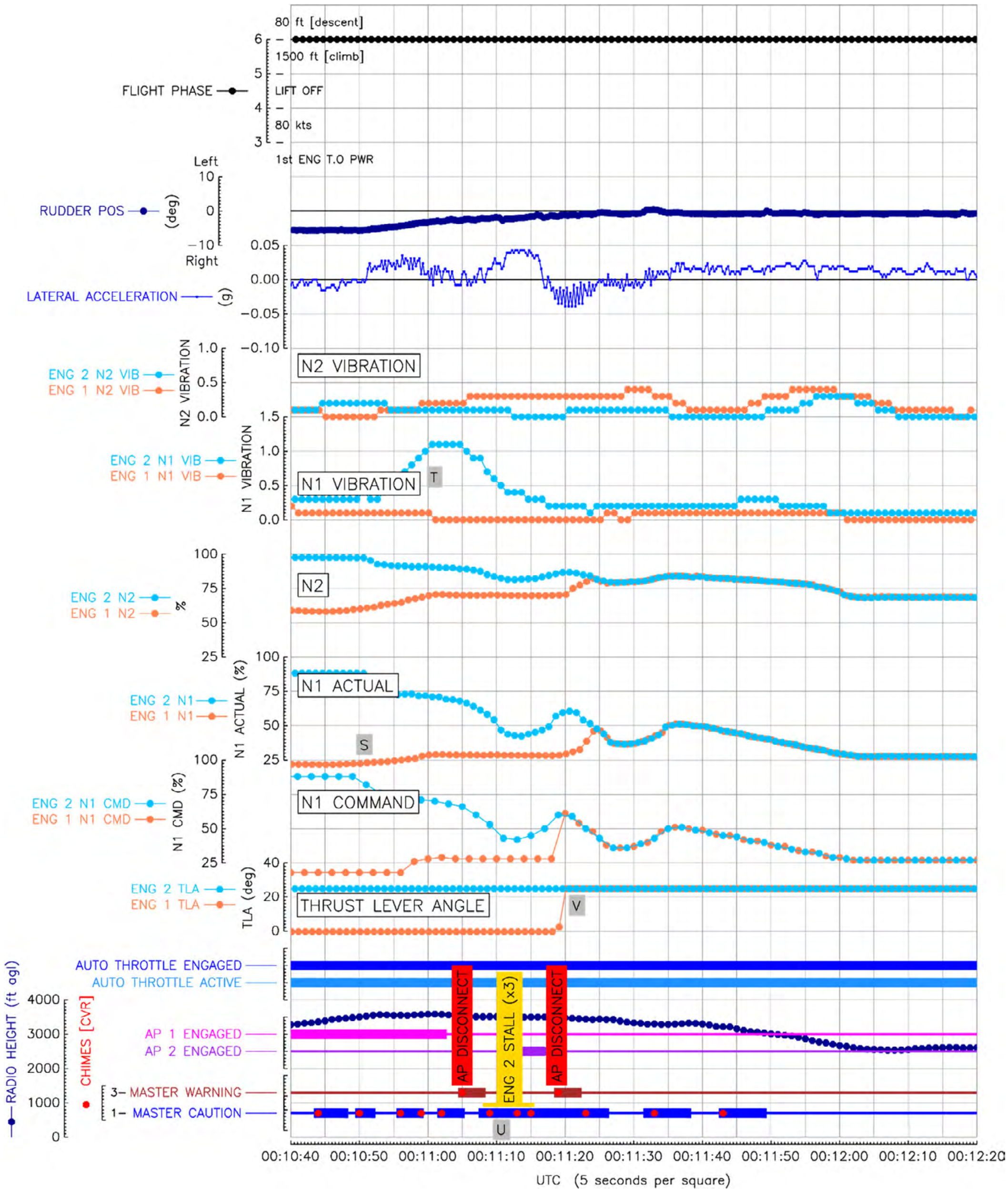


Figure 22

Overview of incident flight data (plot 2 of 2)

Correction May 2023:
Updated title for Figure 22 - see Correction for further details.

Engine shut down

Figure 23 plots data for the engines post the event flight just prior to engine shutdown.

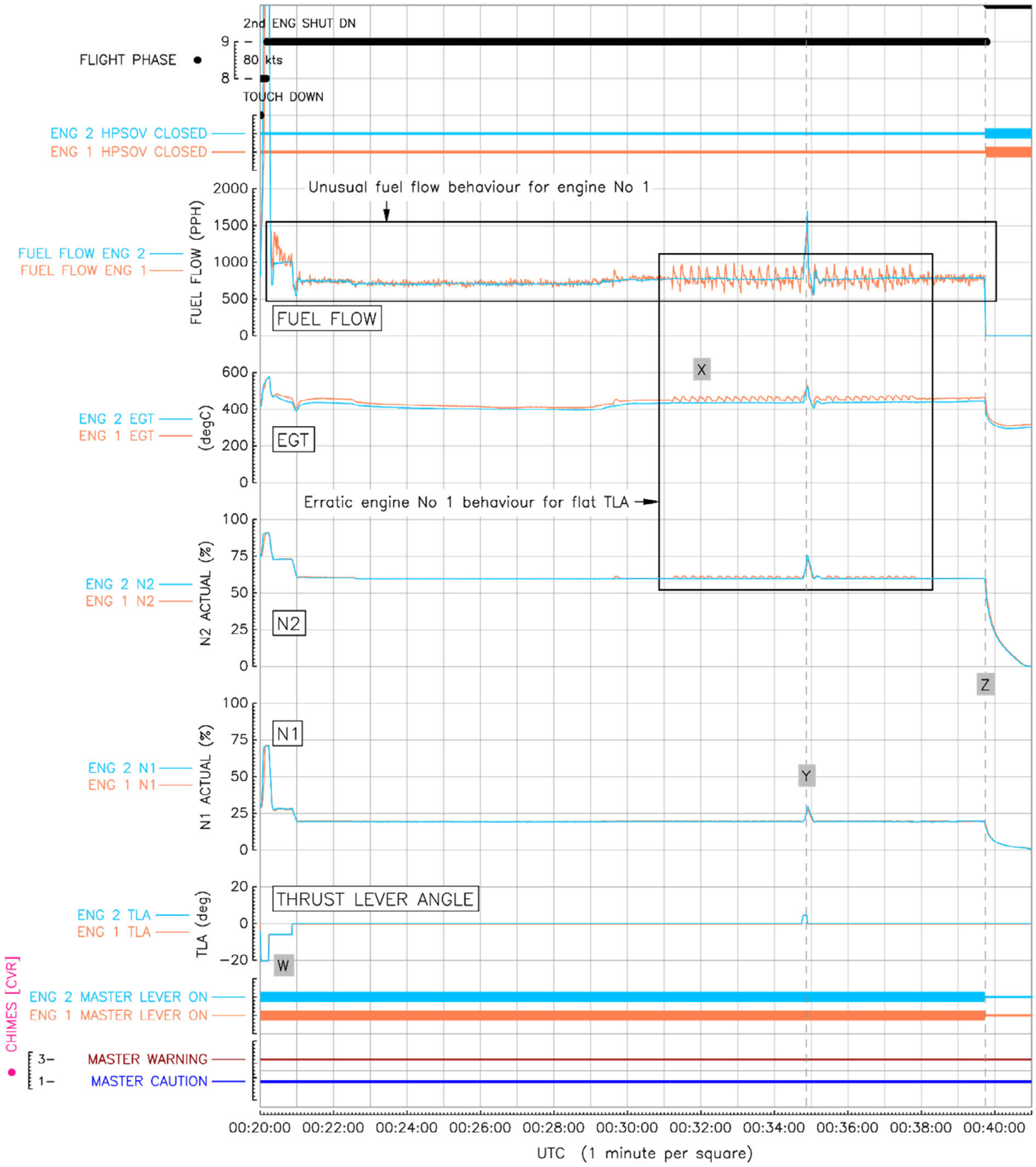


Figure 23

Post incident flight engine behaviour

The key points are:

1. Once on the ground thrust reverse was selected [W]. Within one minute the aircraft was brought to a stop and the throttle levers were moved to the IDLE position.
2. Unusual behaviour of the fuel flow for engine No 1 was recorded compared to engine No 2 (highlighted).
3. For a steady throttle lever angle, erratic behaviour in engine No 1 was recorded compared to the steady response of engine No 2 [X] (highlighted).
4. The engines were run up to about 28% N_1 coincident with the aircraft taxiing onto the taxiway [Y].
5. At time 00:39:45 both engines were shut down [Z].

Factual Information

1.11.3 ECAM – message alerts

Several ECAM message alerts have been referred to in previous paragraphs which are summarised here together with how they were relayed back to the operator.

1.11.3.1 Types of ECAM message alerts

The ECAM message alerts generally fall into two categories: system failures that may require a maintenance action post-flight, and operational alerts to the crew not associated with a system failure. The alerts either require a crew action or monitoring of a system or are just for information and require no action from the crew. Aural (chime) and visual (master caution or master warning lights) cues are used to capture the crews' attention depending on the severity of the alert.

1.11.3.2 Recording of ECAM message alerts

Maintenance alerts are automatically sent to the operator via the ACARS digital datalink when they happen. They also form part of the PFR that can be printed from the cockpit printer after a flight (Figure 24) and which is also sent to the operator via the ACARS to the real-time AIRMAN[52] maintenance tool. There is, however, a three-minute delay following first engine start (ie N_2 > 50%) before

52 AIRMAN (AIRcraft Maintenance ANalysis) is a maintenance and troubleshooting software tool, developed by Airbus that (1) provides real-time receipt and management of on-board maintenance system messages through the ACARS which allows mechanics to prepare a maintenance action while the aircraft is still in-flight, (2) provides easy access to all information connected with an aircraft maintenance message and offers troubleshooting advice for mechanics on-line, and (3) for each aircraft in the fleet, it provides a daily task list of preventive maintenance measures.

the PFR opens and ACARS messages can be sent, to avoid transient failures of some systems because of invalid or out of range parameters being reported during the first engine start with the second engine off line. The consequence of this is that genuine start faults during the first engine start and any for the second engine start within these three minutes are alerted to the crew on the ECAM but are not recorded by the PFR or automatically messaged to the operator.

The PFR for each of the four flights on the day of the serious incident flight are shown in Appendix C. These are the versions of the PFR stored in AIRMAN and include, for completeness, the PFR for the flight from Gatwick to Krakow during which no engine issues were reported.

Operational alerts are neither recorded by the PFR nor messaged to the operator.

```
A/C ID    DATE   GMT   FLTN     CITY PAIR
.G-POWN   26FEB  1324  AWC411W  EGKK EGKK

+---------------------+
:    MAINTENANCE      :         DB/N
: POST FLIGHT REPORT  :     LET4
+---------------------+

A/C ID   DATE    GMT         FLTN       CITY PAIR
.G-POWN  25FEB   2352/0022   AWC411W    EGKK EGKK

WARNING/MAINT.STATUS MESSAGES
-----------------------------
GMT  PH ATA
2353 02 23-00 CIDS 2
2354 02 77-00 ENG 1 FAIL (2)
0011 06 77-00 ENG 2 STALL (3)
0012 06 21-61 AIR PACK 1+2 FAULT

FAILURE MESSAGES
----------------
GMT  PH ATA                               SOURCE   IDENT.
2353 02 23-73-34 DIR2(102RH)               CIDS 2
2355 02 27-93-34 AFS:ELAC2                 AFS
```

Figure 24

Copy of the PFR printout for the event flight with engine No 1 start faults and engine No 2 stall occurrences highlighted

1.11.3.3 Stansted-Gatwick (25 February) – ECAM fault alerts

Time & Flight Phase	ECAM Fault Message	Notes
05:24:45 Eng No 1 start (cycle 1)	ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN	PFR not open - no recording of fault message. The aircraft manufacturer, however, confirmed that the valve had failed to open within the required period following the FADEC command to open.
05:26:28 Eng No 1 start (cycle 1)	ENG 1 HP FUEL VALVE > HP FUEL POS SWT FAULT	The ENG 1 HP FUEL VALVE message was automatically sent via ACARS at 0527 hrs to operator and recorded in the PFR*. The aircraft manufacturer, however, confirmed that as the engine was at idle the cause for the alert was a fault with the valve position switch.

* PFR sent to operator via ACARS at 0602 hrs.

Table 4

ECAM messages for the Stansted-Gatwick flight

1.11.3.4 Krakow-Gatwick (25 February) – ECAM fault alerts

<table>
<tr><th>Time & Flight Phase</th><th>ECAM Fault Message</th><th>Notes</th></tr>
<tr><td>19:53:52
Eng No 1 start
(cycle 1)</td><td>ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN</td><td rowspan="3">PFR not open - no recording of fault message. The aircraft manufacturer, however, confirmed that the valve had failed to open within the required period following the FADEC command to open for the first two alerts.

Crew sent ACARS message at 2032 hrs stating an ENG 1 HP FUEL VALVE fault.

The reason for the third alert is unknown.</td></tr>
<tr><td>19:55:09
Eng No 1 start
(cycle 2)</td><td>ENG 1 HP FUEL VALVE > HP FUEL VALVE NOT OPEN</td></tr>
<tr><td>19:55:14
Eng No 1 start
(cycle 2)</td><td>(reason unknown)</td></tr>
</table>

Time & Flight Phase	ECAM Fault Message	Notes
19:57:17 Eng No 1 start (cycle 3)	ENG 1 START FAULT > ENG 1 STALL	The fault alert was automatically sent via ACARS at 1957 hrs to operator and recorded in the PFR*, but not the triggering condition. For the A321 with CFM56 engines there are six possible triggers of which only three automatically initiate a new start. These are: an EGT over-limit, an ignition fault or an engine stall. The EGT was about 400°C which was below the 725°C over-limit threshold but hot enough for the engine to be ignited; therefore, the only trigger left was a stall condition. This logic was confirmed by the aircraft manufacturer.
21:58:25 FL130	ENG 2 STALL	Automatically sent via ACARS at 2158 hrs to operator and recorded in the PFR*.
21:59:59 FL122	ENG 2 STALL	Recorded in the PFR.*

* PFR sent to operator via ACARS at 2218 hrs.

Table 5

ECAM messages for the Krakow-Gatwick flight

1.11.3.5 Gatwick-Gatwick (25/26 February) – event flight – ECAM fault alerts

Time & Flight Phase	ECAM Fault Message	Notes
23:50:54 Eng No 1 start (cycle 1)	(reason unknown)	PFR not open - no recording of fault alert; however, the crew referred to an ignition fault on the CVR recording.
23:51:11 Eng No 1 start (cycle 1)	ENG 1 START FAULT > ENG 1 IGNITION FAULT	PFR not open - no recording of fault message; however, the crew verbalised the ECAM fault alert and triggering condition (captured by the CVR).

Time & Flight Phase	ECAM Fault Message	Notes
23:51:37 Eng No 1 start (cycle 1)	(reason unknown)	PFR not open - no recording of fault message.
23:54:23 Eng No 1 start (cycle 2)	ENG 1 FAIL	Automatically sent via ACARS at 2354 hrs to operator and recorded in the PFR*.
23:57:33 Eng No 1 start (cycle 3)	ENG 1 FAIL	Recorded in the PFR.*
00:11:09 3,500 ft agl (a/c downwind)	ENG 2 STALL	Automatically sent via ACARS at 0011 hrs to operator and recorded in the PFR*.
00:11:13 3,500 ft agl (a/c downwind)	ENG 2 STALL	Recorded in the PFR.*
00:11:15 3,500 ft agl (a/c downwind)	ENG 2 STALL	Recorded in the PFR.*

* PFR sent to operator via ACARS at 0022 hrs.

Table 6

ECAM messages for the Gatwick-Gatwick event flight

1.12 Aircraft and engine examination

1.12.1 Fuel tanks and engine fuel filters

The left and right wing fuel tanks were drained following the incident, and the tank internal surfaces and components were visually examined. No abnormalities were identified.

The engines' fuel filter and filter bowl fuel samples were analysed. The fuel filters were clean in appearance and generally free from debris, however chemical analysis of the small amount of filter debris present indicated unusually high levels of magnesium, a constituent element present in Kathon.

1.12.2 Engines

The aircraft's engines were subjected to an initial borescope visual examination on the day after the incident flight. Both engines exhibited similar findings. There was no significant damage evident to the fan, LP compressor or HP compressor, and any minor defects that were observed were stated to be within AMM damage limits. However, the combustion chambers, and the HPT and LPT blades were coated in a thin layer of white material that was observed on the turbine blades' convex surfaces (Figure 25). The HPT nozzle guide vanes were also coated in the white material. As the engines were not disassembled, it was not possible to obtain a sample of the white material.

Figure 25

White material deposits on No 2 engine combustion chamber and HPT blades observed during initial borescope inspection (No 1 engine similar)

A second borescope inspection was carried out four months after the incident, following a delay due to Covid-19 restrictions. The purpose of this second inspection was to document the visual condition of the engines prior to their repair and return to service.

The inspection of the No 1 engine did not reveal any damage beyond AMM limits. Inspection of the No 2 engine identified that 16 blades of the Stage 3 HP compressor had smooth impact depressions on the blade root radius outside AMM damage limits. In addition, one Stage 7 HP compressor blade also had an impact mark at the blade root radius outside AMM damage limits. It is not known whether this damage was present before the incident flight.

The white deposits observed during the initial borescope inspections were not evident in the second borescope inspections. The areas where the white deposits had been observed were now covered in a thin layer of crystalline material of a dendritic appearance (Figure 26). It was concluded that the white deposits observed during the initial borescope inspection had, over the intervening four-month period, been dissolved into water that had condensed onto the internal engine surfaces. The white material had then reformed into the dendritic crystalline pattern as the water subsequently evaporated.

Figure 26

Dendritic crystalline surface deposit on engine No 2 LPT

Both borescope inspections revealed that significant deposits of a brown material were present on all the combustion chamber swirl cups, adjacent to the fuel spray nozzles, in both engines (Figures 27 and 28).

Figure 27

Brown material deposits in No 2 engine combustion chamber swirl cups observed during initial borescope inspection

The igniter plugs from each engine were removed and visually examined. No abnormalities were noted and there was no significant difference in appearance between those from the No 1 and No 2 engines.

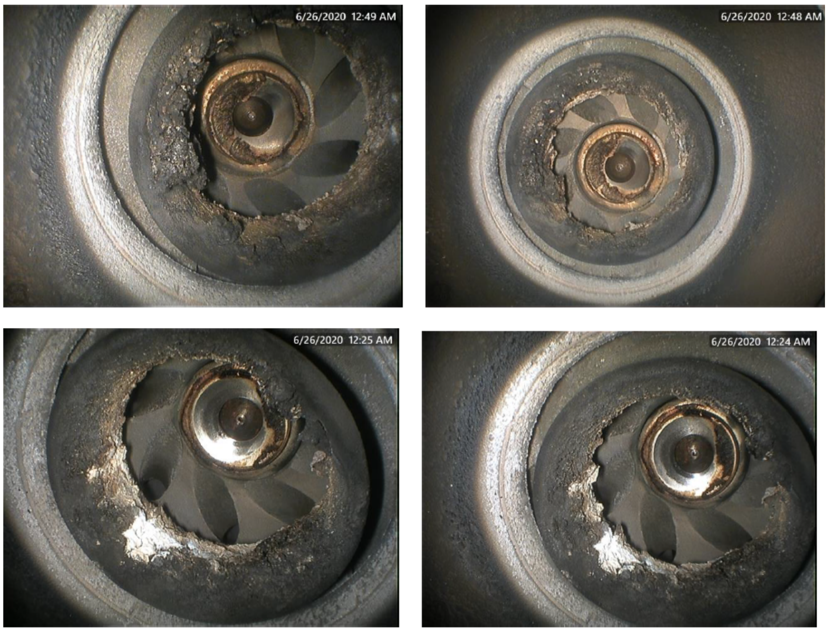


Figure 28

Brown/black material deposits in No 1 engine combustion chamber swirl cups observed during second borescope inspection

1.12.3 Hydro Mechanical Unit examinations

The HMUs were removed from their respective engines and were sent to the manufacturer for disassembly and examination. The units were protected for shipment by capping open apertures, but no inhibiting treatments were applied, to avoid contamination of any trace evidence.

1.12.3.1 HMU from No 1 engine

The examination of the HMU from the No 1 engine took place six weeks after the incident flight. Approximately 100 ml of clear fuel was drained from the unit and was subsequently laboratory tested.

The HMU drive did not readily rotate when checked, and no torque check was attempted in order to prevent further damage to the unit. The unit was disassembled, and a few areas of a viscous, gelatinous substance were observed within (Figure 29).

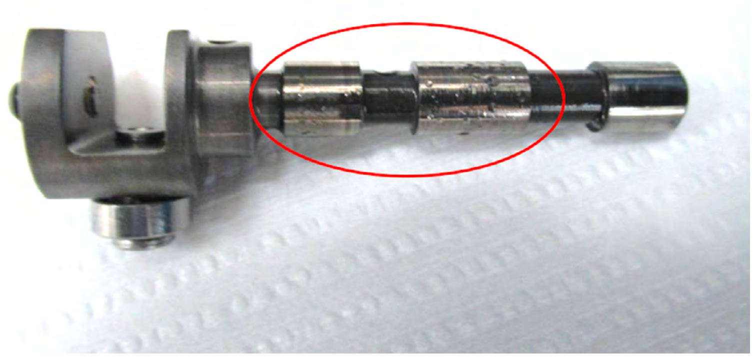


Figure 29

Gelatinous residue (circled in red) on VBV pilot valve
(courtesy Woodward)

The colour of this residue varied between clear to very light yellow. Increased friction above what was considered normal was noted between almost all moving parts. The Delta P valve was seized and its drive pin was observed to be fractured (Figure 30).

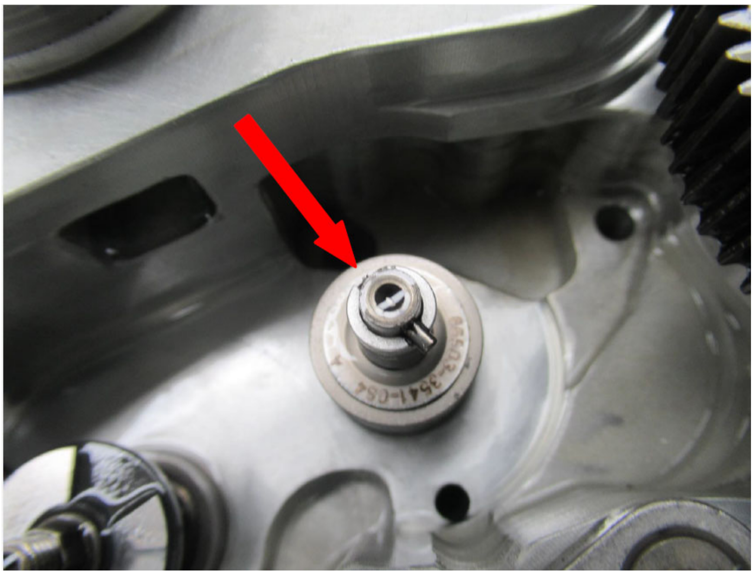


Figure 30

Fractured Delta P valve drive pin
(courtesy Woodward)

The buffer piston was stuck in position and was freed by soaking in deionised water. The pressurising valve piston and shut-off piston were stuck in position and pried free. The control pressure (PC) and control pressure return (PCR) regulators were also stuck in position and were removed after soaking in an aqueous cleaning solution. The VSV and VBV pistons were pried loose to remove them from the unit.

Once these stuck components were removed, the remaining parts within the HMU moved freely.

1.12.3.2 HMU from No 2 engine

The examination of the HMU from No 2 engine took place four weeks after the incident flight. Approximately 50 ml of clear fuel was drained from the unit and was subsequently laboratory tested.

Torque required to rotate the HMU drive was 5.5 in lb. This was considerably in excess of the normal torque level, which is less than 0.5 in lb. The unit was disassembled and it was noted that areas of viscous, gelatinous deposits were present throughout the unit (Figures 31 and 32 show typical examples). The colour of these deposits varied from clear, through light orange to a dark rust colour. The drier the deposits were, the darker the appearance and the more difficult they were to remove. The residue was water-soluble.

Increased friction above what is considered normal was noted between almost all the moving parts within the HMU. The Delta P pilot valve was seized and its drive pin was broken.

The buffer piston was stuck in position and was freed by soaking in deionised water. The PC and PCR regulators were also stuck in position and were removed after soaking in an aqueous cleaning solution. The VSV and VBV valve pistons were pried loose to remove them from the unit.

Once these stuck components were removed, the remaining parts within the HMU moved freely.

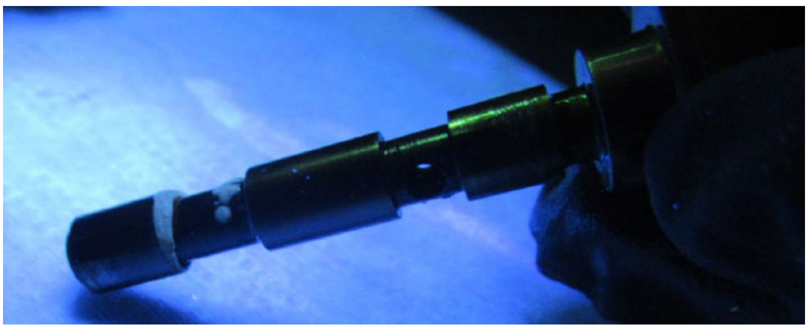


Figure 31

VBV pilot valve first-stage deposits under ultraviolet light
(courtesy Woodward)

Figure 32

Brown, sticky deposits on low-pressure turbine case control turbine clearance valve (courtesy Woodward)

1.12.4 Analysis of deposits found within the HMUs

The sticky brown residue found on the FMV, VBV and VSV valves from both HMUs was analysed. Infra-red analysis showed the presence of a mixture of dipropylene glycol, nitrate salt and water. This chemical signature is consistent with the chemical composition of Kathon biocide.

Analysis of the water-soluble compounds on the surface of the FMV, VBV, VSV, and Delta P valve spools showed the presence of high levels of nitrate, magnesium and chloride along with lower levels of sulphate and sodium. The relative ratio of nitrate, magnesium and chloride found on the valves matched the ratios in Kathon biocide.

Corrosion was observed on the FMV, VBV and VSV valve sleeves but minimal corrosion was present on the spools.

Fuel samples from both HMUs contained higher than typical levels of the Kathon components including the active ingredients 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one, and the dipropylene glycol solvent. Fuel sampled from the No 1 engine's HMU contained Kathon at a concentration by volume of approximately 450 ppm, and fuel sampled from the No 2 engine's HMU contained Kathon at a concentration of approximately 850 ppm by volume.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

No sustained fire occurred during the incident.

1.15 Crashworthiness

Not applicable.

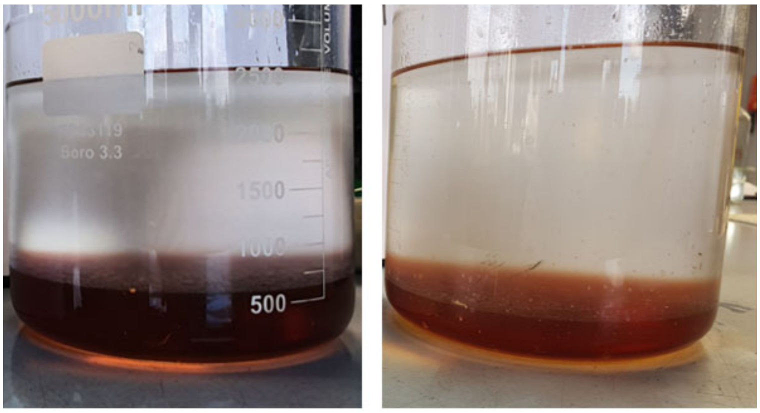
1.16 Tests and research

1.16.1 Fuel samples

Following the serious incident, fuel samples were taken from the left and right wing fuel tank water drain valves and were subjected to laboratory analysis. When the fuel was tested it was found not to comply with the Jet A-1 specification requirements[53] for appearance and water separation characteristics (MSEP[54]). The fuel samples, once the contents had settled out under gravity, contained a separate brown liquid layer beneath the main fuel layer (Figure 33). Trace element results of the fuel and the bottom brown layer showed similar spectra to a reference Kathon sample, but with a higher water content. The laboratory that conducted the fuel testing commented that:

> *'The results indicate contamination with undissolved Kathon. It was noted that the bottom layer that is mostly Kathon plus some unknown products and water, suspected to be causing the darker colour than the reference Kathon sample. This is likely due to the glycol type solvent used in Kathon dissolving polar materials from the fuel and fuel tank surfaces. This may be analogous to observations with another similar glycol additive, FSII (Fuel System Icing Inhibitor), which is used in military jet fuels. It is colourless but forms a brown additive/water layer in tank bottoms.'*

53 DEF STAN 91-091 Issue 11 and AFQRJOS Check List Issue 31.
54 Water Separator Index Modified (MSEP).



Left wing tank **Right wing tank**

Figure 33

Fuel samples drained from left and right wing fuel tanks

1.16.2 Part-145 AMO survey

1.16.2.1 Method

A questionnaire (Appendix B) was developed to identify general practices relating to the aircraft biocide dosing task and use of the Airbus TSM across a wide range of AMOs. The questionnaire was sent to UK and French EASA Part-145 Approved Maintenance Organisations and 21 substantive responses were received. The questionnaire was split into three sections:(1) The biocide dosing task, (2) Use of the Airbus TSM and (3) Response taken to the G-POWN event and AAIB Special Bulletin S1/2020. The following is a summary of the responses received.

1.16.2.2 Findings - Fuel biocide dosing task

Responses were received from AMOs that performed biocide dosing on a wide range of commercial aircraft and rotorcraft. Not all AMOs who responded to the AAIB questionnaire reported performing biocide treatments.

The number of biocide dosings carried out varied widely between AMOs, with the highest average number during the period 2017-19 inclusive being 251 per year across that AMO's global service network. Two other AMOs reported exceeding an average of 10 dosings per year over the period, whereas over half the responding AMOs performed seven per year or fewer over the period, indicating that the task is generally not a routine or common procedure. It was not possible to normalise the number of biocide treatments against the size of the fleets treated, due to lack of data.

Biocide dosing using a metered injection rig was more common than manual dosing, although two of the five AMOs performing the highest number of dosings used manual dosing. Of the AMOs that reported applying biocide manually, only two responded that they used an external fuel tank or bowser to mix the biocide with fuel, whereas five AMOs stated that they applied biocide directly to aircraft fuel tanks. As the variety of aircraft types treated was broad, it was not determined whether direct application of biocide to aircraft fuel tanks was an approved AMM method in all cases.

It was found to be more common for the dosing task to be completed by a Part-66 B1 licensed engineer alone, rather than a mechanic acting under the oversight of a B1 LAE.

Some AMOs have technical support for performing the calculation of biocide quantity required, or an independent check, but this was not a universal safeguard. Four AMOs classified the dosing task as a critical maintenance task, in accordance with EASA Part M.A.402(h), but most AMOs did not.

Most AMOs did not have specific training for the biocide dosing task and those who responded positively mainly referred to the training instructions for the metered injection rigs.

Only one AMO described a stores process that limited the issue of biocide to a maximum amount (of 10 x 0.5 kg bottles). Other safeguards involved checking the biocide quantity to be used with the Chief Engineer or Team Leader.

No AMOs reported previous incidents or errors involving incorrect biocide dosing. Two AMOs stated that familiarity with the metered injection rig was essential. One stated that care had to be taken in its use as the required rig setting was at the low end of the operational range, and the other commented on the possibility of mixing up dosing rates between ppm/vol and ppm/weight. Overall, the questionnaire shows that the Base AMO in the G-POWN investigation was typical of other AMOs that perform this task infrequently, in terms of process and procedure.

1.16.2.3 Findings - Airbus troubleshooting manual

The questionnaire responses indicated that AirN@v and airnav^{X} were used by an equal number of organisations. Of these two applications, a few organisations used both, but it was more common to use one or the other. Most organisations did not have a company policy or specific training that defined how to search the TSM for the right procedure. The responses indicated that most AMOs relied on engineers to do as taught during type training.

According to the responses, all of the different methods to access the TSM were used on both AirN@v and airnav[X]. Only one AMO reported they solely used the application as recommended by the manufacturer. A few reported that they used the recommended method but also used other methods to access information. The remainder did not use the recommended method at all.

1.16.2.4 Findings - response to the G-POWN Serious Incident

Almost all the responding AMOs stated that they were aware of the G-POWN event and had read AAIB Special Bulletin S1/2020. Most AMOs, by a ratio of 3:1, intended to take safety action based on S1/2020 and these included improving existing procedures, independent checks on biocide dosages and communicating the safety messages to staff. Almost all of the safety action reported related to biocide dosing. It was noted that while the biocide dosing issue had prompted safety actions, the use of the TSM had prompted almost none.

1.16.3 Part-145 AMO visits

The AAIB visited three UK Part-145 AMOs that perform biocide treatments and troubleshooting activity on Airbus aircraft, to collect more detailed information on normal practice in AMOs.

1.16.3.1 Biocide treatment

Two of the AMOs visited performed biocide treatments regularly, with the frequency of the task having increased as aircraft were stored during the coronavirus related reduction in flying activity. All three AMOs applied the biocide using a metered injection rig, and the two AMOs that performed the activity regularly had developed error-capturing measures for the task. These included cross-checking of the biocide dosing calculation by other maintenance engineers and the AMOs' Technical Services department, and by the introduction of bespoke spreadsheet calculators to control the way in which the required biocide concentration is determined.

Two of the AMOs had identified that the dosing setting of the metered injection rig was potentially prone to error. They had established a procedure where the dosing rate for an initial quantity of fuel (one AMO used 500 kg, the other 500 ltr) was checked by comparing this fuel quantity to the amount of biocide consumed, prior to completing the biocide dosing task.

The AMOs had noted that the metered injection rigs were typically set to deliver a maximum concentration of approximately 400 ppm/vol, which while preventing a gross overdose, still provided the possibility of allowing an excessive biocide concentration if the rig had not been set properly prior to its use.

Use of the metered injection rig was not restricted to particular individuals, and any LAE, once shown how to use the rig by an experienced user, was expected to be able to do so thereafter.

1.16.3.2 Airbus troubleshooting

During the visits, the AAIB spoke to a sample of typical LAEs about how they approached troubleshooting for Airbus aircraft. The engineers were asked to describe how they would use the PFR and navigate the TSM using the maintenance data application used at their AMO. Some of the engineers' descriptions matched the manufacturer's recommended method of searching and others did not. When told about the manufacturer's recommended method, some of the engineers expressed surprise and stated they had never been taught this. Most of the engineers reported that they would generally expect to find the appropriate troubleshooting procedure in the chapter with the same ATA number as the fault on the PFR but that this was not always the case.

1.17 Organisational and management information

1.17.1 Base AMO

The Base AMO was a relatively new organisation operating from a hangar that had been vacated by the previous operator. One engineer described how the hangar was "like a bare shop" during a visit in August 2019 but by November 2019 there was much more equipment. Several engineers who were interviewed reported that the organisation had a lack of tools in general and were building up their equipment and renting tools where needed.

Several engineers commented that they felt that the amount of work that the Base AMO was contracted to do was too high for its capacity in terms of space, tooling and people. One engineer stated that the Base AMO had capacity for a maximum of two aircraft and during the period when they were working on G-POWN there were six or seven aircraft being worked on.

The operator observed inadequate document control at the Base AMO during a visit when G-POWN was being worked on and raised a safety report on 21 February 2020 for '*Unrecorded maintenance during base input*'.

The AAIB visited the Base AMO and observed the environment and processes there. There was evidence that workload in the planning department was very high and there was not enough space in the planning office to keep work packs well organised. The stores were well controlled with access to records on the issue of all chemicals, but no process was in place to limit the quantity of any chemical that could be issued to an engineer. There was no formal engineering technical support role or department within the organisation. Any engineer that required advice asked for it from colleagues or the maintenance manager.

1.17.2 Substitution test performed by the Line AMO

As part of the Line AMO's internal investigation, an investigator gave five other engineers from the organisation the same engine fault scenario that the line engineer faced. Four of the five engineers attempted to use airnav^{X} first and reverted to AirN@v when this was not possible. Three of the five engineers retrieved the correct maintenance task. One of these three used the '*Start Troubleshooting*' function to search, the other two used the chapter list. Both engineers who did not find the correct procedure browsed Chapter 77 of the TSM. One, who had not filtered the data according to aircraft effectivity, found the task 77-11-00-810-815-A *Stall Above Idle on Engine 1 (2)* for the CFM LEAP-1A engine and appeared to believe this was the correct procedure.

1.17.3 Engineer type training and competency assessment at the Line AMO

Most of the line engineer's recent type training was conducted by the EASA Part-147 maintenance training organisation associated with the Line AMO. The line engineer's most recent type rating training was in November 2017 for Airbus A320 Family fitted with the CFM LEAP-1A engine. His most recent competency assessment was in January 2020. Records from both the training and the competency assessment showed no issues or concerns with any aspect of the line engineer's performance.

Troubleshooting formed a high proportion of the Airbus type courses at the Line AMO's maintenance training organisation. It was assessed in terms of whether the trainees navigated to the correct procedures and understood how to use them. It was not assessed in terms of the specific method the trainees used to search for the procedures. The AirN@v and airnav^{X} applications were both used during engineer type courses, but the syllabi did not specifically include how to search for troubleshooting procedures.

The Line AMO's competency assessment criteria included the ability to find the correct maintenance data and the method by which it was accessed:

> *'By reference to the behavioural indicators and guidance below, document objective evidence that the individual found and referred to the correct maintenance data, pertinent to the task and effectivity of the aircraft. The summary should contain the precise maintenance data reference and how this was accessed.'*

Factual Information

The records from the line engineer's most recent competency assessment on 16 January 2020 confirmed that the engineer could gain access to the Airbus online maintenance data applications but did not document evidence of his method of navigation of them or confirm the maintenance data printed was correct for the task and had the correct effectivity. The station manager that performed this competency assessment was aware of the manufacturer's recommended method of searching the TSM.

1.17.4 Engineer type training at the aircraft manufacturer

The teaching objectives of the manufacturer's Part-147 approved courses for B1 and B2 certifying technicians explicitly included:

- *'Selection of A/C effectivity'*
- *'Difference in-between Start Troubleshooting and TSM'*
- *'Start Troubleshooting concept (Tech log and PFR usage)'*
- *'Pattern search (Start Troubleshooting function)'*

The training materials included visual references showing the relevant interface features of the AirN@v system and the sequence of actions required to correctly search for a procedure in the TSM (Figure 34).

Figure 34

Example of manufacturer's training material relating to method of using the TSM (Courtesy Airbus)

1.17.5 Help functions within the maintenance data applications

The AAIB found two relevant items within the help centre of airnav^{X}, '*Troubleshooting philosophy'* and a video entitled '*How to troubleshoot.'* The '*Troubleshooting philosophy'* document explained that the TSM can be accessed through the '*My library'* tab or the '*Troubleshooting*' tab (Figure 35). The video provided a worked demonstration of using the search via the '*Troubleshooting'* tab (ie the manufacturer's recommended method of doing the task).

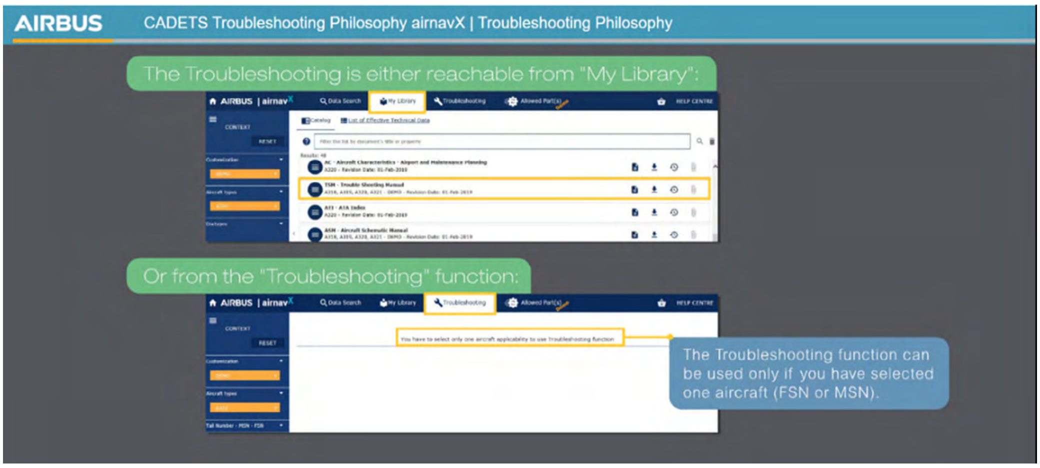


Figure 35

Screenshot from 'Troubleshooting philosophy' document in the Help Centre within airnav^{X} (Courtesy Airbus)

There are no specific instructions or training materials for using AirN@v built into the application itself. The help function within AirN@v links to a content library in AIRBUS World and this includes some e-learning resources for AirN@v.

1.17.6 Regulatory requirements and oversight of engineer type training

Aircraft engineer training and licensing is governed by '*COMMISSION REGULATION (EU) No 1321/2014 of 26 November 2014 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks'.* Specifically, Annex III (Part-66) covers aircraft maintenance licences and Annex IV (Part-147) covers maintenance training organisations.

Organisations that provide training and examination for Part-66 licensed engineers must meet the requirements of Part-147. The Competent Authority inspects candidate Part-147 maintenance training organisations and issues approvals if the requirements are met. Approved Part-147 maintenance training organisations must be audited at least every two years, including monitoring of at least one training course and one exam. The Competent

Authority for assessing Part-147 maintenance training organisations based in the UK is the CAA.

A requirement of Part-147 is that aircraft type training course content for LAEs is to comply with Part-66. Concerning maintenance documentation it also requires '*Students shall have access to examples of maintenance documentation and technical information'* (147.A.120).

Appendix III to Part-66 defines aircraft type training and examination standards. It states one of the objectives of engineer type training for a B1 aeroplanes turbine licence is to '*demonstrate the use, interpret and apply appropriate documentation including structural repair manual, troubleshooting manual, etc.'*

Appendix III to the Acceptable Means of Compliance (AMC) of Part-66 provides additional detail on competence assessment in relation to the use of aircraft documentation. It states the assessment should include: '*Aircraft documentation finding and handling (identify the appropriate aircraft documentation, navigate, execute and obey the prescribed maintenance procedures)'.*

The AMC to point 3.1(d) of Appendix III to Part-66 concerns the use of Training Needs Analysis (TNA)[55] and states that the purpose of the analysis is: '*to adapt and justify the duration of the course for a specific aircraft type.*' It also states: '*The content and the duration deriving from this TNA may be supported by an analysis from the Type Certificate holder.'* The TNA should identify all the areas where there is a need for training, '*considering the design philosophy of the aircraft type,'* among other factors. The AMC lists areas that the TNA should address, which includes '*Use of maintenance publications.'* The AMC states that the TNA should be reviewed or updated based on operational feedback, information about maintenance occurrences and other changes.

The CAA stated that Part-147 maintenance training organisations must submit a declaration of what will be taught and to what level and this is assessed by the CAA to check it meets requirements and is comprehensive. The audit process for maintenance training organisations uses a sampling strategy and depends on availability of course(s) at the time of the audit. The audit criteria are based on the requirements of Part-147 and Part-66. These requirements are not detailed at the level of individual aircraft types or the exact content of

55 Training needs analysis is a process where the knowledge and skills required for a job role are identified and compared to the current skill and knowledge of potential trainees or existing staff who will undertake the role. The gap between the required knowledge and skills and the current knowledge and skills defines the content of training. Training needs analysis often considers the frequency of use, importance and difficulty of each knowledge and skill element to determine the proportion of time to allocate and training method for each.

training on the use of maintenance data. Audits last approximately three hours and must be unobtrusive to the training process. The CAA explained that these practicalities mean that it would be unlikely to identify whether a training course included the manufacturer's recommended method of using the Airbus maintenance data applications (AirN@v or airnav[X]) for troubleshooting or not.

1.17.7 Operational Suitability Data

Commission Regulation (EU) No 69/2014 of 27 January 2014 introduced the requirement of Operational Suitability Data (OSD) to Annex I (Part-21) to Regulation (EU) No 748/2012. This requirement is applicable to aircraft Type Certificate (TC) holders (and holders of supplemental type certificates (STC)) where they must produce certain data considered important for the safe operation of the aircraft. The OSD becomes the reference for customised training courses and Minimum Equipment Lists. It consists of five elements:

1. Master Minimum Equipment List.
2. Data for training pilots.
3. Data for training cabin crew.
4. Data for training maintenance personnel.
5. Data for the qualification of simulators.

All new type certificates issued after 2016 and changes to an existing TC (or STC) must include the relevant OSD. The requirement to produce OSD for pilots and cabin crew has been defined in the relevant Certification Specifications, but the specific requirements for maintenance staff are still under development.

1.17.8 Critical Maintenance Tasks

Critical maintenance tasks are identified within EASA Part M, which contains continued airworthiness regulations, and also EASA Part-145, which contains maintenance organisation approval regulations.

EASA Part M.A.402(h), *'Performance of maintenance'*, requires that critical maintenance tasks are identified and that an error-capturing method is implemented after the completion of any such task. AMC1 M.A.402(h) provides a list of maintenance tasks that should be reviewed to assess their impact on safety – and therefore whether they should be considered as critical tasks – including *'tasks that may affect the propulsive force of the aircraft, including installation of aircraft engines, propellers and rotors'*. The addition of biocide treatments to an aircraft's fuel system is not specifically identified as a critical maintenance task. The associated guidance material for M.A.402(h) provides a list of data sources that may be used for the identification of critical maintenance tasks. This list includes accident reports and the investigation and follow-up of incidents.

EASA Part-145.A.48(b), *'Performance of maintenance'*, also requires that an error-capturing method is implemented after the completion of any critical maintenance task. AMC1 145.A.48(b) states that the maintenance procedure should identify the error-capturing methods, the critical maintenance tasks, the training and qualification of staff applying the error-capturing methods and how the organisation ensures that its staff is familiar with critical maintenance tasks and error-capturing methods.

AMC2 145.A.48(b) provides a list of maintenance tasks that should be reviewed to assess their impact on flight safety, including *'tasks that may affect the propulsive force of the aircraft, including installation of aircraft engines, propellers and rotors'*. As with M.A.402(h), the addition of biocide treatments to an aircraft's fuel system is not specifically identified as a critical maintenance task. AMC4 145.A.48(b) states that independent inspection is one possible error-capturing method.

1.17.9 Regulatory oversight

The EASA, as a Competent Authority, exercises direct regulatory oversight of EASA-approved AMOs and Continuous Airworthiness Management Organisations (CAMO) that are located outside EASA Member States[56]. This regulatory function includes the initial assessment and issue of AMO and CAMO organisational approvals, and the auditing of these organisations to assess their level of compliance with EASA Part M and Part-145 regulations.

Regulatory oversight of AMOs and CAMOs within individual EASA Member States is the responsibility of the National Aviation Authority (NAA) of each Member State. The NAAs conduct compliance audits and EASA is responsible for standardisation across these NAAs to ensure that EASA regulations are implemented in a consistent manner.

1.18 Additional information

1.18.1 Fuel quantity records and maximum possible Kathon concentration

Records of the fuel uplifts, transfers between tanks and recorded fuel-on-board figures at the start and end of each flight sector were analysed to produce the data presented in Figure 36.

56 EASA Member States are the Member States of the European Union, and Liechtenstein, Norway, Switzerland and Iceland.

Research[57] has shown that dipropylene glycol, which forms 90% of the Kathon product, is soluble in Jet A fuel up to limiting values of between 6,600 ppm/vol at 5°C and 11,000 ppm/vol at 22°C. Figure 36 also shows the maximum Kathon concentration, in ppm/vol, if all the Kathon added during the biocide treatment had been fully mixed in the fuel.

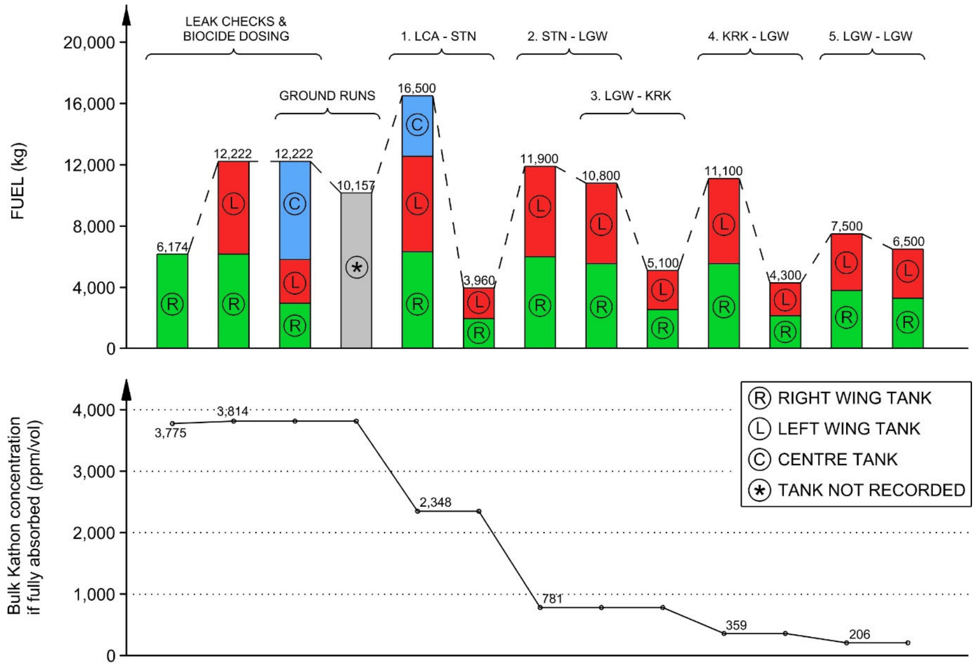


Figure 36

Fuel quantity records and maximum possible Kathon concentration if it had been fully mixed

1.18.2 Other incidents caused by suspected Kathon overdoses

On 28 March 2009, a Eurocopter EC135T2 helicopter, registration JA135E, suffered a left engine failure resulting in a diversion and safe landing. The investigation report[58] identified clogged fuel injectors in part of the left engine combustion chamber which resulted in engine damage. The investigation noted that improper use of Kathon biocide was a probable cause of the incident.

On 29 March 2019, a Boeing 787-9, registration VH-VKJ, experienced an uncommanded reduction in the left engine speed to below idle during descent to Kansai International Airport, Japan. After the left engine had recovered, a similar uncommanded reduction in the right engine speed also occurred, before it also recovered, following which a safe landing was made. The investigation

57 Williams T. M. and Reynolds D. G. (2002), *Partitioning and Solubility of Kathon FP1.5 Biocide in DPG and Jet A*, Rohm and Haas Company.

58 Japan Transport Safety Board (2013), Aircraft Serious Incident Investigation Report AI2013-3.

report[59] concluded that the engine problems were probably caused by their ingestion of fuel containing Kathon in excess of the maximum permitted concentration level of 100 ppm/vol.

The AAIB requested a Mandatory Occurrence Report (MOR) data release from the UK CAA for any events where an engineer or mechanic had incorrectly calculated a chemical quantity. The CAA searched for events reported after 1 January 2017 up to the date of the search involving aircraft with a mass greater than 5,700 Kg. No relevant events were found.

1.18.3 Previous incident relating to incorrect use of maintenance data

G-BXKD[60], an Airbus A320-214, had a hard landing on 15 November 2006 which caused severe internal damage to the landing gear. The damage to the landing gear was not detected during two subsequent maintenance checks and the aircraft made two further flights where PANs were declared due to problems with the landing gear.

Part of the reason the damage was not detected was that an engineer, using the AirN@v system, selected and carried out an incorrect procedure from the AMM. The procedure had the correct effectivity, but the engineer did not find a later, more up to date, version of the task that was required due to a SB that had been implemented on the aircraft. The investigation found issues relating to training on AirN@v and the design of the application. The investigation commented:

> *'Modern aircraft, such as the A320, have complex systems and the maintenance manuals for such systems, which are provided electronically, can be just as complex, particularly when various SBs and variations in equipment are incorporated within an operator's fleet. Therefore, adequate training in the use of these documents is essential to the continued safe operation of the aircraft'.*

The AAIB requested an MOR data release from the UK CAA for any events where an engineer had retrieved the wrong procedure for a maintenance task from an electronic maintenance manual. The CAA searched for events reported after 1 January 2017 up to the date of the search involving aircraft with a mass greater than 5,700 Kg. No relevant events were found.

59 Japan Transport Safety Board (2020), Aircraft Serious Incident Investigation Report AI2020-2.
60 Air Accidents Investigation Branch (2008). Aircraft Accident Report 4/2008. *Report on the incident to Airbus A320-214, registration G-BXKD at Runway 09, Bristol Airport on 15 November 2006*. https://assets.publishing.service.gov.uk/media/5422ec5140f0b613420000ef/4-2008_G-BXKD.pdf [accessed November 2020].

1.18.4 Additional information from Crews A and B

Commander A reported that prior to this serious incident he had experienced around five engine start abnormalities while operating. All but one had resulted in a successful start during the second start cycle.

Commander B had previously experienced an engine stall in flight on the same aircraft type, causing him to divert to a nearby airfield.

Commander A stated he could not recall the nature of the first unrecorded ECAM alert during starting engine No 1 in Stansted. He felt confident he would remember anything significant, and suggested it was a transient navigation-related alert, known to occur on aircraft coming out of the hangar.

After landing in Gatwick, Crew B highlighted to Crew A that the starting problems on engine No 1 could have led to "confirmation bias"[61] that the transient ECAM messages in flight were also associated with that engine, rather than engine No 2. Crew A included that in their threat and error management[62] briefing prior to departure, and subsequently commented that they were particularly careful during the incident to diagnose the failures correctly.

Commander A reflected that after his final telephone call with Technical Control prior to taxiing on the incident flight, both engines were running normally with no open ECAM messages. Therefore, there seemed "no tangible reason" not to depart.

Commander A stated that during the incident he moved engine No 1's thrust lever to idle because the "violent swing" made him feel unwell, and to stop the surging. He considered referring to the *'ALL ENG FAIL'* QRH procedure but instead prioritised flying a prompt and accurate approach. Both of Crew A cited their effective teamwork as assisting their management of the incident.

1.18.5 Additional information from cabin crew

A number of cabin crew indicated that Commander A thoroughly discussed the aircraft's technical status with them prior to departing on the incident flight. The SCCM briefed her team that should they notice anything abnormal during the flight, they should phone the flight crew directly and immediately from their allocated crew seat.

61 Confirmation bias – a selective process that favours information relevant to the presently held view.
62 The practice of thinking ahead in order to predict and avoid operational threats and errors, and to manage any that occur.

The SCCM reported that during the incident she suspected that a number of cabin crew were trying to contact Crew A and was unsure of the status of overall communications. The interphone system's architecture requires the flight crew to "open the line" of communication after receiving a call from the cabin. Previously, the SCCM had experienced situations where she "couldn't hear", for example, if someone picked up a handset too soon. Also, calls occurring within the cabin could prevent receiving a call from the flight deck. Commander A issued the emergency call to the cabin. The interphone line was not "open" so in case it would assist communication, the SCCM requested entry to the flight deck. Commander A approved her entry, calling over his shoulder that they were returning to Gatwick. She initiated relevant communications and procedures with the rest of the cabin crew.

1.18.6 Additional information about operational procedures

The operator's Operations Manual Part A described the procedure for flight crew requiring third-party engineering input. It stated:

> *'…the first contact by Flight Crew with any form of engineering must be via… Tech Control. Tech Control need to task … or liaise directly with third part engineers … Where third parties have been tasked, it is important that crew liaise with … Tech Control post any rectification work prior to departing to ensure all procedures are finalised.'*

Commander A stated that he habitually used the decision-making tool, *'T-DODAR'*[63], when operating. It stands for:

- T – Time available to make the decision
- D – Diagnose the problem
- O – Options (generate)
- D – Decide which option
- A – Assign tasks
- R – Review

1.18.7 Additional information from the operator

The operator released a notice to its aircrew soon after the incident. Based on the information it had available, it stated Crew A *'followed operational procedures'*, and demonstrated *'excellent'* performance.

63 A model commonly used in airline operations.

The operator and Crew A were keen for the G-POWN serious incident to be studied in its subsequent crew resource management (CRM) recurrent training package for mixed groups of flight crew and cabin crew. That began in September 2020.

The operator stated that its own investigation into the event raised an important learning point relating to the management of incoming fault messages by Technical Control. It stated that it had encouraged its engineers to think carefully about which questions to ask flight crew regarding an aircraft's serviceability before necessarily referencing incoming information to a maintenance task. An information management exercise based on the G-POWN incident was included in its engineers' recurrent continuation training, and relevant detail was specified in its safety management system.

Intentionally left blank

2 Analysis

This serious incident occurred because a miscalculation of the required concentration of Kathon biocide led to an overdose of biocide to the aircraft's fuel system during scheduled maintenance. The biocide was added via the overwing refuel aperture with the expectation that it would mix with fuel within G-POWN's fuel tanks, but the intention of the AMM task was that the biocide should have been mixed with fuel before the fuel was uplifted to the aircraft.

The discussion below considers the following themes:

1. How the biocide overdose caused the engines to perform abnormally.
2. How the crews dealt with the engine abnormalities.
3. Why there was an overdose of the aircraft's fuel system.
4. Why troubleshooting to investigate the engine No 2 stall message did not prevent the aircraft departing on the incident flight.

2.1 Effect of the biocide overdose on the aircraft

Examination of the HMUs from both engines confirmed the presence of Kathon biocide residues within all of the fuel-wetted components of the HMUs. These residues were jelly-like deposits and crystalline deposits, both consisting of magnesium salts which form part of the Kathon product. Fuel samples taken from the HMUs showed that the concentration of Kathon in the fuel within the HMUs was significantly above the AMM limit of 100 ppm by volume. It was also significantly higher than would be expected if all the Kathon added during the biocide treatment had been initially fully dissolved in the fuel, and then further diluted by the subsequent fuel uplifts prior to the incident flight. The lack of complete mixing between the Kathon and fuel was further illustrated by the presence of a Kathon-rich layer within the bottom of each wing fuel tank, detected when samples were taken from the fuel tank water drains shortly after the event.

Many of the HMU internal components were found to be seized in position when the HMUs were disassembled for examination. It was not possible to conclude whether this condition was completely representative of the HMUs during engine operation. This was due to the possibility of evaporation of fuel, leaving sticky Kathon residue between HMU components, and by corrosion forming in the period between HMU removal and examination. It was considered likely, however, that the broken Delta P valve drive pins were fractured due to the Delta P valves sticking while being driven, when the engines were running, indicating that high friction levels were present within the HMUs during engine operation.

Correct HMU regulation of the engines relies on the flow of clean fuel, pressure-regulated to specific operating pressures, to the HMU control valves. This pressure-regulated fuel is used to control the movement of pilot valves in the VSV and VBV regulator valves, which in turn position their flow control valves to move the fuel-powered VSV and VBV actuators within the engines. The pressurised fuel is also similarly used to control the single-stage flow control valves in the TBV, HPTCC and LPTCC control valves. The pilot valve and flow control valve spools have very small radial clearances to their mating valve bores and the presence of any foreign objects, including jelly-like deposits, could result in increased friction levels between these moving parts. This could affect the ability of the HMUs to correctly regulate the engines.

The regulation of fuel within the HMU to certain regulated pressures is controlled by the PC and PCR pressure-regulators, which function by movement of a piston within a ported valve body against the action of a spring. Any increased friction between the piston and valve body could also affect the corresponding regulated fuel pressure, and therefore the subsequent operation of HMU components that derive their positions by exposure to this pressure-regulated fuel.

As the position of the HMU control valves and fuel-powered actuators was not recorded, it was not possible to state the exact cause of the No 1 engine surges and the No 2 engine stalls. The HPSOV position was recorded and the analysis of the No 1 engine start failures showed that the HPSOV was moving erratically during the engine start sequence. This is an indication of the FMV closing to a minimum position during the start while not commanded to do so by the engine master lever or ECU. A further indication of disturbance of the engine control is shown by the erratic fuel flow behaviour after engine start, while the thrust levers were in a fixed position, which resulted in corresponding oscillations of the N_2 engine core speed.

Aside from the problems noted within the HMUs, no additional negative effects were identified within the aircraft's fuel system from the excessive Kathon dosing. The fuel system filters were not blocked, and no damage was observed within the wing fuel tanks when they were visually examined.

The white material observed on the surfaces of the combustion chambers and LP and HP turbine stages was considered most likely to be magnesium salt deposits, although a sample was not obtained for chemical analysis. It was observed that the white deposits had changed in appearance from a granular surface deposit into a dendritic surface pattern in the period between the first and second borescope inspections, when the engines were in storage. Magnesium salts are a constituent part of the Kathon product and are soluble in water. It is likely that the change in appearance of the white deposits was due to them having been affected by condensation during the storage period. The chemical composition of the brown residue present on the fuel spray nozzles and swirl cups was not identified but is considered likely to be a residue of Kathon that did not fully burn in the combustion chamber. There was no evidence of damage due to an uneven combustion flame pattern within the combustion chamber or turbine stages.

2.2 Operational review of the flights

The biocide overdose led to engine abnormalities across four flights. Immediately after takeoff on the fourth flight, engine No 1 began to surge. Shortly afterwards, the crew received indications that engine No 2 had stalled. The crew established that the engines were more stable at low thrust settings and the thrust available at those settings was sufficient to maintain a safe flightpath. They returned to the airport and landed at 0020 hrs.

The discussion below considers the crews' actions during the period spanning the four flights in relation to procedures, decision-making, CRM and training.

2.2.1 Engine starting in Stansted (Crew A)

The aircraft had been released from maintenance with no open defects in its technical log, and engine No 2 started normally. While starting engine No 1 an ECAM message indicated the associated HP fuel valve had failed in the closed position, thus prompting Crew A to shut the engine down. They followed company engineering advice to attempt a second start cycle on engine No 1, which was normal. Consistent with FCTM guidance, Crew A concluded the absence of further ECAM messages or abnormal indications meant the original warning was no longer applicable. Therefore, they departed from Stansted and described the fault to Crew B at Gatwick.

2.2.2 Engine starting in Krakow (Crew B)

Crew B were primed for the ENG 1 HP FUEL VALVE ECAM alert, which re-occurred twice in Krakow. They were aware that a company engineer had advised Crew A to perform a subsequent start cycle in Stansted, without apparent concern, resulting in both engines functioning apparently normally for the following two sectors. Both times that alert resulted in Crew B aborting the start cycle. Recorded data indicated that start cycle three generated the ECAM alert ENG 1 START FAULT… ENG 1 STALL – which neither of Crew B said they recalled seeing – however, the FADEC automatically re-started the engine successfully.

There was extensive advice in the pilots' operating manuals on the management of engine stalls in flight – an abnormality that previously resulted in Commander B performing an in-flight diversion. The QRH was not the applicable reference document before the aircraft taxied, therefore Crew B necessarily prioritised the ECAM, which indicated engine No 1 was re-starting. The specific FCOM procedure for an engine start fault triggered by an engine stall stated the FADEC could reduce the fuel schedule in stages to achieve a *'normal condition'* while attempting a restart. It advised other starting methods, for example cross-bleed or manual starts. Consequently, that condition did not appear significantly concerning. The engine did not appear 'damaged' because there were no *'repeated and uncontrollable engine stalls'.*

There was no defined limit on the number of engine start cycles which the crew could attempt. Engine No 1 started during the third cycle with no persisting ECAM messages. Crew B considered the previous warnings no longer applicable and reported the 'HP fuel valve' ECAM alert to Technical Control after departure. Given the ENG 1 START FAULT... ENG 1 STALL was a 'new' fault, and general guidance on engine stalls was that they should be reported for maintenance action, Crew B could have considered reporting all of the starting abnormalities to Technical Control before departure. However, the existence of the start fault was available to Technical Control via the aircraft's PFR prior to the incident flight.

CVR data was not available for the engine start cycles in Krakow. Both pilots in Crew B stated that they remembered receiving the 'HP fuel valve' ECAM alert, and that engine No 1 started during the third cycle. However, neither said they recalled the ENG 1 START FAULT. Evidence indicated that that ECAM alert along with its triggering condition, ENG 1 STALL, remained on the ECAM display for over 20 seconds, throughout the subsequent NEW START IN PROGRESS.

2.2.3 En route Krakow to Gatwick (Crew B).

Approaching Gatwick, Crew B perceived slight airframe vibration, which can be symptomatic of high engine N_1 vibration. There was no engine vibration advisory. Consistent with the contents of the 'High engine vibration' QRH procedure, Crew B checked both engines' parameters, which appeared normal. The subsequent 'Engine stall' ECAM alerts were transient and disappeared from the ECAM screen. Crew B were unsure which was the *'affected engine'* therefore did not run the 'Engine Stall' QRH procedure.

Consequently, Crew B attempted to maintain both engines' N_1 below the perceived airframe vibration threshold, and the value where the ECAM alerts occurred. Consistent with the contents of the 'Engine Stall' QRH procedure, they briefed that if the ECAM alert re-occurred they would initially reduce thrust on the affected engine, but not shut it down. Had the alert re-occurred, the ECAM procedure while presented would have guided them through those actions, in turn referring them to the QRH procedure which was a ‘read and do’ checklist, rather than a memory item.

2.2.4 Ground phase at Gatwick (crews A and B)

On reading the aircraft’s PFR at Gatwick, Crew B discovered that engine No 2 had generated the in-flight ‘Engine Stall’ ECAM alert. Consistent with company procedures relating to third-party engineering, Commander B informed Technical Control of that alert and entered it in the aircraft’s TLB. He was not required to liaise directly with the line engineer.

Thorough discussions appeared to occur between Commander A, Technical Control and the line engineer about engine No 2’s in-flight engine stall. Commander A perceived caution being exhibited in the application of the related troubleshooting procedure, and the aircraft was released as serviceable.

2.2.5 Engine starting in Gatwick (Crew A)

Engine No 2 started normally. Start cycle one on engine No 1 was aborted for an ignition fault. Cycle two generated an ENG 1 FAIL ECAM alert and an ECAM message CONSIDER A RELIGHT. There were no particular symptoms of engine damage so on advice from Technical Control – and still following that ECAM procedure – Commander A initiated a relight. His previous experience of engine starting abnormalities mainly resulted in successful second cycles. He decided he would return to stand if this, third, cycle was unsuccessful, and retained the pushback crew accordingly. The cycle produced a transient ENG FAIL ECAM alert which disappeared, and the engine started. Consequently, Commander A consulted Technical Control again, who suggested engine No 1 had an ignition fault which should be resolved with the engine running. The FCOM advised that ignition faults in flight did not require crew action.

At that point, Crew A’s understanding was that engine No 2 had been signed off as serviceable; engine No 1 had experienced minor, starting-related, problems; and both engines were now running normally with no ECAM alerts. Therefore, Crew A considered there was nothing tangible preventing departure for what was planned to be a short positioning flight to their company’s engineering base, in calm and clear weather conditions, and in quiet controlled airspace. They carefully checked the engines’ parameters, and the resulting status of the cabin, before departing.

2.2.6 Incident flight (Crew A)

Just after the aircraft lifted off the ground, engine No 1 began banging and surging, exhibiting fluctuating parameters. Although Crew A were unaware of flames emitting from its tailpipe, there were other indications – as detailed in the FCOM and FCTM – that engine No 1 was stalling, and that it was damaged. As the FCOM advised could happen, the FADEC did not detect an engine stall; consequently, no ECAM alert was triggered.

The QRH Engine Stall procedure was applicable but the "violent swing" described by Commander A made its use impractical. The critical flight phase eliminated any requirement to allow the FADEC to *'self-recover'*. Therefore, consistent with the contents of the QRH procedure – and to feel more in control of the aircraft – Commander A reduced the affected engine's thrust lever to idle. Because the abnormal engine parameters remained, the next QRH instruction would have been to shut down engine No 1. However, having promptly flown a downwind heading, engine No 2's parameters began fluctuating before any such decision was considered. This prompted Commander A to use equal and appropriate thrust on both engines, irrespective of the subsequent ENG 2 STALL ECAM alert.

Commander A prioritised manually flying a prompt and accurate approach, using less thrust than usual. It is likely that his experience on type and effective workload management, combined with effective support by Co-pilot A, contributed to the safe outcome.

The circumstances of the incident flight were that the aircraft was relatively light in weight, the airspace was quiet, and the weather conditions were calm and clear. Crew A did not have sufficient time to consider shutting down engine No 1 before engine No 2 began stalling and were therefore able to use power from both engines for the remainder of the flight. Had the conditions been less favourable, engine and aircraft performance could have been insufficient to maintain a safe flightpath – possibly while over-flying the built-up areas near Gatwick Airport.

2.2.7 Decision-making

There was no guidance for pilots on fuel contamination, and no specific procedure for it. Commander A recalled some previous simulator training where it affected both engines' fuel and engine indications symmetrically. G-POWN's two engines experienced different abnormalities at different times, over four sectors and two flight crews. The faults mainly generated specific ECAM alerts. There was no 'Fuel filter clog' alert, which would have led the crews to suspect fuel contamination, and the APU ran normally. Consequently, neither crew was predisposed to diagnose an underlying fuel condition. Consistent with the operator's expectations, Crew A responded to the failures that were being presented to them and liaised with Technical Control. Commander A sought technical advice at all stages and participated in extensive technical discussions prior to the incident flight.

The T-DODAR decision-making model used by Commander A relies on diagnosing a problem. Consequently, if a full diagnosis cannot reasonably be made then decisions based on it will be less reliable in affecting the outcome.

2.2.8 CRM and training

Crew B's advice to Crew A regarding confirmation bias resulted in Crew A using particular caution during the incident while referencing fault indications to the engines. While it cannot be known whether that materially affected the outcome, it exemplifies the reasoning behind crew co-operation, and threat and error management briefings. Crew B openly described a threat they experienced (namely misdiagnosing the affected engine), which resulted in Crew A discussing their intended management of that threat before departure on the incident flight. Consequently, Crew A became primed during a period of low workload to avoid that particular error when the related threat presented itself during a subsequent period of high workload.

Effective and inclusive communications were apparent amongst all the incident crew. The SCCM briefed her team to prioritise communications with Commander A should they detect anything unusual. To assist communications during the incident she requested entry to the flight deck, enabling Commander A to inform her of their planned return to Gatwick. Thereafter she initiated relevant procedures with the rest of the crew.

The operator optimised learning from the G-POWN event by disseminating appropriate information and promptly implementing training packages for engineers, flight crew and cabin crew.

2.2.9 Operations summary

Crew A followed operational procedures, engaged effectively with Technical Control, and performed according to the operator's expectations. Effective team-working was demonstrated within the incident crew as a whole and with Crew B. Crew A responded to the technical faults which were presented to them using an industry-standard decision-making tool. However, the unforeseen nature of the underlying cause, which presented itself through seemingly unconnected system faults, meant neither crew was predisposed to diagnose it.

2.3 The biocide treatment

There were two very similar biocide overdosing events at the Base AMO in February 2020, G-POWN and YL-LCQ. The investigation benefitted from the opportunity to consider both events and found that there were similar individual, task and organisational factors that resulted in the inadvertent overdosing.

2.3.1 Individual factors

Individual factors are those that relate to the engineers involved in the event. Both base engineers were correctly licensed and were experienced in terms of the number of years they had worked in aircraft maintenance. However, they had never done a biocide treatment before and they were unfamiliar with the term 'ppm.' They did not have the background knowledge they needed to do the calculation correctly given the sources of information they had access to.

Both base engineers and the base maintenance manager spoke English as a second language but generally used the present tense when speaking to the AAIB even when referring to past events. The biocide task required them to refuel the fuel tanks '*with fuel mixed with Antimicrobial Agent-Fuel System Liquid Additive*', and it is possible they did not appreciate that the word '*mixed'* implied that the mixing should happen before the refuelling. In combination with the task factors discussed below, this may have contributed to why they decided to apply the biocide through G-POWN's and YL-LCQ's overwing refuel apertures believing it would mix with fuel in their tanks.

Licensed engineers are expected to be able to perform unfamiliar maintenance tasks without specific task training and it is common for engineers to be working in a second language. To minimise errors, maintenance tasks and associated written procedures must be developed considering the experience, knowledge and language skills of the likely users. If the written procedures are not suitable for the users, for example if there is insufficient detail or the language is ambiguous, then the chance of misinterpretation is increased.

2.3.2 Task factors

The AMM did not provide any information about what 'ppm' meant or how to do the biocide concentration calculation, so the task relied on the engineers to use their own knowledge. To make the calculation correctly the engineers needed to know: what ppm meant; how to convert ppm into a factor; the difference between weight and volume; how to convert quantities from weight to volume and from volume to weight using specific gravity; and the specific gravity of the fuel and biocide. These latter two pieces of information could only be obtained with reference to the fuel receipt during the uplift and the biocide product information online. The biocide container was marked in 'kg' and the specific gravity value was not on the product label. Overall, this constituted a complicated calculation, and other AMOs that the AAIB visited during the investigation did not expect their licensed engineers to be able to make it correctly without any support or cross-checking.

The two engineers were typical of many Part-66 licensed engineers but, in the absence of more information in the AMM, they sought information elsewhere and did not realise that what they found was insufficient for the task.

Their lack of experience and the extremely small concentration required for the quantity of fuel (less than one litre per wing tank) meant the engineers did not recognise that the concentrations they had calculated were wrong. Having never done the task before, and without an understanding of ppm, a quantity of 30 kg of biocide for 6,200 kg of fuel seemed reasonable to Base Engineer 1. The quantity of biocide available in the stores (150 kg) and the size of the containers of Kathon (5 kg and 20 kg) appeared to additionally confirm to the engineer that the concentration being used was appropriate.

There were two types of AMM task for administering Kathon; pre-mix or metered injection rig. The operator instructed the Base AMO to use the pre-mix AMM procedure but this procedure lacked detail in how the Kathon should be mixed with the fuel. The intention of the AMM task was that the biocide should be pre-mixed at the appropriate concentration and then the fuel and biocide mixture should be uplifted to the aircraft using the standard pressure refuel with automatic control procedure. However, there was no equipment at the Base AMO to mix the biocide and fuel outside of the aircraft. The absence of specific AMM instructions and a lack of suitable equipment, in combination with the Base engineers' lack of experience with the task, contributed to their belief that the method of treatment and amount of Kathon used was correct.

2.3.3 Organisational factors

The biocide treatment was considered simple by everyone involved within the operator and the Base AMO. Workload at the Base AMO was high and the planning department were stretched. The Base AMO did not assess the biocide treatment task to decide if it should be a critical maintenance task and it was given limited attention and oversight by both the operator and the managers at the Base AMO.

It is normal for licensed engineers to be expected to perform AMM tasks independently without specific supervision. Responses to the AAIB questionnaire showed that some AMOs have a technical engineer role or a department that engineers can consult if they need advice, but there was no such service available at the Base AMO. Base engineers 1 and 2 were expected to find a solution themselves or, failing that, ask colleagues or the base maintenance manager. The base maintenance manager, in particular, had a very high workload and did not have the time to assist engineers with in-depth technical queries.

The maintenance on G-POWN was behind schedule predominantly due to the cabin in-seat power modification. The operator's representatives were present at the Base AMO to drive progress so their focus was on this rather than other tasks.

Base Engineers 1 and 2 were working in a high workload environment without structured on-site technical support but the biocide task was considered simple. For G-POWN, it was one of the final tasks required before the aircraft could be released to the operator. Base Engineer 1 and the base maintenance manager believed that they had a suitable treatment method, and Base Engineer 1 believed that the calculation he had made was correct. Given these factors and the overall organisational context, there was no reason at the time for anyone at the Base AMO to explore alternatives.

2.3.4 Example good practice in relation to biocide use

The results of the AMO survey and subsequent follow-up visits highlighted that some AMOs had recognised the potential hazard in the biocide dosing task and had developed error-capturing procedures intended to prevent an inadvertent biocide overdose event.

These procedures included providing technical support in checking the biocide dosing calculation performed by an LAE or mechanic, before the dosing was performed. Some AMOs had developed spreadsheet calculator tools to guide a user through the dosing calculation procedure in a step-by-step manner, to reduce the probability of an error being made. One AMO required two LAEs to independently perform the dosing calculation before they then cross-checked their results, prior to an additional calculation check by their Technical Services function.

AMOs that operated metered injection rigs did so either because it was the only dosing method approved in the AMMs they used, or because they recognised that the equipment has the potential to improve the effectiveness, standardisation and repeatability of the dosing process. They understood, however, that it was still possible to apply an excessive quantity of biocide if the rig dosing level was set too high. This risk had been addressed by implementing a rig setting check before the main fuel dosing was carried out, by verifying that the correct amount of biocide was applied to a small initial quantity of uplifted fuel.

2.3.5 Action by regulators

The EASA issued Safety Information Bulletin SIB 2020-06 on 20 March 2020, to notify affected stakeholders of recent air safety-related events involving Kathon biocide and to remind aircraft owners and operators to ensure that the correct method and dosage is used for approved biocide treatment of aircraft fuel systems. The FAA issued Special Airworthiness Information Bulletin SAIB NE-20-0417 on 25 March 2020 that contained similar regulatory guidance.

As this serious incident and previous events identified in Section 1.18.3 have demonstrated, biocide treatment of aircraft fuel systems contains the potential to adversely affect the fuel quality supplied to, and therefore the thrust available from, all of an aircraft's engines. This fundamentally undermines the redundancy provided by multiple engines. It is clear, therefore, that the biocide treatment of aircraft fuel systems should be classified as a critical maintenance task because this classification would require an error-capturing method to be implemented. However, the existing EASA Part-145 and Part M regulations do not specifically require this classification and therefore the following Safety Recommendations are made:

Safety Recommendation 2021-018

It is recommended that the European Union Aviation Safety Agency amend the Acceptable Means of Compliance AMC2(a (3) for regulation Part-145.A.48(b), *Performance of Maintenance,* to include the treatment of aircraft fuel systems with biocide additives as an example task that is to be considered as a critical maintenance task.

Safety Recommendation 2021-019

It is recommended that the European Union Aviation Safety Agency amend the Acceptable Means of Compliance AMC1(c) for regulation M.A.402(h), *Performance of Maintenance,* to include the treatment of aircraft fuel systems with biocide additives as an example task that is to be considered as a critical maintenance task.

Since the NAAs of EASA Member States are responsible for performing safety oversight and audit of CAMOs and AMOs at the national level, the following Safety Recommendation is made:

Safety Recommendation 2021-020

It is recommended that the European Union Aviation Safety Agency (EASA) conduct safety promotion with the National Aviation Authorities of EASA Member States to promote the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

As the classification of critical maintenance tasks is defined at the organisation level by the planners, supervisors and certifying staff in an AMO or a CAMO, the following Safety Recommendations are made:

Safety Recommendation 2021-021

It is recommended that the European Union Aviation Safety Agency, during future audits of Continued Airworthiness Management Organisations and Approved Maintenance Organisations for which it is the Competent Authority, include a check that consideration has been given to the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

Safety Recommendation 2021-022

It is recommended that the Civil Aviation Authority (CAA), during future audits of CAA-approved Continued Airworthiness Management Organisations and Approved Maintenance Organisations, include a check that consideration has been given to the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

2.4 Line maintenance troubleshooting

The line engineer who performed the engine No 2 troubleshooting on G-POWN accessed and then carried out the procedure for a different engine type than that fitted to the aircraft. The procedure was carried out correctly, but it did not detect the problem as it only required an external visual inspection of the engine and a check for fault messages.

The procedure for the correct engine type would have prevented the incident because not only did it require the external visual inspection, it also required a borescope inspection of the compressor and turbine sections. The borescope of the turbine section would have identified abnormal white deposits on the blades, resulting in the involvement of the engine manufacturer for review. The engine manufacturer confirmed that, on seeing the engine condition, they would have required the engine to be removed for further investigation before any further flights.

There were no individual factors that contributed to the line engineer carrying out the wrong procedure. The line engineer was properly licensed and had many years of experience. He was relatively well rested, considering that it was the second night shift and final shift in the working block, and he was not feeling under pressure by the workload that night.

2.4.1 Interaction between the line engineer and the AirN@v interface

After attending G-POWN, printing the PFR and talking to the flight crew, the line engineer returned to the Line AMO office to find the appropriate troubleshooting procedure using the Airbus maintenance data applications. Data for this operator's aircraft was only available in AirN@v.

The line engineer chose to select 'all' when setting the 'applicability configuration' which meant that procedures for any of the operator's aircraft could be accessed. The line engineer was not aware that the operator was buying aircraft equipped with LEAP-1A32 engines. The LEAP-1A32 engine was listed in the 'applicability configuration' filtering interface on AirN@v but the line engineer either did not notice this or it was obscured, depending on the settings for the size of the box and the columns at the time.

Having not seen the LEAP engine in the list, and based on his knowledge of the operator's fleet, he approached the task expecting to have to choose between procedures for a CFM56 engine and a V2500 engine. The line engineer accessed the TSM using the table of contents and looked in Chapter 77 because this corresponded to the ATA code given in the ECAM maintenance alert recorded on the PFR. The line engineer was looking for the difference between CFM and IAE. The difference between the initial part of the chapter titles for the LEAP engine and the CFM56 engine was a single letter; '*CFMI*' for the CFM56 and '*CFML*' for the LEAP engine. The two chapter titles were also visually very similar. The line engineer was not expecting to have to choose between two options both labelled starting with CFM and clicked on the option labelled '*77 – (CFML)*', which was immediately above '*77 – (IAE)'.* He did not realise this was not the correct chapter.

2.4.2 Method for using the TSM, and associated training

Entering the TSM via the table of contents does not use the underlying system intelligence, which considers the PFR and other sources of information. The line engineer was not aware of the importance of using the intelligent search function via '*Start Troubleshooting'.* This would have led to the correct procedure which was in Chapter 73 (*73-00-00-810-866-A, Stall of engine 1 or 2 in flight*).

Analysis

He was not unique in using this approach; the AMO survey and the visits during the investigation showed that other licensed engineers use the table of contents and regular search functions to interrogate the TSM. Some engineers during the AMO visits were not aware of the manufacturer's recommended approach and others were. The survey showed that AMOs rely on engineers to learn this during type training and it is sometimes checked during on-going competence assessments. The Line AMO did explicitly assess this area during a recent competence assessment with the line engineer but did not detect this gap in his understanding.

Investigation of the type training at the Line AMO found that the means of navigating the TSM in the AirN@v and airnav^{X} applications is not formally included or assessed. This is likely to be the case at other Approved Training Organisations and accounts for why other licensed engineers do not always use the manufacturer's recommended approach. In contrast, the manufacturer's own training does explicitly include how to search for troubleshooting procedures, including the selection of a specific aircraft, on a 'click by click' basis. There is also some online support provided by the manufacturer: a 'click by click' demonstration of the recommended approach is built into the e-learning resources for airnav^{X} but not AirN@v.

The content of engineer type training must be developed in accordance with Part-147 and Part-66 using a TNA. These regulations are clear that the use of maintenance documentation must be included, and they recommend that the TNA is supported by an analysis from the TC holder. However, it appears that this important, safety-related message from the manufacturer was not included in all Airbus engineer type rating training and the regulator audit process is not designed to look at all training content in enough detail to detect this.

There are no current requirements to ensure that manufacturers' instructions, which are deemed important for the safe maintenance of an aircraft (like those relating to the use of the TSM), are included in engineer training for existing aircraft types. In the future, TC applicants will be required to produce OSD that covers the minimum syllabus of maintenance staff type rating training for new types. This will not be applied retrospectively for existing types, unless there is a significant change to the TC (or STC), so there is currently a gap where some engineers with Airbus type ratings are not aware that they should use only the manufacturer's recommended method of using the TSM. The Part-147 organisation that trained the line engineer have taken safety action to address this. The TNA review process for Part-147 training organisations is also expected to consider past occurrences so the learning from G-POWN should filter into type courses and continuation training from other training providers in due course.

2.4.3 Opportunity to realise the incorrect procedure had been selected

The reason that this has rarely been found to be a problem before could be that, in most cases, if an engineer clicked into the wrong chapter, they would not find a procedure that was appropriate for the issue they were working on. They would realise what had happened and correct it. In this event, there happened to be a plausible procedure in the chapter list for the engine No 2 issue '*77-11-00-810-815-A, Stall Above Idle on Engine 1(2)*' so the line engineer was not alerted.

The line engineer believed that he had printed the correct procedure. Once printed, there was little to capture his attention and make him realise what had happened. When printed in black and white, the 'effectivity' statement was inconspicuous, and the procedure did not mention the name of the applicable engine type anywhere within it. All the steps in the procedure were possible to carry out on the CFM56 engine so the line engineer was not presented with any salient cues to make him rethink.

2.4.4 Comparison of AirN@v and airnav^{X} and the transition between the two systems

The investigation assessed the graphical interfaces of AirN@v and airnav^{X} to determine whether the unavailability of airnav^{X} was contributory to the line engineer accessing the wrong procedure. It was possible to select the wrong procedure, in the same way as the line engineer had, using either system. However, more clicks were required to achieve this in airnav^{X} than the manufacturer's preferred method, so this was comparatively discouraged. The design of airnav^{X} encourages users to filter the maintenance data by permanently presenting the 'context' interface (aircraft filtering) to the left of the screen. In AirN@v, the filtering box must be manually opened and is closed after selecting the desired filters. Furthermore, in airnav^{X} users must filter to the individual aircraft to use the troubleshooting function. Overall, the design of airnav^{X} helped users to follow the manufacturer's recommended approach more than the design of AirN@v. The line engineer may have been less likely to use the wrong procedure if airnav^{X} had been available on the evening of the incident.

The transition of operators from AirN@v to airnav^{X} was being progressed with operators on a case by case basis when convenient. This meant that even though the improved application was available from April 2017 for some operators, transition of all operators onto the new system for maintenance data was planned to be completed in June 2021. The AMO survey showed that, in summer 2020, an equal number of AMOs were using AirN@v and airnav^{X}.

The operator in this case had transitioned to airnav[X] but the process was not complete because their contracted Line AMO had not been given access. Airnav[X] appeared to have a usable and easy to learn interface but this was not the case with the interface for access delegation, which showed that access to airnav[X] was delegated when it was not. The terminology for the actions required to delegate airnav[X] access to the Line AMO (delegate access to *RNMC – Maintenance data set consult*) did not clearly correspond to the desired outcome.

The patchiness of the transition programme and the interface of the delegation screen account for why no one at the Line AMO questioned not having airnav[X] access for this operator and why the operator was unaware that airnav[X] access had not been delegated successfully.

When the transition to airnav[X] is fully completed there will be less opportunity for an engineer to use the wrong procedure because the design of airnav[X] facilitates the use of the recommended method. According to the manufacturer, that transition will be completed in less than six months from the publication of this report. Improvements to engineer type and continuation training should flow from the G-POWN event as part of the normal TNA review process. For future types and types with any significant changes, Part-147 organisations should benefit from OSD for maintenance training. Overall, these future improvements should address this hazard.

3 Conclusion

3.1 Findings

3.1.1 Operation of the aircraft

1. Engine No 1 exhibited starting abnormalities before flights one, three and four. The crews employed up to three starting cycles on those occasions resulting in the engine starting apparently normally.
2. All four flights departed with no persisting ECAM messages.
3. Engine No 2 exhibited symptoms of a stall during the approach to Gatwick on flight three, including a transient ECAM message, which Crew B reported to Technical Control on arrival.
4. Crew A were properly licenced and qualified, and sufficiently rested for the event flight.
5. Commander A engaged with relevant engineers regarding each engine abnormality affecting the flights he was operating, including a telephone call with Technical Control after both engines had started before the incident flight.
6. There was no clear information available to either crew for them to diagnose the engine abnormalities as being symptomatic of an underlying issue of fuel contamination.
7. Prior to taxiing on the incident flight, the engine abnormalities were associated with seemingly unconnected system faults.
8. During the incident, Crew A did not have time to consider shutting down engine No 1 after it began to surge and before engine No 2 exhibited indications of a stall.
9. After receiving indications of a stall on engine No 2, Crew A found a thrust setting using both engines that enabled the aircraft to maintain a safe flightpath.
10. Calm and clear weather conditions meant Crew A could perform an immediate visual return to Rwy 26L.
11. During the incident, effective workload management and crew co-operation amongst the whole crew resulted in a prompt and successful return to Rwy 26L.

3.1.2 The biocide overdose

1. Base Engineer 1 was correctly licensed and qualified to perform the tasks he was assigned on G-POWN.
2. Neither engineer at the Base AMO had performed biocide treatment before and neither knew what ‘ppm’ meant.
3. Each engineer attempted to use internet calculators to help with the calculation but did not have the background knowledge needed to do the calculation correctly.
4. G-POWN was treated with approximately 38 times the required concentration of Kathon biocide.
5. Other than the excessive Kathon biocide treatment, the aircraft had been adequately maintained and had a valid certification of airworthiness.
6. YL-LCQ was also treated with too much Kathon biocide at the Base AMO shortly after G-POWN’s treatment.
7. A critical maintenance task identified in accordance with EASA Part M.A.402(h) or Part-145.A.48(b) requires an error-capturing method to be implemented.
8. The Base AMO had not classified the biocide dosing task as a critical maintenance task.
9. The Base AMO had not introduced a means of error capture during the biocide dosing task.
10. All the AMOs surveyed after publication of AAIB Special Bulletin S1/2020 classified fuel biocide treatment as a critical maintenance task.
11. The AMM procedure lacked detail in terms of the method of mixing the Kathon with the fuel.
12. Facilities at the Base AMO did not provide any practical means of mixing the Kathon with fuel prior to uplifting the fuel to the aircraft.
13. Personnel at the Base AMO believed that the Kathon administration method they used on G-POWN and YL-LCQ would result in sufficient mixing to successfully and safely treat the aircraft.
14. The Kathon was administered via the overwing aperture, which meant it did not mix effectively with the fuel that was uplifted, resulting in local areas of high Kathon concentration in the wing fuel tanks and engine fuel systems.

15. Kathon concentration in the fuel was in excess of the AMM limit of 100 ppm/vol.

16. Excess Kathon caused contamination of the engine HMUs.

17. The HMU contamination led to starting problems on engine No 1.

18. The HMU contamination caused a loss of engine regulation resulting in the surge and stall events on engines No 1 and No 2 during the incident flight.

19. Further evidence of excessive Kathon content in the aircraft fuel was shown by the deposits observed in the engines' combustion chambers and turbine stages.

20. No engine damage was directly attributed to the presence of these deposits. The cause of the damage to the engine No 2 HPC blades was not identified and it is possible that this damage may have been present prior to the incident.

21. A survey of British and French AMOs that perform biocide treatments for commercial aircraft showed that the Base AMO was typical of other AMOs that perform this task infrequently, in terms of process and procedure.

3.1.3. Troubleshooting at Gatwick Airport

1. The line engineer was correctly licenced and qualified to perform the tasks he was assigned on G-POWN.

2. The TSM was accessed through AirN@v and was not searched using the manufacturer's recommended method.

3. During the search of the TSM for a suitable procedure, the data was not filtered to ensure that only procedures applicable to G-POWN were accessible.

4. A troubleshooting procedure was carried out on G-POWN that applied to LEAP-1A32 engines, but the aircraft was fitted with CFM56-5B3/3 engines.

5. The troubleshooting procedure used (for LEAP-1A engines) only required an external general visual inspection of the engine.

6. The correct TSM procedure (for CFM56 engines) required an additional internal borescope inspection which would have resulted in the engines being removed before further flight.

7. Several factors in combination led to the selection of the wrong procedure:

   a. The ATA fault code reference from the PFR was used as a chapter reference for the TSM.

   b. It was relatively easy to select the wrong TSM chapter (and therefore the wrong procedure) because the chapter labels were similar in appearance.

   c. There was an apparently appropriate procedure in the TSM chapter consulted even though it was the incorrect chapter.

   d. Procedures for LEAP-1A engines were not expected to be found within the operator's maintenance data.

   e. There were no attention-getting stimuli on the printed procedure to prompt an awareness that the incorrect procedure had been selected.

8. The line engineer was not aware of the importance of only using the manufacturer's recommended method of searching the TSM.

9. It was common for engineers at the Line AMO and other AMOs consulted by the AAIB to search the TSM in a similar way to the line engineer.

3.1.4 Training in the use of maintenance documentation

1. Engineer type training is the primary means for licensed engineers to learn to use the TSM and associated applications for accessing it.

2. Training needs analyses for engineer type training should be supported with input from the aircraft TC holder.

3. Engineer type training provided by the manufacturer includes the recommended method for searching for troubleshooting procedures.

4. The line engineer received all his most recent Airbus type training from an approved EASA Part-147 maintenance training organisation associated with the Line AMO, which did not explicitly emphasise the manufacturer's recommended way to search for troubleshooting procedures using AirN@v and airnav^{X}.

5. The regulatory approval and audit process is unlikely to identify whether a training course emphasises the manufacturer's recommended method of using maintenance data applications.

6. The competency assessment criteria for the line engineer did include how maintenance data was accessed and his most recent competency assessment in January 2020 did not document any issues with the way he used the maintenance data applications.

3.1.5 Online applications to access maintenance documentation

1. The Line AMO did not have access to the operator's maintenance data in airnav^{X} because access had not been delegated by the operator.

2. The operator believed that airnav^{X} access had been delegated to the Line AMO.

3. The line engineer would have been less likely to select the wrong procedure using airnavX than AirN@v.

4. It was possible to select the wrong procedure in either AirN@v or airnavX.

5. The graphical interface of the operator's delegation screen provided misleading cues that suggested access to airnav^{X} had been delegated.

6. The method of delegating access to airnav^{X} was difficult without specific instructions from the manufacturer.

3.2 Causal factors

The investigation identified the following causal factors:

1. G-POWN's fuel tanks were treated with approximately 38 times the recommended concentration of Kathon.

2. The excessive Kathon level in the aircraft's fuel system caused contamination of the engine HMUs resulting in a loss of correct HMU regulation of the aircraft's engines.

3. A troubleshooting procedure was used for the engine No 2 stall that applied to LEAP-1A32 engines, but G-POWN was fitted with CFM56-5B3/3-engines. The procedure for CFM56-5B3/3 engines required additional steps that would have precluded G-POWN's departure on the incident flight.

3.3 Contributory factors

The investigation identified the following contributory factors:

1. The Aircraft Maintenance Manual (AMM) procedure did not provide enough information to enable maintenance engineers to reliably calculate the quantity of Kathon required, and the specific gravity value of Kathon was not readily available.

2. There were no independent checking procedures in place at the base maintenance Approved Maintenance Organisation (Base AMO) to prevent, or reduce the likelihood of, calculating and administering an incorrect quantity of biocide.

3. There were organisational factors at the Base AMO that contributed to the incorrect Kathon quantity calculations. In particular, the workload was high for the available facilities and personnel, and there was no internal technical support function for engineers to consult when they were uncertain.

4. The manufacturer's recommended method of searching the troubleshooting manual was not used to find the applicable procedure relating to the engine No 2 stall.

4 Safety Recommendations and Action

4.1 Safety Recommendations

The following Safety Recommendations have been made:

Safety Recommendation 2021-018

It is recommended that the European Union Aviation Safety Agency amend the Acceptable Means of Compliance AMC2(a)(3) for regulation Part-145.A.48(b), *Performance of Maintenance,* to include the treatment of aircraft fuel systems with biocide additives as an example task that is to be considered as a critical maintenance task.

Safety Recommendation 2021-019

It is recommended that the European Union Aviation Safety Agency amend the Acceptable Means of Compliance AMC1(c) for regulation M.A.402(h), *Performance of Maintenance,* to include the treatment of aircraft fuel systems with biocide additives as an example task that is to be considered as a critical maintenance task.

Safety Recommendation 2021-020

It is recommended that the European Union Aviation Safety Agency (EASA) conduct safety promotion with the National Aviation Authorities (NAAs) of EASA Member States to promote the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

Safety Recommendation 2021-021

It is recommended that the European Union Aviation Safety Agency, during future audits of Continued Airworthiness Management Organisations and Approved Maintenance Organisations for which it is the Competent Authority, include a check that consideration has been given to the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

Safety Recommendation 2021-022

It is recommended that the Civil Aviation Authority (CAA), during future audits of CAA-approved Continued Airworthiness Management Organisations and Approved Maintenance Organisations, include a check that consideration has been given to the classification of biocide treatment of aircraft fuel systems as a critical maintenance task.

4.2 Safety Actions

As a result of this serious incident, Safety Action was taken by various organisations as set out below.

4.2.1 Action by regulators

The EASA issued Safety Information Bulletin SIB 2020-06 on 20 March 2020, to notify affected stakeholders of recent air safety-related events involving Kathon biocide and to remind aircraft owners and operators to ensure that the correct method and dosage is used for approved biocide treatment of aircraft fuel systems.

The FAA issued Special Airworthiness Information Bulletin SAIB NE-20-0417 on 25 March 2020 that contained similar regulatory guidance.

4.2.2 Action by IATA

IATA's Technical Fuel Group established an informal Biocide Task Force with the following tasks:

1. Support the development of an equipment standard for biocide metered injection systems.
2. Support research into alternative biocide products.
3. Facilitate sharing of industry experience and best practices between airlines, AMOs and OEMs.
4. Informing European airlines of news and developments relating to fuel biocide treatments.
5. Lobbying the European Chemicals Agency in support of approval of Biobor JF and for unified REACH derogations in the interim period.

4.2.3 Action by the manufacturers of the biocide and the engines

The manufacturer of Kathon discontinued the use of its product for aviation fuel applications on 10 March 2020.

On 16 March 2020, CFM, the manufacturer of G-POWN's engines, issued Alert Service Bulletin 73-A0296 recommending that operators of CFM56-5B engines suspend the use of Kathon during aircraft fuel system biocide treatments. Similar instructions were issued for other variants of the CFM56 engine family, as well as all General Electric turbofan engines.

AMOs in the EU are continuing to use Biobor JF for biocide treatments, through the approval of temporary national derogations of the REACH regulations.

4.2.4 Action by the aircraft manufacturer

The aircraft manufacturer is revising the AMMs across their product range to replace 'ppm' with the term 'ml/1,000ltrs', and also plans to include a definition of ppm in the AMM glossary in cases where this term is used elsewhere.

The AMM biocide dosing procedures are being revised to simplify the task instructions and to provide a step-by-step methodology. Explanatory notes will be added so that an operative understands why each step is being carried out. It is also planned to include a table giving the biocide volumes required for each fuel tank. The revised AMM procedures will include a check on the biocide dosing calculation, prior to the calculated biocide quantity being added to the fuel tanks.

The aircraft manufacturer undertook to confirm the level of biocide-to-fuel mixing achieved when biocide is added to fuel prior to refuelling the aircraft, using the 'pre-mixing' method as currently defined in the AMM. This work would ensure that this dosing method achieves the same degree of biocide mixing as is the case with a metered injection rig. The manufacturer stated that if the testing revealed a lower level of mixing, the pre-mixing method could be removed from the AMM. A joint approach with Boeing would be taken to ensure consistency and best practice, in line with IATA guidance.

4.2.5 Action by the Base AMO that performed the biocide treatment

The AMO that performed the biocide treatment on G-POWN introduced a new role of 'technical engineer'. The technical engineer would be an EASA Part-66 B1 licensed engineer, outside of the management chain within the organisation, who would be available to assist other licensed engineers and mechanics with technical queries, such as calculations.

The AMO undertook to introduce usage limits in stores so that staff would not be able to withdraw chemicals in quantities that significantly exceed the maximum permitted.

The AMO increased the amount of office space available to the planning department and nominated a room dedicated to work pack compiling.

The EASA SIB 2020-06 was included in the recurrent training syllabus for all AMO staff.

The AMO undertook to write a procedure for biocide treatment, which would incorporate the following:

1. Two independent licensed engineers would make the calculation. Both calculations would be verified by the Technical Engineer against their own independent calculation.
2. A spreadsheet-based biocide calculator to allow the engineer to calculate the amount of biocide to be administered by entering the specific details of the fuel.
3. Biocide treatment would be considered as a "critical maintenance task" and would require duplicate/independent inspection of the calculations and the accomplishment of the task.

The AMO would provide additional training on the differences between Airn@v, and Airnav X.

The AMO would provide additional training on using the TSM within each application.

4.2.6 Action by the Line AMO

The Line AMO liaised with the manufacturer and the operator for delegated access to airnav[x].

A safety and compliance notice was issued to all staff concerning the use of AirN@v and the importance of filtering for the correct Fleet Serial Number.

Station managers were reminded to perform competency assessments to an adequate standard.

An additional check of competence was introduced using maintenance data in the certification authorisation interview.

A safety and compliance notice was issued to disseminate the manufacturer's training material on using the AirN@v TSM. This was also added to their Airbus engineer type training courses and equivalent material for airnav[x].

The Part-147 maintenance training organisation included a sign-off task in their practical logbooks for engineers regarding the use of effectivity and troubleshooting manual for Airbus and other manufacturers' types.

The G-POWN incident was included in continuation training and instructor awareness from September 2020 onwards.

4.2.7 Action by the operator

The operator undertook to maximise crew learning from the G-POWN serious incident, by incorporating it in its recurrent CRM training package for all aircrew, starting in September 2020.

The operator incorporated into its engineer continuation training an exercise on communication and information management, based on this event, to enable duty engineers to maximise their awareness of the ongoing serviceability of an aircraft. It also added related detail to its Safety Management System.

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Appendix A

Comparison of biocide tasks

Task Number	Biocide	Application	Treatment	Contamination	Concentration	Volume or Weight	Parts Per Million	Sample Calculation	Title
28-11-00-600-008-A	Biobor	Pre-mix	Shock	Moderate	<=270	Weight	Yes	Yes	Biocidal Shock Treatment for Moderate Contamination - With Fuel Mixed with Biobor Biocide
28-11-00-600-008-A01	Kathon	Pre-mix	Shock	Moderate	100	Volume	No	No	Biocidal Shock Treatment for Moderate Contamination - With Fuel Mixed with Kathon Biocide
28-11-00-600-008-A02	Biobor	Metered Rig	Shock	Moderate	<=270	Weight	Yes	Yes	Biocidal Shock Treatment for Moderate Contamination - Using Biobor Biocide with a Metered Injection Rig
28-11-00-600-008-A03	Kathon	Metered Rig	Shock	Moderate	<=100	Volume	No	No	Biocidal Shock Treatment for Moderate Contamination - Using Kathon Biocide with a Metered Injection Rig
28-11-00-600-009-A	Biobor	Pre-mix	Shock	Heavy	<=270	Weight	Yes	Yes	Biocidal Shock Treatment for Heavy Contamination - With Fuel Mixed with Biobor Biocide
28-11-00-600-009-A01	Kathon	Pre-mix	Shock	Heavy	100	Volume	No	No	Biocidal Shock Treatment for Heavy Contamination - With Fuel Mixed with Kathon Biocide
28-11-00-600-009-A02	Biobor	Metered Rig	Shock	Heavy	<=270	Weight	Yes	Yes	Biocidal Shock Treatment for Heavy Contamination - Using Biobor Biocide with a Metered Injection Rig

Cont....

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Task Number	Biocide	Application	Treatment	Contamination	Concentration	Volume or Weight	Parts Per Million	Sample Calculation	Title
28-11-00-600-009-A03	Kathon	Metered Rig	Shock	Heavy	100	Volume	No	No	Biocidal Shock Treatment for Heavy Contamination - Using Kathon Biocide with a Metered Injection Rig
28-11-00-600-010-A	Biobor	Pre-mix	Prevention	Nil	135	Weight	No	No	Biocidal Preventative Treatment for Aircraft in Long-Term Storage - With Fuel Mixed with Biobor Biocide
28-11-00-600-010-A01	Kathon	Pre-mix	Prevention	Nil	50	Volume	No	No	Biocidal Preventative Treatment for Aircraft in Long-Term Storage - With Fuel Mixed with Kathon Biocide
28-11-00-600-010-A02	Biobor	Metered Rig	Prevention	Nil	135	Weight	No	No	Biocidal Preventative Treatment for Aircraft in Long-Term Storage - Using Biobor Biocide with a Metered Injection Rig
28-11-00-600-010-A03	Kathon	Metered Rig	Prevention	Nil	50	Volume	No	No	Biocidal Preventative Treatment for Aircraft in Long-Term Storage - Using Kathon Biocide with a Metered Injection Rig

Appendix B

Copy of AMO questionnaire

AAIB Biocide Dosing Questionnaire

Air Accidents Investigation Branch

Note: This questionnaire is designed to collect data from Part 145 Approved Maintenance Organisations in support on an ongoing AAIB Field Investigation ref. AAIB-26436 (Airbus A321-211 G-POWN, Serious Incident at London Gatwick Airport, 26 February 2020, AAIB Special Bulletin S1/2020). The results of this questionnaire will be treated in confidence by the AAIB and the identity of any organisation providing data to the AAIB will not be disclosed. The AAIB will analyse of all the responses received and may present an anonymised summary of these data in its final report.

Thank you for taking the time to assist the AAIB by completing this questionnaire. When complete, please email this questionnaire to [redacted]

Part 1 - Fuel Biocide Dosing Task

1. Does your organisation carry out fuel biocide treatments? If not, please continue to Part 2.

☐ Yes
☐ No

2. Which aircraft types receive the biocide treatment?

3. How many biocide treatments were carried out in the following years?

2017:

2018:

2019:

4. Which personnel (i.e. mechanic, LAE etc.) carry out the biocide treatments in your organisation?

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5. How is the biocide applied - manual dosing, metered injection fuel cart, or other?

- [ ] Manual dosing
- [ ] Metered injection fuel cart
- [ ] Other (please state method in box below)

Other method:

6. If manual dosing is used, how is the biocide applied?

- [ ] N/A, manual dosing not used
- [ ] Direct application into the aircraft's fuel tanks
- [ ] Into a fuel bowser prior to refuelling the aircraft with dosed fuel
- [ ] Other (please state method in box below)

Other method:

7. Does your organisation operate a fuel bowser for biocide-dosed fuel?

- [ ] Yes
- [ ] No

8. Does your organisation operate a metered injection fuel cart for biocide application?

- [ ] Yes
- [ ] No

9. Please describe how the quantity of biocide to be applied is determined, and who performs the calculation?

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10. Is the biocide quantity calculation checked, once it has been performed?

☐ Yes (please describe in box below)
☐ No

Calculation check method:

11. Does your organisation classify the application of biocide as a Critical Maintenance Task as defined in EASA Part M, M.A.402(h) *'Critical Maintenance Tasks'*? If yes, please describe how this classification affects how the task is performed in the box below.

☐ Yes (please describe in box below)
☐ No

Effect on biocide application task (or attach separate documents):

12. Is any specific training provided for personnel carrying out the biocide dosing task?

☐ Yes (please describe in box below)
☐ No

Training provided (or attached separate documents):

13. Does your Stores Department have any procedure in place to prevent the issuance of unusually large quantities of material or chemicals to maintenance personnel?

☐ Yes (please describe in box below)
☐ No

Procedure detail (or attach separate documents):

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14. Please describe any problems that your organisation has encountered when performing biocide treatments, including any previous occasions where the treatment was performed using an incorrect dose of biocide.

Part 2 - Airbus Troubleshooting Manual

This section of the questionnaire is concerned with how engineers use the Troubleshooting Manual for Airbus aircraft and any difficulties that your organisation has experienced when using the Troubleshooting Manual. The AAIB recognises that practice may have changed recently, we are interested in practice prior to 21 April 2020.

15. Does your organisation perform troubleshooting for Airbus aircraft? If not, please continue to Part 3.

☐ Yes
☐ No

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16. How did your engineers access the Airbus Troubleshooting Manual? Please tick all that apply:

- ☐ airnavX
- ☐ AirN@V
- ☐ edoc browser
- ☐ Private/standalone version of Airbus Navigator
- ☐ Other (please specify):

Other:

17. Did your organisation have a policy or procedure describing how engineers should use the Troubleshooting Manual? If yes, please describe or attach a copy of the policy or procedure.

- ☐ Yes
- ☐ No

Description of policy or procedure:

18. What method(s) did your engineers use to find the appropriate procedure in the Trouble Shooting Manual using airnavX? Tick all that apply:

- ☐ N/A – Engineers do not use airnavX
- ☐ 'Troubleshooting' function
- ☐ 'Data search' function
- ☐ Browsing chapter list via 'My Library'
- ☐ Other (please specify)

Other:

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19. What method(s) did your engineers use to find the appropriate procedure in the Trouble Shooting Manual using AirN@v / Maintenance? Tick all that apply:

- ☐ N/A – Engineers do not use AirN@v / Maintenance
- ☐ 'Start Troubleshooting' function under the 'TSM' tab
- ☐ 'Troubleshooting' tab
- ☐ 'Search' tab
- ☐ Browsing chapter list via 'Table of contents'
- ☐ Other (please specify)

Other:

20. What training did your engineers receive on how to use the Troubleshooting Manual?

21. Does your organisation delegate access to your Airbus maintenance data to other Part 145 AMOs?

- ☐ Yes
- ☐ No

22. Please describe any problems that your engineers have encountered when using the Airbus Troubleshooting Manual, including any previous occasions when an incorrect procedure was retrieved from the manual.

Appendices

Part 3 - Response to the G-POWN Serious Incident

23. Have you read the AAIB Special Bulletin S1/2020 which describes the Serious Incident that occurred to G-POWN on 26 February 2020? Link: AAIB S1/2020

☐ Yes
☐ No

24. Will your organisation be taking any safety action in response to Special Bulletin S1/2020?

☐ Yes (please describe action(s) below)
☐ No

Safety action(s):

25. Would you be willing for AAIB Inspectors to visit, or meet with you virtually, to collect more detailed information about these topics?

☐ Yes
☐ No

Appendices

Appendix C

Post-Flight Reports

Stansted-Gatwick (25 February)

Title: Flight Details

Leg	-3	**Flight Number**	ZT411Y	**A/C ID**	G-POWN
From	STN	**First Event Date**	25 Feb 20 - 05:18		
To	LGW	**Last Event Date**	25 Feb 20 - 06:10		

CMS:PFR_TAB

Fault Tracking	Phase	Date Time	ATA	Source	Title	Subtitle	Class	Occurrence History	Priority	Dispatch Message	Work	Note
OCCURRENCE	02-ENG START	25 Feb 20 - 05:26	7700		[ENG 1 HP FUEL VALVE]			x	High	false		
					[null]					false		
OCCURRENCE	02-ENG START	25 Feb 20 - 05:27	761200	EIU1FADEC	[MASTER LEVER, HMU ENG1B]			x		false		
					[null]					false		
	02-ENG START	25 Feb 20 - 05:27	383141	TOILET	[TOILET ASSY LAV E]			x		false		
					[null]					false		
	02-ENG START	25 Feb 20 - 05:28	279334	AFS	[AFS:ELAC2]			............x.x		false		
					[null]					false		
	05-LIFT OFF	*25 Feb 20 - 05:40*		*PHC 1*	*[]*			x		*false*		
					[null]					false		
OCCURRENCE	05-LIFT OFF	25 Feb 20 - 05:40	303134	PHC 1	[PHC 6DA1]			x		false		
					[null]					false		

Gatwick-Krakow (25 February)

Title: Flight Details

Leg	-2	**Flight Number**	ZT111	**A/C ID**	G-POWN
From	LGW	**First Event Date**	25 Feb 20 - 07:10		
To	KRK	**Last Event Date**	25 Feb 20 - 09:26		

CMS:CFR_TAB

Fault Tracking	Phase	Date Time	ATA	Source	Title	Occurrence History	Priority	Work	Note
OCCURRENCE	02-ENG START	25 Feb 20 - 07:15	345800	AFS	[AFS:GPSSU1 2]	x			
					[null]				
	02-ENG START	25 Feb 20 - 07:15	383141	TOILET	[TOILET ASSY LAV E]	xx			
					[null]				
	05-LIFT OFF	*25 Feb 20 - 07:29*		*PHC 1*	*[]*	x			
					[null]				
OCCURRENCE	05-LIFT OFF	25 Feb 20 - 07:29	303134	PHC 1	[PHC 6DA1]	xx			
					[null]				
OCCURRENCE	06-CRUISE	25 Feb 20 - 08:28	345831	ECAM 1	[FWC1 :NO DATA FROM GPS2]	x			
	06-CRUISE	25 Feb 20 - 08:28	3458		[NAV GPS1 FAULT]	x	Medium		
	06-CRUISE	25 Feb 20 - 08:28	3458		[NAV GPS2 FAULT]	x	Medium		
					[null]				
	06-CRUISE	25 Feb 20 - 08:28	3400		[IR]	x			
	06-CRUISE	*25 Feb 20 - 08:28*	*3400*		*[NAV ADS-B RPTG 1 FAULT]*	............x.x			
	06-CRUISE	*25 Feb 20 - 08:29*	*3400*		*[NAV ADS-B RPTG 2 FAULT]*	x			
	06-CRUISE	*25 Feb 20 - 08:30*	*3400*		*[NAV ADS-B RPTG 1 FAULT]*	............x.x			
					[null]				
	06-CRUISE	25 Feb 20 - 08:28	3436		[NAV ILS 1 2 FAULT]	x	Medium		
	06-CRUISE	25 Feb 20 - 08:28	343631	CFDS	[NO MMR 2 DATA]	x			
					[null]				

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Krakow-Gatwick (25 February)

Title: Flight Details

Leg	-1	Flight Number	ZT112	A/C ID	G-POWN
From	KRK	First Event Date	25 Feb 20 - 19:52		
To	LGW	Last Event Date	25 Feb 20 - 22:25		

CMS:PFR_TAB

Fault Tracking	Phase	Date Time	ATA	Source	Title	Subtitle	Class	Occurrence History	Priority	Dispatch Message	Work	Note
OCCURRENCE	02-ENG START	25 Feb 20 - 19:56	2300		[CIDS 2]			..........X...X		false		
OCCURRENCE	02-ENG START	25 Feb 20 - 19:56	237334	CIDS 2	[DIR2(102RH)]			X		false		
					[null]					false		
	02-ENG START	25 Feb 20 - 19:57	7700		[ENG 1 START FAULT]			X	Low	false		
					[null]					false		
OCCURRENCE	06-CRUISE	25 Feb 20 - 21:52	344133	RADAR 1	[WXR1(1SQ1)]			...X.......X..X		false		
					[null]					false		
	06-CRUISE	25 Feb 20 - 21:58	7700		[ENG 2 STALL (2)]			X	Low	false		
					[null]					false		

Gatwick-Gatwick (25/26 February) – event flight

Title: Flight Details

Leg	0	Flight Number	ZT411W	A/C ID	G-POWN
From	LGW	First Event Date	25 Feb 20 - 23:48		
To	LGW	Last Event Date	26 Feb 20 - 01:07		

CMS:PFR_TAB

Fault Tracking	Phase	Date Time	ATA	Source	Title	Subtitle	Class	Occurrence History	Priority	Dispatch Message	Work	Note
OCCURRENCE	02-ENG START	25 Feb 20 - 23:53	2300		[CIDS 2]			.........X...XX		false		
OCCURRENCE	02-ENG START	25 Feb 20 - 23:53	237334	CIDS 2	[DIR2(102RH)]			XX		false		
					[null]					false		
OCCURRENCE	02-ENG START	25 Feb 20 - 23:54	7700		[ENG 1 FAIL (2)]			X	Low	false		
					[null]					false		
	02-ENG START	25 Feb 20 - 23:55	279334	AFS	[AFS:ELAC2]			.........X.X..X		false		
					[null]					false		
	06-CRUISE	26 Feb 20 - 00:11	7700		[ENG 2 STALL (3)]			XX	Low	false		
					[null]					false		
	06-CRUISE	26 Feb 20 - 00:12	2161		[AIR PACK 1 2 FAULT]			X	Low	false		
					[null]					false		

Appendices

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AIRCRAFT SERIOUS INCIDENT REPORT CORRECTION

Aircraft Type and Registration:	Airbus A321-211, G-POWN
Date & Time (UTC):	26 February 2020 at 0009 hrs
Location:	London Gatwick Airport, UK
Information Source:	AAIB Field Investigation

In February 2023, it was noted that Figures 19 and 21 in the report were incorrect in that they were identical to Figures 18 and 20 respectively. The correct versions of Figures 19 and 21 are shown below.

While making this correction, the opportunity was also taken to update Figure 9; change the titles of Figures 21 and 22 to make them clearer; and correct a typographical error in Section 1.6.7.7.

Commencing with the typographical error in Section 1.6.7.7, the other corrections will follow on subsequent pages.

Page 23: Section 1.6.7.7 (penultimate sentence)

New text:

> It has a specific gravity of 1,040 kg / m^3 and is available in 5 or 20 kg polythene containers.

Original text:

> It has a specific gravity of 1.04 kg / m^3 and is available in 5 or 20 kg polythene containers.

The online version of this report was corrected on 11 May 2023 and can be read on the AAIB website at: https://www.gov.uk/aaib-reports/aircraft-accident-report-aar-1-slash-2021-airbus-a321-211-g-pown-26-february-2020 [accessed April 2023].

Details of the correction were published in the May 2023 AAIB Bulletin.

Correct version of Figure 19:

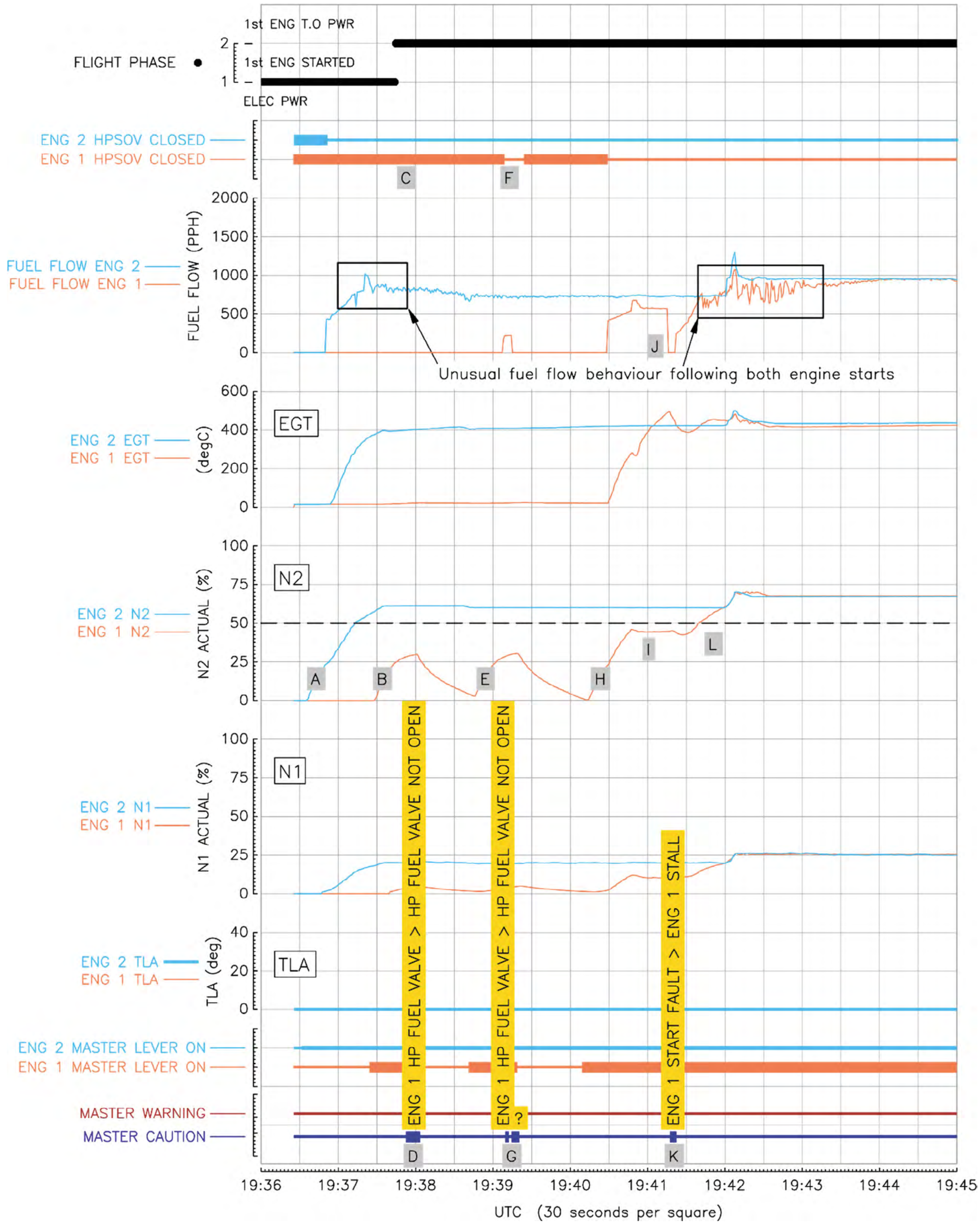

Figure 19

Krakow to Gatwick flight engine starts

Original version of Figure 19:

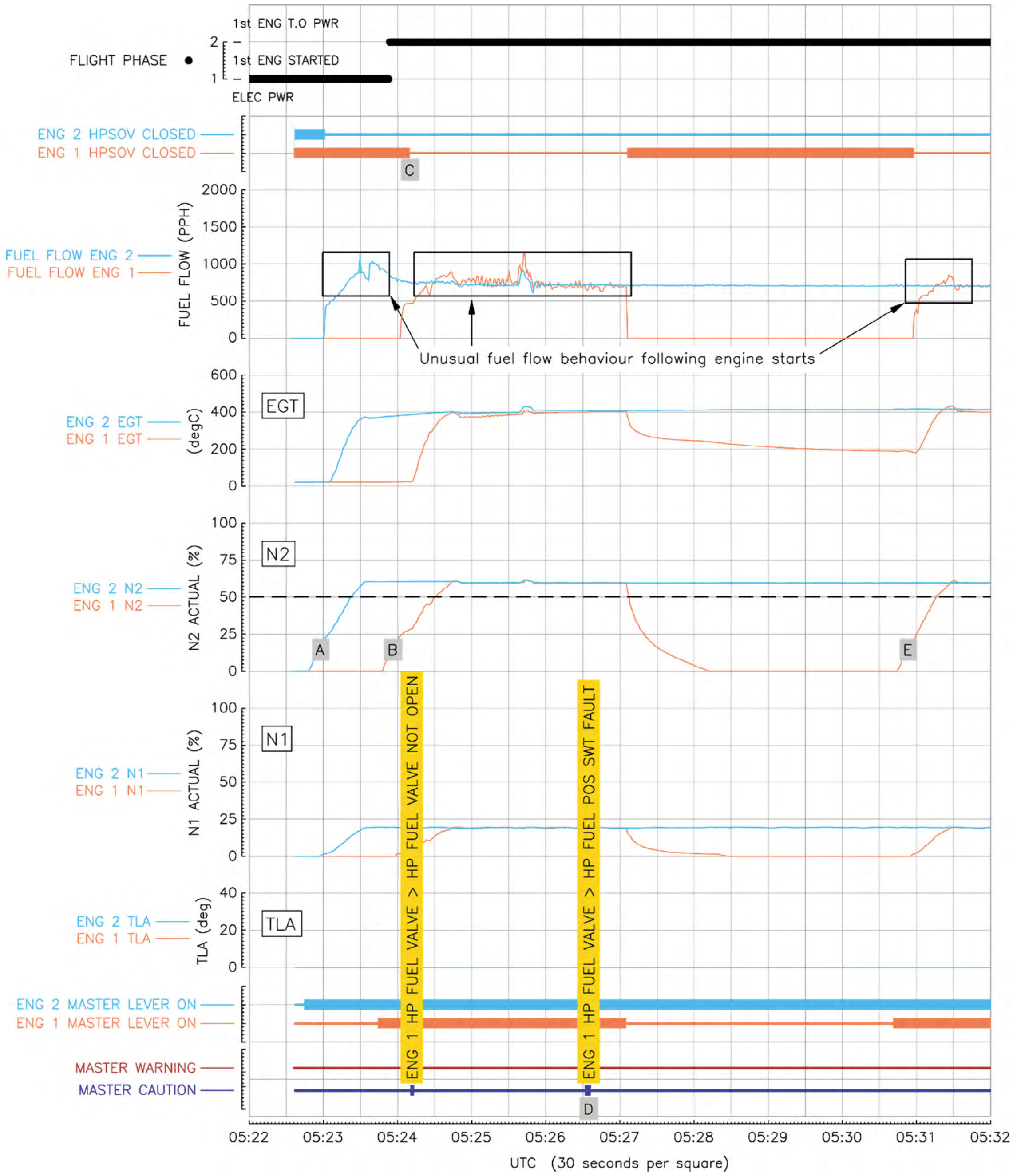

Figure 19

Krakow to Gatwick flight engine starts

Correct version of Figure 21:

This also includes the new title for this figure.

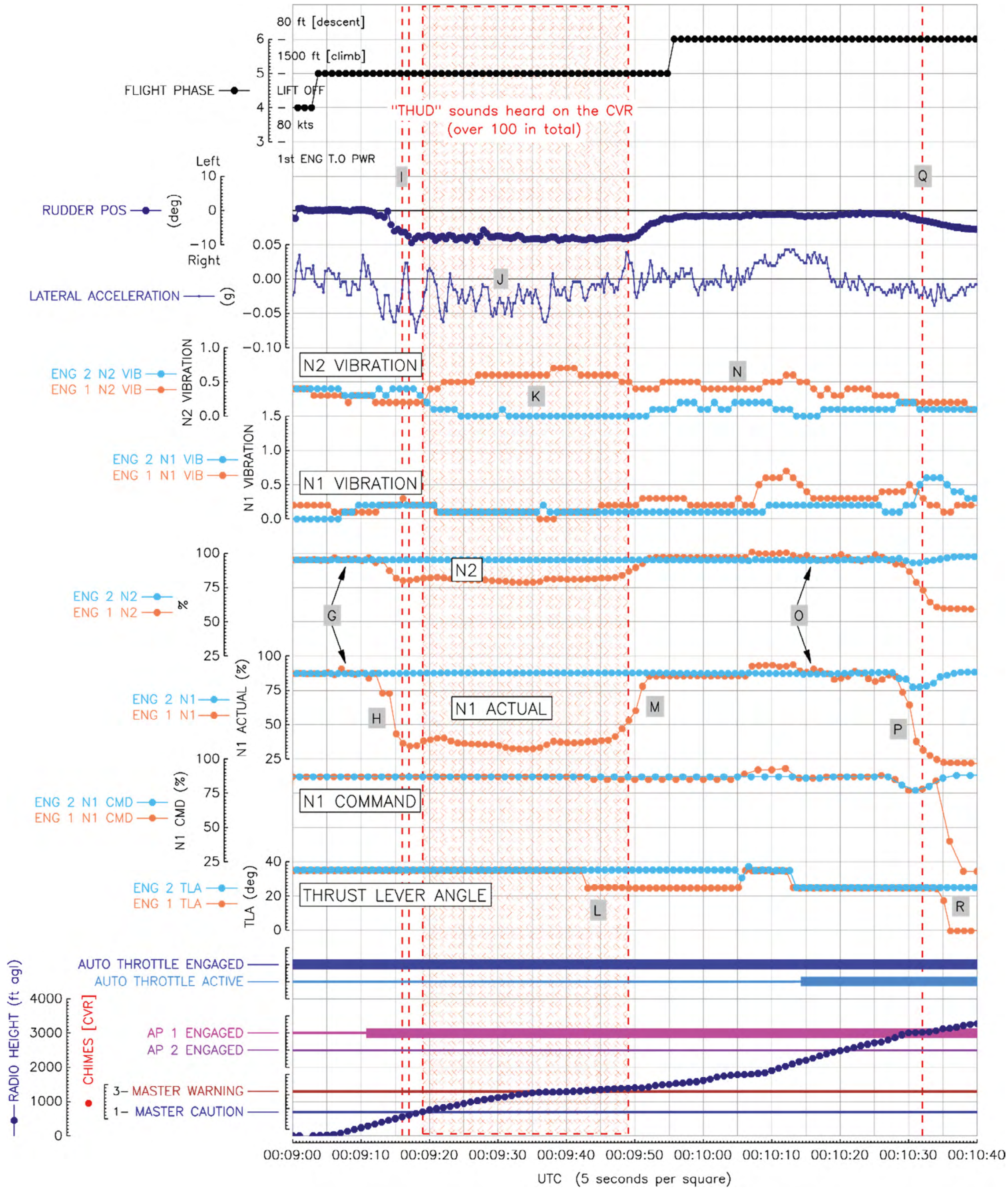

Figure 21

Overview of flight data from the incident (plot 1 of 2)

Original version of Figure 21:

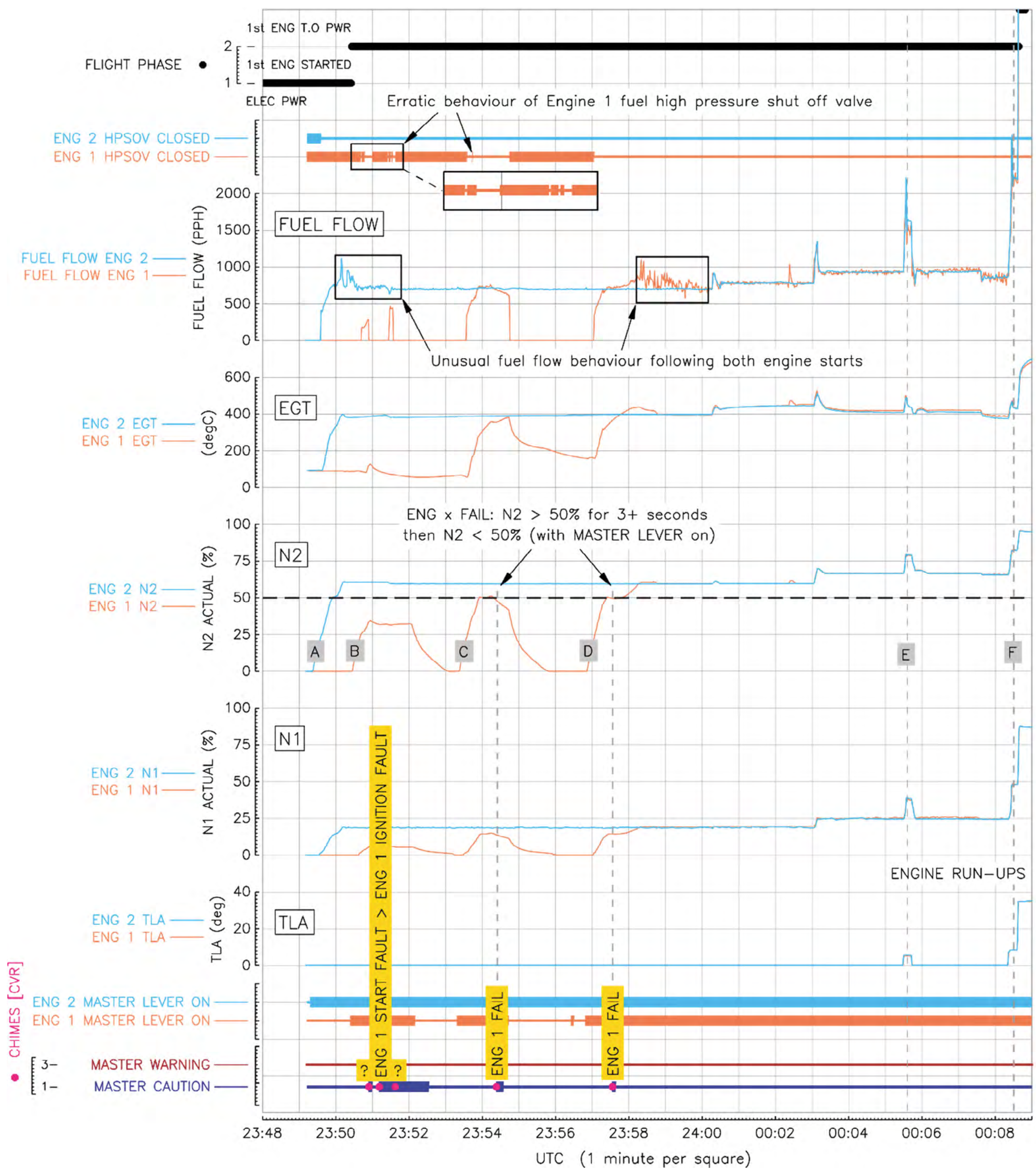

Figure 21

Overview of incident flight data (plot 1 of 2)

New version of Figure 9:

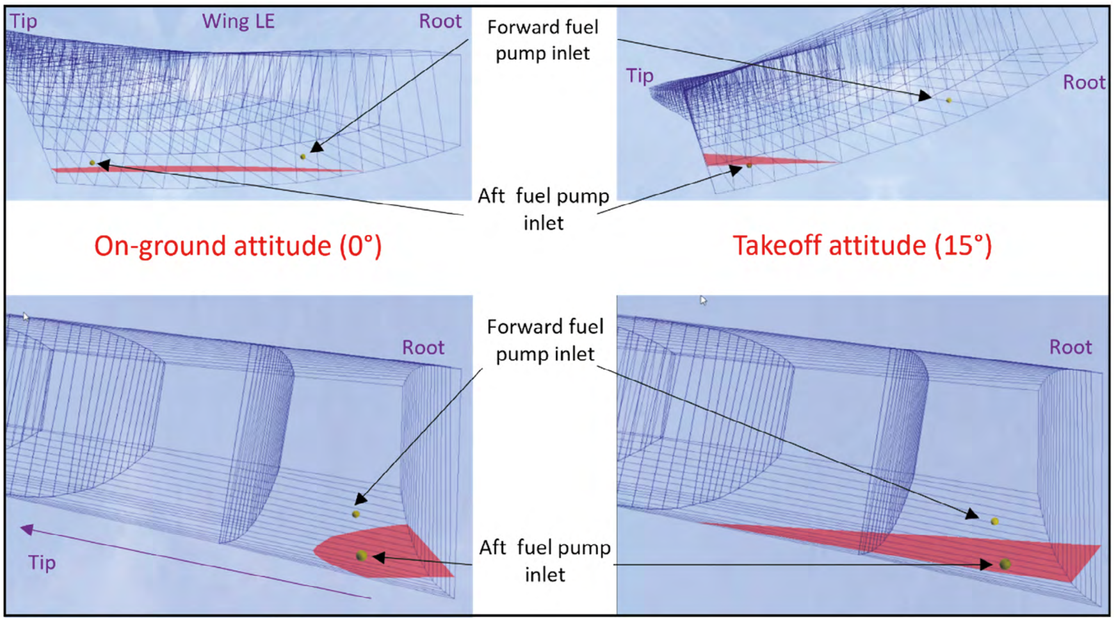

Figure 9

View of the left wing fuel tank at the root showing the fuel pump inlet positions in relation to approximately 30 kg of Kathon (shown in red) (images courtesy of Airbus)

Original version of Figure 9:

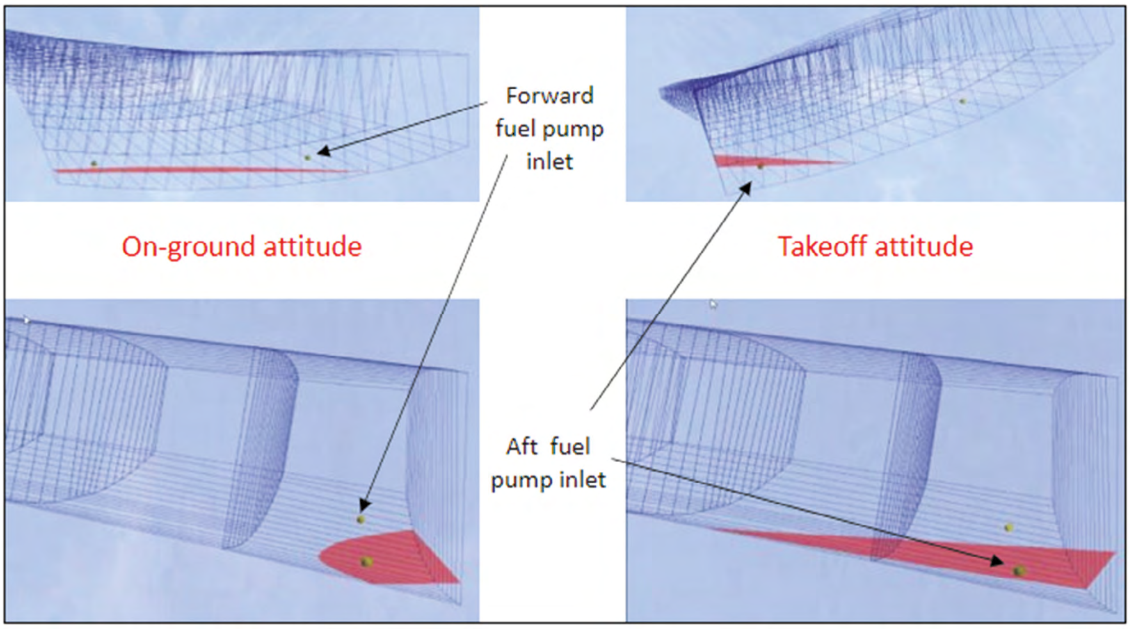

Figure 9

View of the left wing fuel tank at the root with the fuel pump inlet positions in relation to approximately 30 kg of Kathon.
Left – on-ground (0°). Right – takeoff (15°)
(images courtesy Airbus)

New title to Figure 22:

Figure 22 remains the same, however the title has been amended.

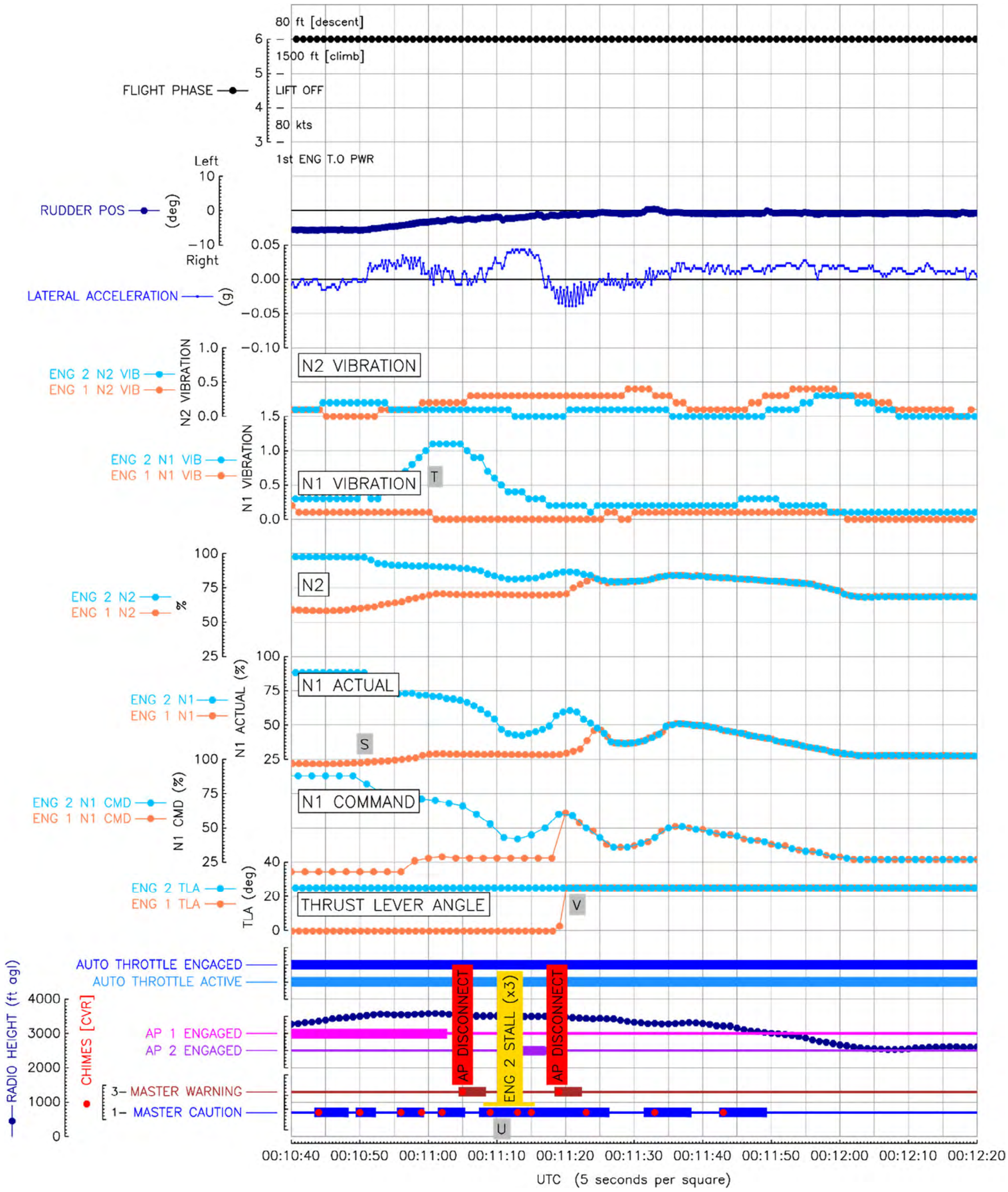

Figure 22

Overview of flight data from the incident (plot 2 of 2)

Original title to Figure 22:

The original title to Figure 22 read:

Overview of incident flight data (plot 2 of 2)

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Unless otherwise indicated, recommendations in this report are addressed to the appropriate regulatory authorities having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken. In the United Kingdom the responsible authority is the Civil Aviation Authority, Westferry Circus, Canary Wharf, London, E14 4HD.

Aircraft Accident Report 1/2021

Report on the serious incident to
Airbus A321-211, G-POWN
at London Gatwick Airport
on 26 February 2020