ACCIDENT

Aircraft Type and Registration:	ERJ 190-200 LR (Embraer 195), G-FBEJ
No & Type of Engines:	2 General Electric Co CF34-10E7 turbofan engines
Year of Manufacture:	2007 (Serial no: 19000155)
Date & Time (UTC):	28 February 2019 at 0745 hrs
Location:	Exeter Airport, Devon
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 5 Passengers - 100
Injuries:	Crew - 1 (Minor) Passengers - 1 (Serious)
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	61 years
Commander's Flying Experience:	13,211 hours (of which 3,069 were on type) Last 90 days - 77 hours Last 28 days - 15 hours
Information Source:	AAIB Field investigation

Synopsis

As the thrust levers were advanced for takeoff, on an early morning scheduled passenger flight, the flight crew detected an unusual odour and observed smoke entering the cockpit. They then moved the thrust levers to the idle position and applied the parking brake. The cabin crew subsequently reported that there were smoke and fumes in the cabin. Following an assessment of the situation, the commander initiated an emergency evacuation. During the evacuation, passengers who evacuated via the overwing exits reported being unsure of how to get down from the wing to the ground and several re-entered the cabin and exited via one of the escape slides.

The smoke and fumes were subsequently attributed to an incorrectly performed engine compressor wash procedure, which was carried out by maintenance personnel the night before the occurrence flight.

As a result of the findings of this investigation, the European Union Aviation Safety Agency (EASA) has undertaken two safety actions relating to the certification requirements for overwing emergency exits. The operator has also undertaken several safety actions relating to passenger safety briefings, processes for maintenance planning, engineer training, competency and welfare and monitoring of ground equipment.

Four Safety Recommendations are made relating to the certification requirements for overwing exit markings and the height requirement for overwing exits to be equipped with an assisted means of escape.

History of the flight

The aircraft was operating the first sector of the day and was scheduled to fly from Exeter Airport, UK to Alicante Airport, Spain. While the aircraft was being prepared for flight, both pilots reported being aware of a sweet-smelling odour after the APU and APU bleed had been turned on to heat the cabin. They described the smell as being like caramel but considered that such odours were not unusual after the APU is started and the air conditioning is switched on at the beginning of the day.

Following completion of passenger boarding, the aircraft pushed back and taxied before being cleared to enter Runway 26, back-track and line up for takeoff. It was daylight, the visibility was in excess of 10 km and the wind was from 210° at 5 kt.

The APU was shut down as the aircraft entered the runway and the air conditioning packs remained on with air supplied from the engines. A few seconds later, while back-tracking, both pilots became aware of fumes in the flight deck with a different odour, which the co-pilot described as being like paint or white spirit. The wind was behind the aircraft at this point, so they initially thought the fumes were due to exhaust gas ingestion. Upon lining up at the runway threshold the flight crew had a brief discussion about whether the fumes were decreasing and decided that they were.

Upon receiving takeoff clearance, the co-pilot advanced the thrust levers to 40% while holding the aircraft on the brakes and checked the engine indications, which were all normal. He then slowly advanced the thrust levers towards the takeoff setting, while still holding the aircraft on the brakes. As the engines reached approximately 55% power, he saw something out of the corner of his eye which he believed to have been a puff of smoke coming from an air conditioning vent. He immediately stated that he was not happy with the situation and retarded the thrust levers to idle. By then the smell of fumes had grown worse and smoke was visibly entering the flight deck.

The commander set the park brake and asked the co-pilot to turn the engine bleeds and air conditioning packs to OFF and the flight deck windows were opened to ventilate the flight deck. There were no EICAS messages or warnings.

The commander established contact with the senior cabin crew member (SCCM), who had simultaneously been trying to contact the flight deck. The SCCM reported that there was smoke and fumes in the cabin, but that the cabin crew could not identify the source.

The commander decided to evacuate the aircraft. The co-pilot immediately selected FLAP 5, notified ATC of the intention to evacuate and requested assistance. Both pilots then carried out the Emergency Evacuation 'vital actions'. After the commander had given the order to evacuate over the passenger address system, the flight crew followed the EMERGENCY EVACUATION checklist on the back of the QRH.

The Airport Rescue Fire Fighting Services (ARFFS) arrived at the aircraft and were briefed on the nature of the emergency by the co-pilot through the flightdeck window. The ARFFS then assisted passengers on the ground as they exited the aircraft.

Aircraft evacuation

General

The aircraft was equipped with six emergency exits: four doors fitted with inflatable slides, two at either end of the cabin, and two 'Type III' emergency exits located approximately midway along the cabin, over the wings. On hearing the order to evacuate, the cabin crew opened their allocated doors and all four escape slides inflated automatically. Passengers opened the overwing exits.

The cabin crew reported that the passengers remained calm. The vast majority of passengers reported being able to hear and follow the announcements made by the flight and cabin crew, and the instructions contained therein. Some passengers attempted to take baggage with them, but most complied with the emergency evacuation instructions and left their belongings behind. Several passengers commented that the cabin crew were calm throughout and acted efficiently and professionally.

Overwing exits

Passengers evacuating via the overwing exits reported that once out on the wing, there was confusion as to how they should get off the wing down to the ground. Passengers still in the cabin reported that this led to a bottle-neck forming around the overwing exits. Two passengers who evacuated via the left overwing exit were able to jump down from the wing and assist other passengers to the ground. Despite this, several passengers commented that it was a very long drop to the ground and some landed awkwardly, sustaining minor injuries. Many of the passengers who exited via the overwing exits commented that the wing surface was "very slippy" and one fell over resulting in a minor injury. The overriding comment from those who had exited via the overwing exits was that it was not obvious to them that they were meant to climb off the wing via the trailing edge and some re-entered the cabin to find an alternative exit route. A 61 cm-wide walkway was demarcated at the wing root in black paint, with arrows pointing towards the trailing edge (Figure 1). None of the passengers mentioned noticing this, but several did mention a lack of instructions, support or guidance once they were out on the wing.

Escape slides

Several passengers commented that they found the rear slides very steep and were surprised by the speed at which they slid down them. The slides at the rear do not round out at the bottom unlike the front slides, which means that individuals slid very fast onto the ground. This, and attempts by passengers to slow themselves on the slides, were the principal causes of the reported injuries. Two passengers assisted other passengers at the bottom of the rear slides. A number of passengers suffered minor cuts and grazes and one elderly passenger who had exited via D2R sustained a broken ankle. Two cabin crew members who exited via the rear slides, one carrying the megaphone and the other carrying the first aid kit, reported that this made it difficult to slow themselves down and one sustained an ankle injury.

Cabin crew noticed that some passengers hesitated when instructed to jump and slide. They therefore advised the passengers to sit and slide rather than jump and slide.

Figure 1

Overwing exit escape route markings on E195 (view towards wing trailing edge)

When the cabin crew believed that all passengers had left the aircraft, they checked the cabin and found several passengers stood on the wings unwilling to jump due to the height above the ground. These passengers were escorted back into the cabin and subsequently exited via the rear slides.

On completing the emergency evacuation checklist, the commander left the flight deck and confirmed with the SCSM that all the passengers and other cabin crew members had evacuated. They were joined by the co-pilot and all three left the aircraft via the forward left slide. Out of the 100 passengers on board G-FBEJ, 93 completed AAIB questionnaires regarding the evacuation. Figure 2 illustrates the exits used by the passengers, correlated by seat position.

Post-evacuation

Following the evacuation, the ARFFS entered the aircraft with protective breathing equipment and a thermal imaging camera but were unable to identify the source of the smoke and fumes.

The flight crew later returned to the aircraft to retrieve personal belongings and the commander noted that although the slat/flap selector was set to FLAP 5, the EICAS showed that the movement of the flaps and slats had not been completed. He concluded that insufficient time had elapsed between selecting FLAP 5 and shutting down the engines for the slats and flaps to deploy to the selected positions. The commander commented that this was not a situation he had encountered during simulator training before, when an evacuation most commonly occurs following a rejected takeoff scenario. In that scenario, FLAP 5 is selected as soon as the decision to reject is made and the flaps have time to travel to the selected position while the aircraft is slowed, turned into wind and stopped, before the emergency evacuation drill is actioned.

The FLAP 5 selection is made to facilitate passengers, exiting via the overwing exits, to get off the wing by sliding down the extended flaps. Figure 3 shows the drop to the ground from the left wing during the evacuation. The operator subsequently measured the height of the wing trailing edge above the ground when the flaps were not deployed and determined that it would be in excess of 2 m, depending on the aircraft weight and fuel load.

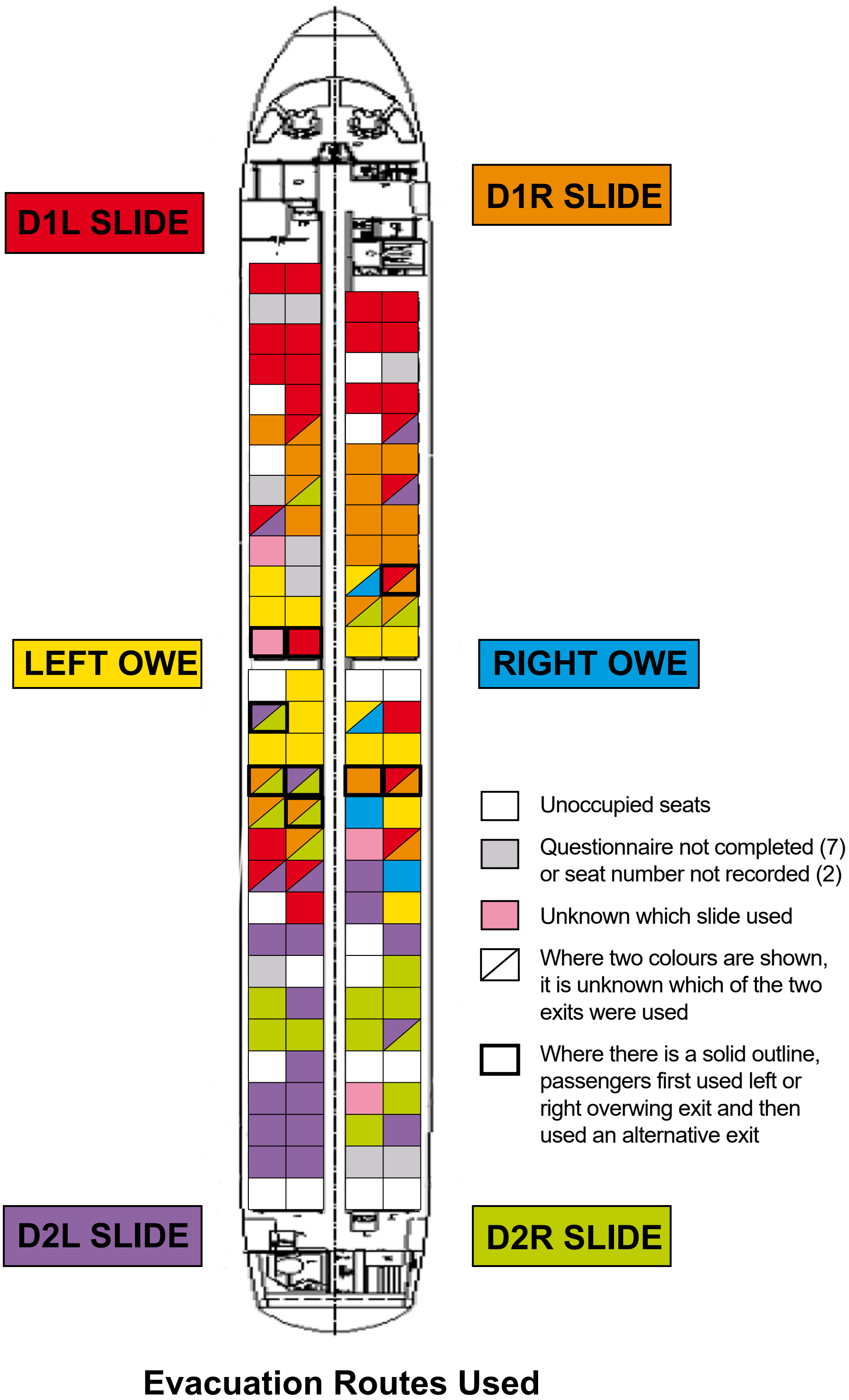

Figure 2

Evacuation routes used by passengers, correlated by seat position

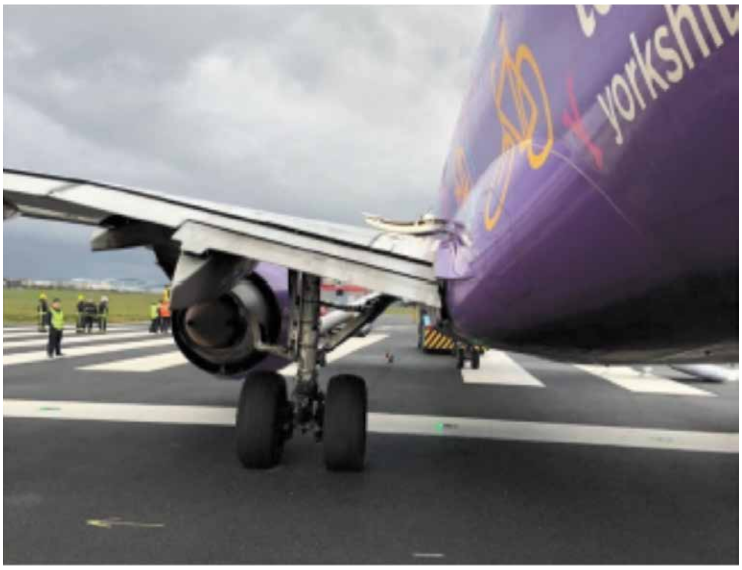

Figure 3

Drop to the ground from wing trailing edge with flaps in FLAP 1 setting

Pre-flight emergency briefing

Prior to departure, passengers seated next to the overwing exits were briefed by the cabin crew on how to operate the exit. While the cabin crew passenger brief for the overwing exits included mention of the height between the exit and the wing surface and instructions on the direction of evacuation, it did not provide instructions on how the passengers should get off the wing (eg jump, or sit and slide).

The passenger safety information cards, provided for all passengers, included diagrams showing the direction of evacuation from the wing but it was not clear whether passengers would understand that they need to slide off the wing from the information depicted on the card.

Following this accident, the operator revised its briefing to passengers seated next to the overwing exits of the Embraer 195 (E195). Changes included: simplifying terminology, instructing those passengers of the need to be first out on the wing, informing them of the need to help and direct other passengers, and highlighting that there is no escape slide attached to the overwing exits.

Recorded information

A review of the DFDR data confirmed that the flap selector lever was moved from the takeoff flap setting (FLAP 1) to FLAP 5. Although the flaps started moving in response to this selection, the engine 1 and 2 selectors were set to the OFF position approximately 2 seconds later when the flight crew shutdown the engines. This removed electrical power to the flaps and prevented them from travelling to the selected position. In the FLAP 1 position the flap angle had been 6.9°; the flaps reached 7.2° before stopping.

Evacuation procedures

The operator's Emergency Evacuation vital actions and callouts, assigned by flightcrew member are shown in Figure 4:

Table 3.5 – Emergency Evacuation Actions and Call-outs	
Captain	**First Officer**
"Carry out the emergency evacuation procedure"	
Puts the parking brake on	
	Confirms Flap 5
Sets both thrust levers to IDLE Sets both START/STOP selectors to STOP	
	Pulls fire handle 1 and rotates it to the left Pulls fire handle 2 and rotates it to the right (The fire handle actions are not required if the engine fire checklist has been completed) Presses the APU emergency stop button Presses the APU fire extinguishing button Presses the pressurisation dump button
Sets the passenger seat belt signs to OFF	
"This is the Captain, Evacuate, Evacuate." Notifies ATC	
Both pilots review the emergency evacuation checklist	
	Selects the batteries off

Figure 4

Emergency Evacuation actions from operator's operations manual

The E195 QRH EMERGENCY EVACUATION checklist is shown in Figure 5. The flight crew did not action the QRH SMOKE/FIRE/FUMES checklist.

EMERGENCY EVACUATION

EMBRAER 195

EMERGENCY EVACUATION	
Emergency/Parking Brake...............	ON
SLAT/FLAP Lever...........................	5
Thrust Levers...................................	IDLE
Engine 1 and 2 START/STOP Selectors...	STOP
Engine 1 and 2 FIRE EXTINGUISHER Handles..............	PULL AND ROTATE (1-L and 2-R)
APU EMER STOP Button................	PUSH IN
Fire Extinguisher APU Button..........	PUSH
DUMP Button...................................	PUSH IN
ATC..	NOTIFY
Emergency Evacuation....................	ANNOUNCE
BATT 1 and BATT 2 Knobs.............	OFF

Figure 5

QRH Emergency evacuation checklist

Certification requirements

The E195 is a derivative model of the E190 and both have been certificated by the FAA and the EASA. Certification requirements for emergency egress and escape routes on large transport aircraft, specified in FAR 25.810[1] and CS 25.810[2] respectively, only require provision of evacuation slides for exits or escape routes, overwing or otherwise, that are 1.8 m (6 ft) or more above the ground. For lesser heights, passengers are expected to jump down to the ground.

Information from the aircraft manufacturer

The aircraft manufacturer was not aware of any previous events involving delays in emergency evacuation due to the flaps not reaching a surface deflection of 20°, which corresponds to FLAP 3, 4 AND 5. It stated that it did not consider the evacuation checklist required amendment as a result of this incident, because the normal flow of actions allows enough time for the flaps to reach a position beyond FLAP 1, which has a flap surface deflection of 7°. It indicated that, among the available takeoff and landing configurations, FLAP 1 results in the greatest flap trailing edge height above ground and complies with the maximum of 6 ft certification requirement of FAR 25.810(d), under which the E190/195 aircraft were certified.

Additional information

Previous evacuation incidents

The AAIB investigated a serious incident on 1 August 2008, in which the cabin of an E195 G-FBEH (EW/C2008/08/01) filled with smoke and fumes during flight. An emergency evacuation was subsequently carried out, during which passengers using the overwing exits experienced similar problems getting from the wing to the ground. As a result of that investigation the AAIB made Safety Recommendation 2010-007.

Safety Recommendation 2010-007

It is recommended that the European Aviation Safety Agency review the design, contrast and conspicuity of wing surface markings associated with emergency exits on Public Transport aircraft, with the aim of ensuring that the route to be taken from wing to ground is marked unambiguously.

Safety Recommendation 2010-007 was a re-issue of previous Safety Recommendation 2002-42, which had been made to the Civil Aviation Authority (CAA) and Joint Aviation Authority (JAA), following an AAIB investigation into an incident on 1 April 2002 (EW/C2002/4/1), in which the cabin of a Fokker F28 filled with smoke. In FACTOR F7/2003[3], the CAA accepted Safety Recommendation 2002-42 and indicated that action was due to be taken by the end of October 2003. But no response was received from the JAA and the responsibility for aircraft certification within Europe subsequently passed to the EASA.

Footnote

1 US Federal Aviation Regulations (FAR), 14 Code of Federal Regulations (CFR), Part 25.810.
2 EASA Certification Specification (CS) 25.810.
3 https://publicapps.caa.co.uk/docs/33/FACTOR200307.PDF [accessed 23 June 2020].

In its initial response to Safety Recommendation 2010-007, the EASA agreed to review ways of improving the specifications relating to emergency exit escape routes. In its final response on this matter EASA indicated that a study it had commissioned in 2009 into cabin safety threats[4] (the 2009 EASA study) did not identify any issues relating to overwing exit markings, and on that basis could not justify changing the existing specifications of CS 25.810(c) on markings for overwing exits.

Royal Aeronautical Society paper on Emergency evacuation

In April 2018, the Royal Aeronautical Society (RAeS) published a paper titled '*Emergency evacuation of commercial passenger aeroplanes'* (RAeS paper). The intention of the paper was to provide aviation authorities, aircraft manufacturers, operators, and air accident investigation authorities, with a wide range of information on evacuation issues. With respect to aircraft which are not required to be equipped with evacuation slides, the paper states:

> *'For aeroplanes that are not required to be equipped with evacuation slides, passengers and crew will have to jump down from a height which some will find challenging or even injurious. Delays in an evacuation are possible if passengers decide to sit on the emergency exit sill and jump, or sit and slide at exits equipped with evacuation slides. This is more likely to be the case for elderly and infirm passengers, for children, as well as for adults with infants. The 1.8 metre maximum height limit for evacuation slides might be too high for such passengers to manage without serious injury.'*

With respect to overwing exits, the paper states:

> *'Having evacuated via a Type III or Type IV emergency exit, passengers usually have to reach the ground without any supervision from the aeroplane crew. Such an evacuation would normally be achieved by use of the trailing edge of the wing. Arrow markings are required to be on the surface of the wing to indicate the evacuation route but these are not always readily identifiable to evacuating passengers, and even less identifiable in conditions of darkness.*
>
> *For all aeroplanes, including those that have Type III or Type IV emergency exits installed over the wings, and do not need to meet the 1.8 metre (6 foot) CS 25 criteria for evacuation slides, the usual route for passengers to evacuate is by the trailing edge of the wing. In order to facilitate evacuation, the flight crew have to retract the wing spoilers and extend the trailing edge wing flaps. Failure to do so will hinder the evacuation and may cause injury to passengers and crew. Flight crew emergency evacuation checklists usually specify such actions; for example, the Boeing 737 evacuation checklist states: "Verify that the flaps are 40 before the engine start levers are moved to cutoff". Some operators have decided that this should be a checklist 'memory' item.'*

Footnote

[4] 'Study on CS-25 Cabin safety requirements', Issue 6, dated December 2009, prepared for the EASA.

The RAeS paper referenced an NTSB Safety Study on *'Emergency evacuation of commercial aeroplanes'* published in June 2000 (the NTSB safety study). Safety Recommendation A-00-79 made in the NTSB safety study, recommended that the FAA:

> *'Review the 6-foot height requirement for exit assist means to determine if 6 feet continues to be the appropriate height below which an assist means is not needed. The review should include, at a minimum, an examination of injuries sustained during evacuations.'*

The RAeS paper also identified that the 2009 EASA study addressed similar issues and quoted the following extract from it:

> *'The evidence available from accidents and research studies suggests that the requirement to jump to the ground from a height of 1.8m (6 feet) during evacuation, without assist means, may potentially cause serious injury or may delay the progress of an evacuation due to hesitation or unwillingness to jump.'*

Overwing escape route markings

As a result of the issues identified in the accident, the AAIB asked the EASA to review the subject of markings on overwing emergency exits. In its initial response the EASA indicated that all applicable certification requirements for the E195 with respect to evacuation from overwing emergency exits had been met. It stated:

> *'In general, EASA finds that the requirements applicable to the marking of evacuation paths over the wings of CS-25 types are adequate and ensure that evacuees are effectively directed to the safest location from which they can descend from the wing onto the ground. However, based on the experience gathered in certification projects in recent years, EASA considers to introduce a new [acceptable means of compliance] AMC 25.810(c) in order to identify acceptable guidelines and options for the measurement of the contrast between the marking of the escape path located over the wing and the background colour of the wing surface.'*

With regards to the requirement for the provision of escape slides in CS 25.810(a) and (d), the EASA indicated that it intended to discuss and coordinate with other aviation authorities and with the aviation industry. It outlined its intention to discuss these issues at an FAA Aviation Rulemaking Committee (ARC) on Emergency Evacuation Standards[5], which had been tasked to review data from commercial air transport accidents and incidents involving passenger evacuations in the past ten years, to identify safety issues. The EASA indicated that the ARC would provide a forum for participants to discuss and provide recommendations to the FAA on the certification of emergency evacuation

Footnote

[5] https://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/document/information/documentID/3983 [accessed 23 June 2020].

systems and procedures which may in the future be translated in harmonized rulemaking tasks by the participating Aviation Authorities. It stated that:

> *'EASA will propose to the ARC to evaluate to which extent we can consider reasonable that evacuees may jump from a 1.8 m height to reach the ground instead of benefitting from the installation of a properly designed emergency egress assisting* [sic].*'*

In April 2020, the EASA stated that its cabin safety expert had participated in the ARC meetings and provided the following update:

> *'The ARC has reached consensus to include in the report a recommendation to the FAA to consider, in coordination with other Aviation Authorities, if changes need to be introduced to the requirements currently included in 25.810 with the scope to allow easier identification of the evacuation path by the evacuees and their faster and safer transition from the wing to the ground. The regulatory changes may involve a combination of one or more of the following options:*
>
> 1. *Improvement of the marking that for each overwing exit describes the proper method of opening the exit (ref. 25.813(c)), to include, if the exit is over a wing, and the aircraft design does not include an off-wing assist means per 25.810(d), indication of the evacuation route on the wing.*
> 2. *improvement of marking visibility/design to facilitate better recognition by passengers evacuating through overwing exits of proper direction to exit from wing.*
> 3. *revision of the requirements under 25.810 to define conditions that would require an escape slide. Other factors may drive different recommendations for overwing exits (25.810(d)) verses non-overwing exits governed by 25.810(a).*
>
> *The report will include another recommendation that will address the need to improve passenger briefing materials in regards to egressing an overwing exit without assist means.'*

Aircraft maintenance

Engine compressor wash - general

During overnight maintenance on the night before the accident, an engine compressor wash was carried out on G-FBEJ's No 1 engine.

Aircraft gas turbine engines can accumulate substances such as dust, sand and salt on the compressor blades and stator vanes. This can lead to a reduction in compressor performance and increased fuel consumption. The engine manufacturer recommends engine cleaning to reduce contaminant build-up and counteract these effects. Compressor washes are performed by maintenance personnel, using a wash rig, which uses either water or a water and detergent mix.

Compressor wash rig used on G-FBEJ

The engine wash rig used on G-FBEJ was fitted with two pressurised fluid tanks, one which contained water and the other a water/detergent mix. During operation, the fluid can be directed into a water-wash manifold installed on the engine, to dispense water/detergent into the compressor.

Compressor wash procedure

The Engine Service Manual (ESM) task used by the maintenance personnel was 72-00-00-100-801 *'Engine performance recovery,'* revision date 31 March 2016. The following general information is included at the beginning of the ESM task:

> *'For some environments, washing with a cleaning solution … may be more effective than washing with water only….If a cleaning solution is used, it is important to follow instructions for rinsing and drying-out the bleed systems.'*

The ESM task lists several approved detergents[6] and indicates that the cleaning solution should be mixed according to a ratio of one part detergent to four parts water and rinses should be conducted with fresh water.

The task requires a minimum of two people, one to operate the engine and system controls in the cockpit and one to operate the compressor wash rig.

One subtask describes the procedure to wash the internal engine airflow components with water only and an alternative subtask[7] describes the procedure to do the wash with a cleaning solution. It recommends that to get the best cleaning results, two washes should be done as well as a soak period between application of the cleaner, followed by two rinses to make sure that the cleaning solution is removed. A further subtask[8] describes the rinse procedure and states that any remaining cleaning solution should be drained from the compressor wash rig and the fluid tanks filled with rinse solution (water).

Post compressor wash engine drying procedure

Following completion of the engine wash and disconnection of the compressor wash rig, a further subtask[9] describes the procedure to dry the internal engine airflow components. A caution in the procedure states:

> *'FAILURE TO ADEQUATELY DRY THE INTERNAL ENGINE AIRFLOW COMPONENTS AFTER AN ENGINE WASH CAN RESULT IN ODOR-IN-CABIN EVENTS WHICH HAVE CONTRIBUTED TO SITUATIONS SUCH AS AIR TURNBACKS AND ABORTED TAKEOFFS. PROPER ENGINE DRY-OUT IS IMPORTANT TO PREVENT THOSE SITUATIONS.'*

Footnote

6 The detergent used by the operator was Turco 5884.
7 ESM Subtask 72-00-00-110-009.
8 ESM Subtask 72-00-00-170-004.
9 ESM Subtask 72-00-00-410-004.

The procedure instructs personnel to run the engine at idle for five minutes before operating the anti-ice and engine bleed systems, while the engine continues to be run at idle. The aircraft's pneumatic and environmental control (ECS) systems use bleed air extracted from the high pressure compressor (HPC). The purpose of this procedure is to purge fluid which may be trapped in the engine bleed ducts or ECS. A note in the procedure states:

> *'… If the engine is installed on an aircraft, the idle speed cannot fully dry-out the aircraft ECS system. If the ECS system can be verified to be dry or a water-wash without cleaner was done, engine run at 65 percent N1[10] can be considered optional. If not, drying-out the ECS system via operation up to 65 percent N1 is recommended.'*

At low engine power settings engine bleed air is extracted from the ninth stage of the HPC while at high engine power settings, bleed air is extracted from the fifth stage of the HPC. The purpose of reaching 65 % N1 during the engine dry-out ground run is so that the engine speed is high enough that the ECS bleed source has switched to HPC fifth stage bleed, so that the fifth stage bleed ducts are dried out. A further caution states:

> *'OPERATORS MAY OBSERVE SOME RESIDUAL VAPOR IN THE CABIN AS A RESULT OF THE WASH DURING ENGINE DRY-OUT. IF VAPORS ARE OBSERVED IN THE CABIN DURING ENGINE DRY-OUT, IT IS RECOMMENDED THAT THE OPERATOR EXTENDS THE ENGINE DRY-OUT UNTIL VAPOR EVAPORATES. THESE VAPORS ARE THE RESULT OF RESIDUAL DETERGENT IN THE BLEED SYSTEM, WHICH IS NON-TOXIC BUT CONSIDERED A NUSIANCE TO OPERATORS.'*

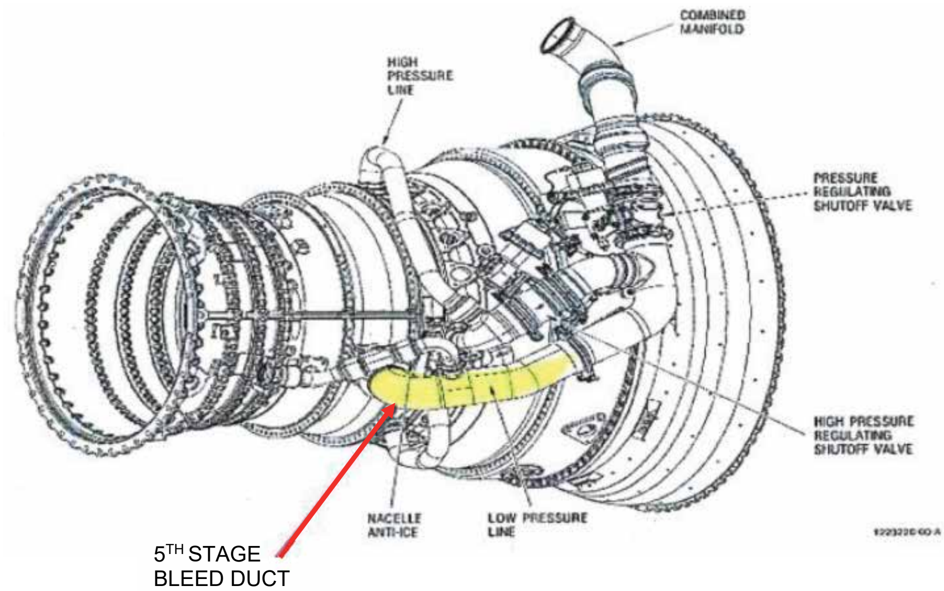

Figure 6

Engine schematic showing location of high pressure compressor fifth stage bleed duct

Footnote

10 Engine fan speed.

The procedure requires that an observer is positioned in the aircraft cabin to detect any odour or detergent after completion of the ECS and anti-ice dry-out procedure. If odours or fumes are detected, the engine dry-out should be continued until none are detected.

Operator's internal safety investigation

General

The operator conducted an internal safety investigation into the circumstances around the compressor wash on G-FBEJ. This included interviewing the maintenance personnel involved and reviewing relevant procedures, policies and training records. The findings of the internal safety investigation are described in the subsequent paragraphs.

Information from interviews with maintenance personnel

Several engineers were involved in this task. Engineer 1 carried out the engine ground runs from the cockpit and certified the task. Two safety personnel were positioned outside the aircraft, one to operate the compressor wash rig and communicate with Engineer 1 via a headset and the other to check the engine. When Engineer 1 arrived at the aircraft, the compressor wash rig fluid tanks were full and it was already attached to the No 1 engine, having been attached by the day shift. One compressor wash cycle was carried out using a water/detergent mix and four rinse cycles using water. Engineer 1 then performed the engine drying procedure using idle power only.

He could not recall any warnings or cautions for the ECS when carrying out the dry-out run. Although he could smell the cleaning solution when the dry-out run began, he could no longer smell it after the run had finished but the aircraft doors had been opened to aid venting.

Engineer 1 commented that when compressor washes had previously been done by the night shift, they were part of a larger maintenance input rather than a stand-alone task; this allowed for the high-power engine dry-out runs to be carried out by the oncoming day shift. He considered that the night shifts were generally undermanned and there was a lack of support functions that would be present during the normal working day.

Engineer 2 was the hangar bay supervisor and allocated the compressor wash task to Engineer 1. He stated that the night shift was normally pushed for time, with aircraft often not arriving in the hangar until 2200 hrs and needing to be back on-stand by 0300 hrs. He stated that he does not have the opportunity to review resources and required materials before work is carried out and it is often left to him to address any issues with the work packs, missing materials or tasks that cannot be performed.

Engineer 4 accepted the aircraft into the hangar for the compressor wash. Although he attempted to check if the engineers on the oncoming shifts had the approval to carry out the task, the databases he consulted were out of date and he did not have the knowledge to verify the approvals by other means. The work had been planned in for the day shift but problems encountered with sourcing a serviceable compressor wash rig meant the task had to be carried out by the night shift.

Preparations for the compressor wash had been undertaken by the hangar day shift. This included replenishing the compressor wash rig with air, detergent and water and attaching it to the No 1 engine. Engineer 3 had undertaken these actions. He reported that prior to replenishment, the cylinder with the detergent/water mix was already approximately half full, with what he assumed to be the correct concentration of detergent/water. He then continued to add to the liquid already in the cylinder using a ratio of four parts water to one part detergent.

Engine ground runs

There were only two engineers (including Engineer 1) on the night shift who were qualified to conduct engine ground runs on the E195. Both had limited experience in doing so and were only approved to conduct low power engine ground runs. Engineer 1 was an experienced engineer who held company approvals for the E195 and another aircraft type in the operator's fleet. He predominantly worked on the other aircraft type, on which he was experienced in conducting engine compressor washes, but these required only idle power engine runs. He did not have any recent experience carrying out engine ground runs on the E195 and had not performed a compressor wash on an E195 before.

There were only two engineers within the operator's maintenance organisation company who were qualified to train others on conducting engine ground runs on the E195. A lack of trainers, training opportunities and access to simulators had resulted in a reduction in the number of competent authorised engineers available.

The engineers involved, and others consulted, considered that the ESM task used to carry out the compressor wash was poorly laid out and difficult to interpret. The maintenance organisation typically used process sheets for complicated maintenance tasks but did not have a specific process sheet for performing compressor washes.

Ground equipment

Prior to being replenished by Engineer 3, it was not determined when or by whom the compressor wash rig had last been used. When the rig was examined after the accident the water cylinder was empty and the water/detergent cylinder was half full.

It was found that the organisation had limited processes in in place to trace ground servicing equipment such as the compressor wash rigs. No records were kept of when, or on which aircraft, the rigs had been used, when they were last replenished and with what type or concentration of fluid. The limited and simple instructions shown on placards on the compressor wash rigs were considered insufficient and no detailed instructions or training on how to use the rigs was available. The operator identified that this was a specific type of maintenance task that would benefit from on-the-job training. An audit of compressor wash rigs following the accident found that many were in poor condition and that the fluid tanks did not have sight glasses or any method of establishing the correct fluid concentration. The compressor wash rigs were subsequently quarantined until they had been drained, flushed and replenished with a known concentration of fluids.

Maintenance planning

The requirement for the compressor wash had been identified by the operator's maintenance control department on the preceding afternoon, to rectify a decreasing trend in engine turbine temperature, which had been highlighted by routine engine performance monitoring. Maintenance planning for the task did not identify the time, resources or competence required for the compressor wash task, nor confirm that the required resources were available. There was no process in place for the acceptance of aircraft maintenance at short notice.

Engineer 4 accepted the aircraft into the hangar on the understanding that the compressor wash would be completed by the day shift, which had appropriately authorised engineers available. Due to the poor condition of the compressor wash rig engineers on the day shift spent considerable time getting it ready and as a result, the task was handed over to the night shift for completion.

Engineer 2 allocated the compressor wash task to Engineer 1, without fully understanding the requirements of the task. The night shift did not have engineers available with the correct authorisations to complete the task. Information regarding approvals and authorisations held by engineers was not readily accessible by managers, shift supervisors and maintenance planners which made it difficult to plan resources and assess the capabilities of the current or oncoming shift. This information was normally accessible by staff working core office hours.

Engineer 1 did not hold the necessary approvals to conduct high powered engine ground runs on E195 aircraft, and thus was not qualified to carry out all the required maintenance actions described in the ESM compressor wash and engine dry-out procedure. Engineer 1 certified the task despite several elements of the task not being completed.

Engineer 2 signed the certificate of release to service following the compressor wash despite not holding the correct approvals to release E195 aircraft to service.

Nature and scope of maintenance work

In the months preceding this incident, the nature and volume of the maintenance work carried out by the night shift at the operator's base had changed considerably. Termination of a contract with an external maintenance provider had resulted in an increase in maintenance work being undertaken at the operator's own maintenance facility. Previously the bulk of the work undertaken was in-depth planned maintenance tasks, but in the period preceding the accident most of the maintenance undertaken was reactive with short turnaround times and little prior notice of the type of work required. Engineers considered that the maintenance was often not correctly resourced with respect to spares, tooling or manpower and the time allocated for tasks was often incorrect and did not take account of the time needed to tow the aircraft from its location to the hangar and back.

While the operator had implemented a change management process to support the transition of maintenance from the external maintenance provider to its own maintenance facility, the internal investigation identified that procedures and processes had not been adapted to cater for the change in maintenance type.

In common with other shifts, on the night shift a small number of engineers, often in supervisory roles, held the majority of approvals and authorisations for conducting maintenance such as engine ground runs, certifying maintenance and certifying the release of aircraft to service. This placed substantial responsibility on a small number of individuals.

Maintenance culture

Although the aircraft required a compressor wash, this was not an urgent requirement and could have been allocated to a suitably resourced shift. The operator's investigation identified that there was a 'can do' culture throughout its engineering departments and a 'willingness to get the job done'. This may have contributed to several opportunities being missed, to prevent the improperly authorised maintenance, at the maintenance planning, task acceptance and task allocation stages and during the task itself.

Company policies implemented as part of its change management process had endeavoured to empower engineers to call 'stop' if they felt they could not complete maintenance safely but in the absence of supporting procedures, these were found to place an over-reliance on the individuals.

Welfare

During the investigation Engineer 1 and Engineer 2 disclosed that they were each experiencing personal issues which had been occupying their thoughts, but each considered that they were fit to continue working and to certify maintenance. Although their managers had been aware of their circumstances, no specific support had been put in place, nor any restrictions on what they could supervise or certify. Supervisors and managers had received only minimal training in how an individual's welfare can affect their performance.

Fatigue

The engineers on the night shift worked a permanent shift pattern of four 12-hour night shifts, followed by four nights off. The compressor wash was carried out on the third night of the shift and the work was performed between 2300 hrs and 0300 hrs. The operator did not determine whether fatigue was a factor in how the compressor wash was performed, but its internal investigation identified that although the operator had a fatigue risk management system in place for flight crew, no such system was in place for engineers.

Post-accident maintenance

Before the aircraft was returned to service the operator's maintenance staff, in consultation with the engine manufacturer, performed several additional compressor rinse cycles to flush any residual detergent from the No 1 engine and fifth stage bleed ducts. Despite this, detergent bubbles continued to come out of the engine during idle power engine runs, which led the operator to consider that the dilution of the cleaning solution used may have been incorrect. A sample of the detergent/water mix taken from the compressor wash rig was subjected to FTIR[11] analysis and compared to a calibration curve for the detergent.

Footnote

[11] Fourier transform infrared spectroscopy.

This determined that the concentration of the sample was 31.3% detergent. It could not be determined if and to what extent the compressor wash rig had been topped up during the compressor wash and rinse cycles, which could have altered the dilution from that used on G-FBEJ's engine. Given the difficulty purging the residual detergent from the engine, and the result of the sample analysis, the operator considered that the compressor wash rig may have contained an overly strong concentration of cleaning solution, prior to being replenished by Engineer 3. As the precise concentration of cleaning solution used could not be established, nor the effect of its long exposure to engine parts, the engine was withdrawn from service on the engine manufacturer's recommendation.

Analysis

General

On the aircraft's first flight of the day fumes became apparent in the cockpit during the latter stages of the taxi out and were subsequently accompanied by smoke as the thrust levers were advanced for takeoff. The takeoff was discontinued after which the intensity of the smoke and fumes increased. Following the flight crew's assessment of the situation, and confirmation from the SCCM of fumes and smoke in the cabin, the commander made the decision to evacuate.

An engine compressor wash had been performed on the aircraft's No 1 engine during overnight maintenance on the night before the accident. A high-power engine ground run was not performed following the compressor wash, resulting in residual cleaning solution remaining in the compressor bleed air ducts. This can lead to fumes or unusual odours entering the cockpit and cabin.

Source of the smoke and fumes

During the engine dry-out procedure following the compressor wash, the engines were run only at idle power. At idle power the engine power setting would have been insufficient for the engine bleed source to switch to the HPC fifth stage bleed. To dry out the fifth stage bleed ducts, the procedure recommended running the engine up to 65% N1. By not performing a high-power engine ground run, residual cleaning solution remained within the fifth stage bleed ducts.

As the thrust levers were advanced for takeoff the ECS bleed source would have switched to HPC fifth stage engine bleed, allowing smoke and fumes from the residual detergent to enter the cockpit and cabin.

Compressor wash and dry-out procedure

The ESM task for *'Engine performance recovery'* is comprised of many subtasks covering several wash, rinse and drying scenarios. It contains multiple notes and cautions, not all of which stand out from the main text and some of which contain critical information. In particular, the information relating to the need to perform a high-power engine run during the dry-out procedure is included in a note rather than in a procedural step. The ESM indicated that this was a recommended rather than required action. The AAIB questioned the engine manufacturer's rationale for this step being recommended rather than required.

They advised that for consistency with the other strong cautions throughout the ESM task, conducting a high-power engine run should be a required step following a compressor wash with detergent. In June 2020, it updated ESM subtask 72-00-00-410-004 task to reflect this.

Engineer 1 was more accustomed to working on another aircraft type. He had never performed a compressor wash on an E195 before, had limited experience in conducting engine runs on the E195 and was not qualified to conduct high-power engine runs. This, coupled with the fact that the procedure only recommended rather than required, a high-power engine run, likely influenced his decision to proceed with and certify the task without alerting his supervisors of the need for a high-power ground run.

The operator's internal investigation identified that complex maintenance tasks, such as that for a compressor wash would benefit from a company process sheet to supplement manufacturer's procedures.

Organisational factors

Maintenance planning, both at the operator and hangar level, did not adequately identify the resources required to undertake the compressor wash, nor attempt to match the requirements of the task to the capabilities of the oncoming hangar shifts. Systems in place did not assist maintenance planners and managers to easily establish the competence and approval status of individual engineers.

As a result, this maintenance task was allocated to a shift which did not have the correct competence and approvals to carry out and certify the task, or to release the aircraft to service. Had Engineer 2 fully understood the requirements of the task, the resources required to complete it and the approval status of the engineers on the night shift, it is likely that the task would have been rejected by the night shift instead of being allocated to Engineer 1. Similarly, had Engineer 4 understood these aspects, it is likely the task would have been deferred when it could not be completed by the day shift. The operator's internal investigation found that willingness to get the job done, may have led to opportunities to stop the task being missed and existing policies may have placed too much reliance on individual engineers to identify tasks that could not be safely accomplished.

With regard to conducting engine ground runs, the operator's internal investigation identified a lack of suitably trained engineers, trainers and training opportunities. It also identified a lack of specific training or assisting documentation for conducting engine compressor washes and using compressor wash rigs.

Many of the compressor wash rigs were found to be in poor condition. There were no records of when they were last replenished, the type or concentration of detergent used or on which aircraft they had been used. The lack of records meant that it was not possible to determine the concentration of cleaning solution that had been in the rig, prior to its replenishment by Engineer 3.

Although night shift engineers permanently worked nights, no fatigue risk assessment had been carried out to understand the potential impact on individual performance. Both Engineer 1 and 2 disclosed that they had been experiencing personal issues, which could have been affecting their mental state. Although aware, it was not determined whether their managers had taken any steps to determine whether they were capable of being on duty and certifying aircraft, and the operator's internal investigation identified that only minimal training was available for supervisors and managers in this regard.

The operator had taken several safety actions to address these and other issues. However, it ceased operations before all intended safety actions could be fully implemented.

Evacuation

The commander's decision to evacuate was based on his concern that there may have been a fire on the aircraft and was likely influenced by the increase in intensity of the fumes, the appearance of smoke in the cockpit and confirmation of smoke and fumes of unknown origin in the cabin.

The flight crew actioned the emergency evacuation vital actions (memory items) followed by the QRH EMERGENCY EVACUATION checklist. Both the memory actions and the QRH checklist require the flight crew to set the emergency/parking brake to ON, select FLAP 5 and then move the thrust levers to IDLE. In this case, as the aircraft was stationary the thrust levers had already been retarded to flight idle and the parking brake set. The vital actions were therefore performed somewhat out of sequence and proceeded more rapidly than might be expected if an emergency evacuation followed a rejected takeoff or emergency landing scenario. Therefore, despite selection of FLAP 5, the flaps had insufficient time to travel to the selected position before the engines were shutdown. This resulted in an increased drop to the ground for passengers evacuating via the overwing exits, with many reluctant to jump or slide off the wing, leading to an increase in the time taken to complete the evacuation.

The emergency evacuation vital actions use the term 'confirm FLAP 5,' which suggests that this action requires the flight crew to confirm that the flaps have already travelled to FLAP 5. The commander commented that in training, an emergency evacuation is most often practiced following a rejected takeoff scenario and FLAP 5 is selected as soon as the decision to reject is made and before the aircraft has been brought to a stop. The flaps would therefore have travelled to the selected position by the time the emergency evacuation vital actions were actioned.

The aircraft manufacturer did not consider that any amendment of the QRH EMERGENCY EVACUATION checklist was required as a result of this occurrence. It considered that the normal flow of actions allows enough time for the flaps to reach a position beyond FLAP 1 and even if this did not occur, the drop to the ground from the FLAP 1 setting was still within with the maximum of six feet certification requirement of CS/FAR 25.810(d).

Some passengers attempted to take their baggage with them during the evacuation. This can slow down an evacuation, as cabin crew attempt to remove baggage from the passengers. Removed baggage can also create an obstruction in the cabin for others. In its report into the accident involving A320 registration OE-LOA on 1 March 2019 (AAIB report AAIB-25599, published in September 2020) the AAIB discussed the increasing trend in passengers attempting to carry cabin baggage with them during emergency evacuations. The AAIB made Safety Recommendations SR 2020-018 and SR 2020-019 to the EASA on this subject.

Overwing escape route markings

Despite the presence of a marked exit route on the wing with a non-slip surface, many passengers who exited via the overwing exits reported being uncertain where to go once out of the aircraft. None of them mentioned noticing the marked walkway on the wing. The evacuation took place during daylight hours with good visibility. As noted in the RAeS paper, overwing exit route markings are not always readily identifiable and may be even less so in darkness. Poor weather conditions or the presence of smoke could also hinder identification of an exit route.

The large drop to the ground and the absence of obvious immediate danger meant that passengers did not feel compelled to jump or slide off the wing. This led to passengers gathering on the wing surface, which was reported as slippery, increasing the risk of slips and falls. A bottle-neck also formed in the cabin around the overwing exits creating a delay for those still trying to exit.

It is apparent from this accident and the RAeS paper that the issue of ambiguous overwing escape route markings that resulted in previous AAIB Safety Recommendations 2002-42 and 2010-007 still exists. It is therefore appropriate that this matter is re-examined. The AAIB asked the EASA to review the issues identified relating to overwing escape route markings. The EASA indicated that while it considered all applicable certification requirements for the E195 relating to evacuation from overwing emergency exits had been met, it intended to consider introducing a new AMC to:

> *'identify acceptable guidelines and options for the measurement of the contrast between the marking of the escape path located over the wing and the background colour of the wing surface.'*

The EASA also outlined its participation in the FAA Emergency Evacuation Standards ARC, which was expected to produce its final report on 15 May 2020. The EASA stated that the ARC will recommend that the FAA, in conjunction with other Aviation Authorities, considers changes to the certification requirements for overwing exits, to allow easier identification of the evacuation path by passengers and a faster safer transition from the wing to the ground.

As this regulatory process is ongoing at the time of publication of this report, and it is not known to what extent the FAA will accept the recommendations of the ARC, the following Safety Recommendations are made:

Safety Recommendation 2020-020

It is recommended that the European Union Aviation Safety Agency amends the certification requirements relating to the design, contrast and conspicuity of overwing exit escape route markings on commercial air transport aircraft, to ensure that the route to be taken from wing to ground is immediately apparent to evacuating passengers, in a range of emergency scenarios.

Safety Recommendation 2020-021

It is recommended that the Federal Aviation Administration amends the certification requirements relating to the design, contrast and conspicuity of overwing exit escape route markings on commercial air transport aircraft, to ensure that the route to be taken from wing to ground is immediately apparent to evacuating passengers, in a range of emergency scenarios.

Provision of evacuation slides

Emergency exits that do not meet the 1.8 m maximum height criteria of FAR/CS 25.810 are not required to be equipped with an evacuation slide. This applies equally to overwing and non-overwing exits. The RAeS paper identified that jumping from heights of up to 1.8 m can be challenging for many passengers and has the potential to cause injury. Similar findings were documented in the 2009 EASA study and prior to that, the NTSB safety study, which made a Safety Recommendation to the FAA on this subject.

Overwing exits on many aircraft types rely on the trailing edge wing flaps being lowered to reduce the drop to the ground below 1.8 m. As this accident, and the findings of the RAeS paper demonstrate, this condition is not always achieved. Failure to lower the flaps, for whatever reason, can hinder an evacuation and may cause injury to passengers and crew.

In addition to the subject of overwing exit markings, the ARC evaluated the extent to which it is reasonable to expect passengers to jump to the ground from a height of 1.8 m, instead of benefitting from the installation of a properly designed emergency egress system. As a result, the ARC proposed that the FAA consider reviewing the requirements of FAR 25.810 (a) and (d) to define conditions that would require the provision of an escape slide at such exits.

As this regulatory process is ongoing at the time of publication of this report, and it is not known to what extent the FAA will accept the recommendations of the ARC, the following Safety Recommendations are made:

Safety Recommendation 2020-022

It is recommended that the European Union Aviation Safety Agency, re-evaluate and reduce the 1.8 m height criteria in CS 25.810(a) and (d), for the provision of an assisted means of escape at emergency exits, to minimise passenger injuries and reduce egress time during emergency evacuations.

Safety Recommendation 2020-023

It is recommended that the Federal Aviation Administration, re-evaluate and reduce the 1.8 m height criteria in FAR 25.810(a) and (d), for the provision of an assisted means of escape at emergency exits, to minimise passenger injuries and reduce egress time during emergency evacuations.

The operator also updated the content of its briefing to passengers seated in the overwing exits of the E195 as a result of this occurrence. Changes included: simplifying terminology, instructing those passengers of the need to be first out on the wing, informing them of the need to help and direct other passengers, and highlighting that there is no escape slide attached to the overwing exits.

Conclusion

A lack of maintenance planning, training and control of resources led to an undesirable situation where a maintenance task was allocated to an engineer who was neither qualified nor competent to complete the task. A key step in the engine drying procedure was only described as 'recommended' and the engineer did not complete all the elements of the task. This resulted in residual cleaning solution remaining within the ECS system, causing smoke and fumes within the cabin and cockpit and leading to an emergency evacuation. The engine drying procedure has since been amended to require this step to be carried out.

Due to the order in which the emergency evacuation vital actions were performed, the flaps had insufficient time to travel to the selected position. This resulted in an increased drop to the ground for passengers evacuating via the overwing exits, with many reluctant to jump or slide off the wing. Additionally, despite the presence of a marked exit route on the wing with a non-slip surface, many passengers who exited via the overwing exits were uncertain where to go once out of the aircraft. Both of these factors increased the time taken for emergency evacuation to be completed.

Safety Actions/Recommendations

As a result of this accident the operator undertook the following safety actions:

- Updated the content of its briefing to passengers seated in the overwing exits of the E195.
- Enhanced the control and tracking of maintenance ground support equipment to enable calibration expiry dates to be managed more effectively.

- Introduced a maintenance planning procedure so that maintenance requirements are identified earlier in the working day to allow appropriate resources to be identified and allocated.
- Undertook a review of tasks performed within the hangar to identify specific training requirements with a view to developing training programmes.
- Launched an engineer's competency passport scheme to enable maintenance planning departments to allocate specific maintenance tasks to maintenance stations where the correct resources are available.
- Introduced additional simulator training for engineers to undertake engine ground runs and committed to review the its recency period for conducting engine ground runs.
- Introduced a programme to verify that engineers have the correct procedures, records, equipment and tooling, personnel requirements, approvals, replacement parts, environment and information before commencing a maintenance task.
- Committed to undertake fatigue risk assessments for night shift maintenance personnel and initiated an engineer welfare programme.
- Updated its change management process to ensure appropriate management of the risks associated with the changing nature of maintenance being conducted in its base hangar.

In June 2020, the engine manufacturer updated ESM subtask 72-00-00-410-004 to require, rather than recommend, that a high-power engine dry-out run is conducted after a compressor wash using detergent.

Additionally, the following Safety Recommendations have been made to the EASA and the FAA:

Safety Recommendation 2020-020

It is recommended that the European Union Aviation Safety Agency amends the certification requirements relating to the design, contrast and conspicuity of overwing exit escape route markings on commercial air transport aircraft, to ensure that the route to be taken from wing to ground is immediately apparent to evacuating passengers, in a range of emergency scenarios.

Safety Recommendation 2020-021

It is recommended that the Federal Aviation Administration amends the certification requirements relating to the design, contrast and conspicuity of overwing exit escape route markings on commercial air transport aircraft, to ensure that the route to be taken from wing to ground is immediately apparent to evacuating passengers, in a range of emergency scenarios.

Safety Recommendation 2020-022

It is recommended that the European Union Aviation Safety Agency, re-evaluate and reduce the 1.8 m height criteria in CS 25.810(a) and (d), for the provision of an assisted means of escape at emergency exits, to minimise passenger injuries and reduce egress time during emergency evacuations.

Safety Recommendation 2020-023

It is recommended that the Federal Aviation Administration, re-evaluate and reduce the 1.8 m height criteria in FAR 25.810(a) and (d), for the provision of an assisted means of escape at emergency exits, to minimise passenger injuries and reduce egress time during emergency evacuations.

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