Serious Incident

Aircraft Type and Registration:	Boeing 767-332(ER), N197DN
No & Type of Engines:	2 Pratt & Whitney PW4060 turbofan engines
Year of Manufacture:	1997 (Serial no: 28454 LN: 683)
Date & Time (UTC):	10 February 2023 at 1130 hrs
Location:	Prestwick Airport
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 10 Passengers - 211
Injuries:	Crew - None Passengers - None
Nature of Damage:	Contained engine failure, fractured water drain tube
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	62 Years
Commander's Flying Experience:	21,000 hours (of which 12,000 were on type) Last 90 days - 180 hours Last 28 days - 50 hours
Information Source:	AAIB Field Investigation

Synopsis

During takeoff from Edinburgh Airport bound for New York, a high-pressure turbine blade fractured in the right engine. The blade damaged a further five blades, but the engine was still capable of producing thrust. The out of balance turbine caused vibrations sufficient to cause a slat track housing drain tube to fracture in the wing which allowed fuel to escape from the right wing fuel tank.

Due to the high engine vibration, the flight crew diverted the aircraft to Prestwick Airport. During the diversion, fuel escaping from the wing was ignited by the hot engine exhaust, and this was recorded on video by a passenger, but the flames extinguished before the landing. The aircraft landed promptly, with full emergency service attendance. After the aircraft arrived on stand, the airport fire service noticed the fuel coming from the right wing and put provisions in place to capture the fuel, preventing it igniting on the hot engine or brakes. The passengers were rapidly disembarked, with no injuries.

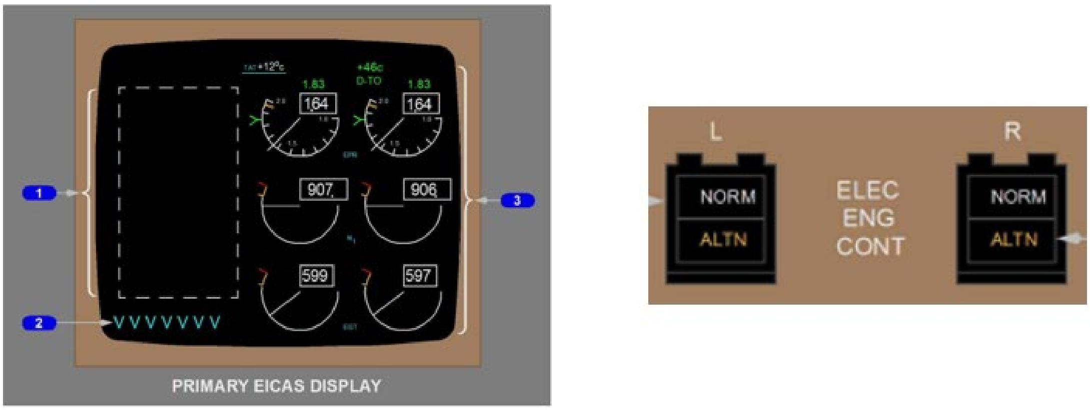
A Safety Recommendation has been made to the Federal Aviation Administration that requires the Boeing Aircraft Company to demonstrate that following this serious incident, the design of the slat track housing drain tube on the Boeing 767 family of aircraft continues to comply with the certification requirements for large transport aircraft.

History of the flight

The aircraft was operating a scheduled passenger flight from Edinburgh Airport (Edinburgh) to New York JFK Airport (New York). The co-pilot was PF and a relief pilot[1] occupied the flight deck jump seat.

Around 1100 hrs, while the aircraft was taxiing to Runway 24, two members of the cabin crew stationed at the overwing exits recalled hearing "rattling" as though something was loose in the cargo compartment. During the takeoff[2], the commander made normal standard operating procedure calls of "POWER SET" and "EIGHTY KNOTS THRUST NORMAL". No unusual sounds were apparent on the CVR recording. Several members of cabin crew described a continuous loud vibration from the mid-cabin after takeoff power was set. The cabin crew at the overwing exits reported this vibration to the purser using the interphone. She, in turn, called the flight crew although was initially unable to get through.

Soon after the flight crew set climb power[3], the autothrottle disconnected, the right Electronic Engine Control (EEC)[4] alternate mode light illuminated (Figure 1 right), and the Engine Indicating and Crew Alerting System (EICAS) advisory message R ENG EEC MODE appeared[5] (Figure 1 left). The commander announced an "OVERTEMP[6] ON THE RIGHT SIDE".



(1) **EICAS Message Field**
Eleven lines are available for system and communications alerts.
Additional pages are available.

(2) **Engine Secondary Data Cue**
Displays (cyan) – secondary engine data should be displayed on lower CRT.

(3) **Primary Engine Indications**
Displays full time on the EICAS display.

Figure 1

Example primary EICAS display and overhead EEC panel from the operator's 'Flight Operations Volume 2' manual

Footnote

1 The relief pilot monitors the operation, assisting the PF and PM as necessary.
2 Takeoff time was recorded as 1102 hrs.
3 Climb power was set at the beginning of the acceleration segment of the takeoff (normally around 1,000 ft agl).
4 Each EEC monitors autothrottle and thrust lever inputs to automatically control the respective engine.
5 The advisory message and amber ALTN light indicated that the EEC was not receiving adequate inputs using normal (Engine Pressure Ratio) mode, so was operating in alternate (N1) mode.
6 Probably referring to a high exhaust gas temperature.

After being instructed by ATC to climb to FL140, the flight crew completed the *'After takeoff checklist'*. The commander and relief pilot tried unsuccessfully to re-set the EEC using the appropriate Quick Reference Handbook (QRH) procedure, so the co-pilot continued flying the aircraft using manual thrust, with the EEC in ALTN mode. The purser successfully contacted the flight crew on her second attempt at calling them. She explained that a vibration which began while taxiing was now "QUITE BAD", and that passengers seemed concerned. The commander called ATC, requesting to level the aircraft at FL100 and to maintain an airspeed of 250 KIAS. He asked the relief pilot to ask[7] the operator's engineering[8] department whether the EEC in alternate mode would affect their Extended Range Twin Operations (ETOPS) clearance. He did not sense the vibration in the flight deck so asked the relief pilot to assess it in the cabin, informing ATC they were doing so. He commented to the co-pilot "THEY KNOW IN THE BACK IF IT'S BAD… IF IT'S A BAD VIBRATION WE'RE GOING BACK".

At around 1110 hrs, while trying unsuccessfully to re-engage the autothrottle, the commander observed the right engine's Exhaust Gas Temperature (EGT) indication was fluctuating. Deciding they should return to Edinburgh, he informed ATC "WE DON'T HAVE AN EMERGENCY[9] AT THIS TIME WE JUST HAVE A MAINTENANCE PROBLEM", and flew heading 030°. The commander took control of the aircraft so the co-pilot could prepare for the arrival, but realised a longer runway would be preferable, with the aircraft being significantly heavier than its Maximum Landing Weight.

The relief pilot returned from the cabin saying he "WALKED ALL THE WAY TO THE BACK" without noticing anything obviously abnormal, and suggested any noise might relate to the pressurisation system. The commander explained they were diverting anyway, commenting "I DON'T WANT TO STAY IN THE AIR WITH THAT ENGINE", and asked him to check performance information for Prestwick and Belfast International airports. The commander handed control of the aircraft back to the co-pilot and informed ATC they sought a long runway for landing overweight. ATC suggested nearby Prestwick, Runway 30, with an available landing distance of 2,987 m.

The relief pilot informed the cabin crew, passengers, and operator they were diverting to Prestwick. ATC called "FIFTY-ONE MILES TO TOUCHDOWN" and issued a heading of 205° and a descent. The purser reported the cabin noise had diminished although the flight crew attributed that to the aircraft slowing down. After ATC queried whether the aircraft required special handling at Prestwick, the commander requested the Airport Fire Service (AFS)[10] attendance for potentially hot brakes. Preferring to perform the overweight landing himself, he resumed control of the aircraft from the co-pilot. The aircraft was transferred to Prestwick Radar frequency who gave the weather information of wind from 210° at 14 kt, visibility 10 km or more, scattered cloud at 900 ft, broken cloud at 1,300 ft, and temperature 9°C.

Footnote

[7] Any contact with the operator during the flight was via the Aircraft Communication Addressing and Reporting System (ACARS).
[8] Termed 'maintenance' in the US.
[9] Emergency – aircraft requires urgent assistance.
[10] AFS, rather than RFSS, used throughout this report for consistency with the airport's documentation.

The commander briefed using FLAPS 25 for landing, indicating the associated reference landing speed (V_{REF}) was slower than for FLAPS 30. The relief pilot suggested using the single engine landing setting of FLAPS 20 instead, but the commander, showing possible signs of stress, responded "NO BOTH ENGINES ARE RUNNING. I'M NOT SHUTTING ONE DOWN YET".

While the aircraft was maintaining 6,000 ft amsl on a long right base leg, the commander throttled back the right engine, which reduced some vibration he had started to notice (Figure 6, point 16). They selected FLAPS 1 (Figure 6, point 17) which briefly generated an abnormal noise on the CVR. The commander commented "THAT'S A BIG VIBRATION", then requested selection of FLAPS 5. ATC instructed them to turn right onto a heading of 240°, with 21 miles to touchdown. Around this time a passenger videoed what looked like flames coming from under the right wing (Figure 2 and Figure 6, point 18). The commander briefly considered changing to landing FLAPS 20, asking the co-pilot for the associated V_{REF}.

Figure 2
Image from passenger video

The flight crew set FLAPS 15, followed an ATC descent instruction, and slowed the aircraft to 180 KIAS. The commander expressed a preference for operating the right engine using idle thrust. The relief pilot suggested shutting down the engine, but the co-pilot agreed to keep it running. ATC gave them an intercept heading for the ILS localiser, and further descent.

By the time a member of the cabin crew reported the possible flames[11] to the purser, they had disappeared. Concurrently, the relief pilot informed the purser they had a yellow[12] emergency with less than ten minutes to landing, anticipating no evacuation. The purser reported the engine appeared to shut down, with some associated electrical power loss in the cabin, so she instructed the other cabin crew members to sit down as soon as possible. The flight crew remained unaware of any flames until after the flight.

Footnote

11 She described an "orange streaking" which *'seemed like flames'*.
12 The operator categorised emergencies as *'red'*, *'yellow'* or *'medical'*.

The relief pilot queried whether they should perform the “ENGINE FAILURE” items, but the commander indicated there was insufficient time and requested the *‘Approach checklist’*. The relief pilot made effective suggestions throughout the approach, including starting the APU and briefing the single engine go-around procedure. The flight crew lowered the landing gear while the aircraft intercepted the ILS glideslope. The commander said, “WE CAN’T AUTOLAND SINGLE ENGINE BUT WE’VE GOT TWO ENGINES RUNNING SO I’M GONNA AUTOLAND IT” and selected the autobrake to MAX AUTO[13]. They used FLAPS 25 for the landing.

The aircraft landed at 1131 hrs with wind from 210° at 16 kt, and wet runway conditions. While vacating Runway 30 onto taxiway Kilo, the commander requested the AFS vehicles to follow them to Stand 5 (Figure 3). The flight crew reported noticing then that the right engine’s primary indications read zero. The commander said “LOOK… I THINK THE RIGHT ENGINE FAILED WHEN WE LANDED”, before selecting its fuel control switch to CUT OFF and requesting the *‘After landing checklist’.*

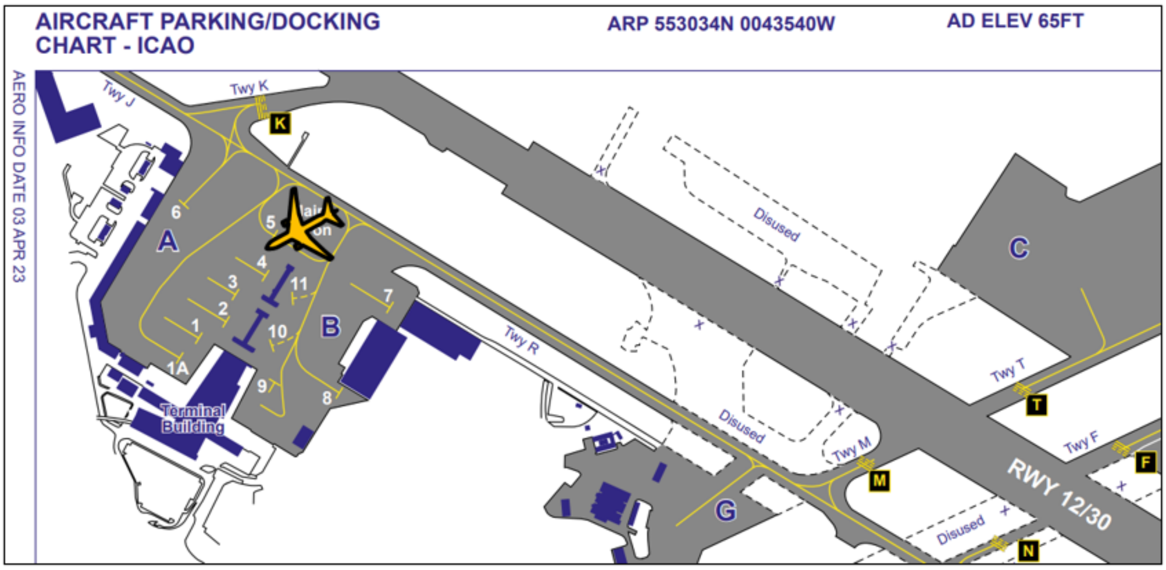


Figure 3

Aircraft location (aircraft not to scale)

The aircraft was parked facing in a southerly direction at around 1133 hrs. The flight crew told the passengers to remain seated and then performed the *‘Shutdown checklist’*. ATC relayed a message from the ground marshaller that there was something leaking from the aircraft’s right wing (Figure 4). The commander requested the stairs “REAL QUICK”, telling the passengers to expect an “ORDERLY DEPLANING”. The relief pilot went outside to liaise with the AFS crew who were monitoring the brakes with thermal imaging cameras. They radioed the co-pilot saying “YOU HAVE FUEL LEAKING BEHIND THE ENGINE ON THE STARBOARD WING. WE’RE GONNA PUT OUT A CHARGE LINE[14]”.

Footnote

[13] Maximum autobrake setting for landing.
[14] Water-filled hose.

Figure 4
Fuel leaking from the right wing

With the stairs in place, the commander instructed the passengers "PLEASE LEAVE YOUR BAGS BEHIND AND DEPLANE…". One member of cabin crew reported making "very strong PAs" when passengers tried to access their bags. The commander asked the co-pilot to perform the *'Secure checklist'* so they could disembark quickly, when the relief pilot returned saying "THERE'S FUEL POURING OUT OF THE WING". It took approximately 5 minutes, 20 seconds[15] for all the passengers to vacate the aircraft, which was then shut down at 1144 hrs.

The AFS put in place several actions to contain the fuel spill including using containers, containment booms and absorbent materials. Approximately 30 minutes after the aircraft arrived on stand an engineer from a maintenance organisation at the airport, arrived and after discussions with the crew and operator, assisted in coordinating actions to stop the fuel leak. He had recognised that fuel was coming from a drain hole in the wing dry bay and concluded that if fuel were transferred out of the right wing fuel tank, it might stop the leak. The aircraft had landed with 99,000 lb of fuel onboard, split between 19,000 lb in the centre tank, and 40,000 lb in each wing tank. There was sufficient empty capacity in the centre fuel tank and so they used the aircraft fuel transfer pumps to move the fuel from the right wing fuel tank. As the fuel quantity in the wing tank reduced below 7,000 lb the leak stopped. The aircraft was then shut down again.

Recorded information

Sources of recorded information

The FDR and CVR from the aircraft were downloaded, providing audio and data for the incident flight. Additional sources of recorded data were:

- Maintenance messages that had been automatically sent during the flight by the aircraft systems, triggered by engine related events.

Footnote

[15] From CCTV this was the time between what appeared to be the first and last passengers stepping off the exit stairs on to the tarmac.

- Engine management system data that was downloaded at the operator's engine maintenance facility.
- QAR data recovered from the aircraft.[16]
- A passenger video which was widely circulated on social media, filmed through a cabin window, showing a short period with flames that appeared to come from under the wing.
- Handheld video taken from the tower at Prestwick which showed a normal landing, from the left side of the aircraft, with no evidence of a leak or flame.
- CCTV recordings from many cameras were provided by Prestwick Airport.

Incident flight

Selected data from the FDR, QAR and ACARS are shown in Figures 5 and 6. The aircraft engines were throttled up for takeoff from Edinburgh at 1102 hrs on 10 February 2023. There was a step increase in the recorded N2 vibration parameter soon after the engines reached their peak speed for the takeoff, indicating a level of damage was present at that time.

Footnote

[16] The operator advised that once the aircraft returned to its base in the USA, the QAR data would be automatically processed and would not be available to the investigation due to deidentification protocols. This was not as expected and necessitated the AAIB removing and processing of the QAR memory card.

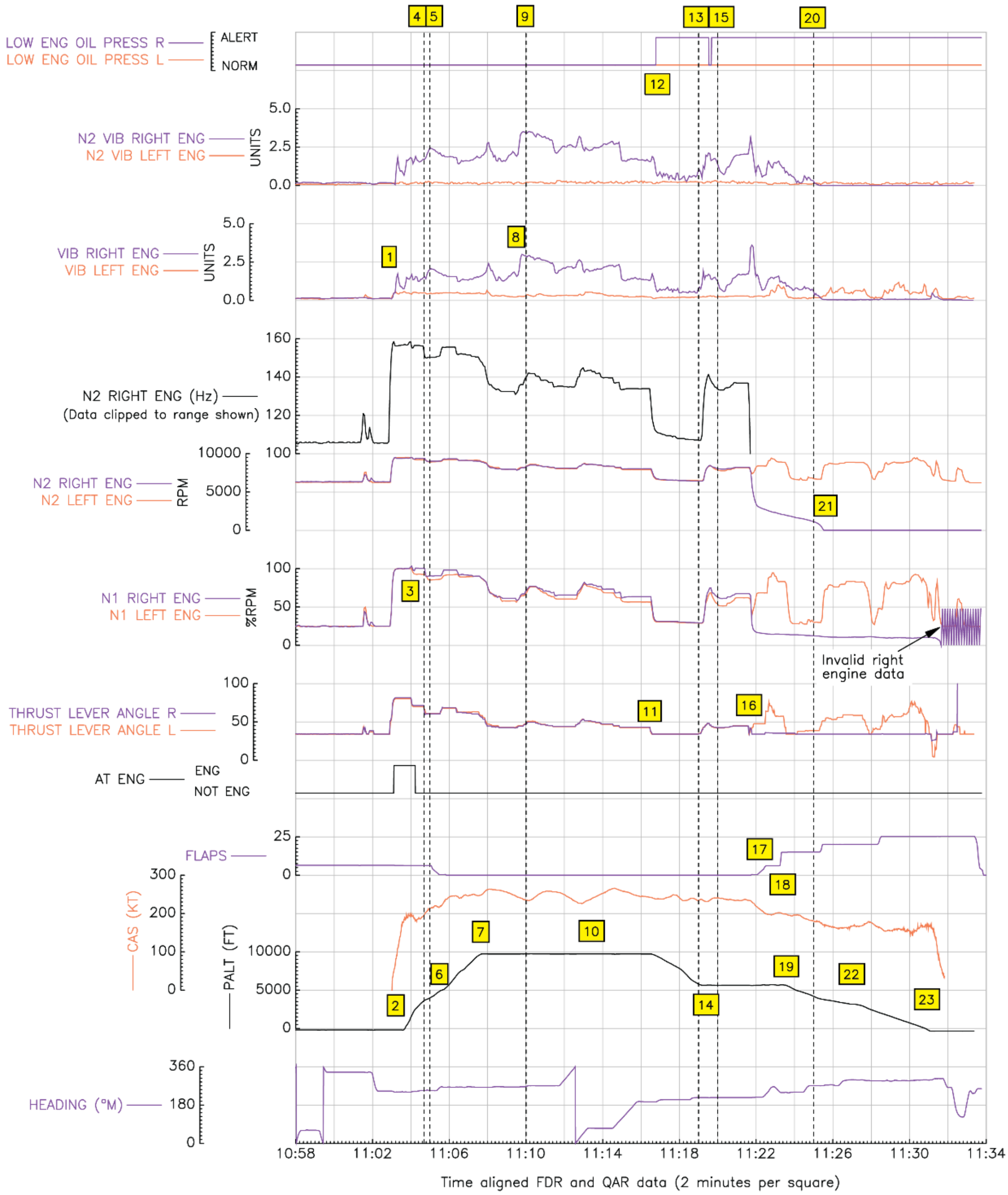


Figure 5

Selected FDR and QAR parameters, ACARS message timings, and marked events (see report text)

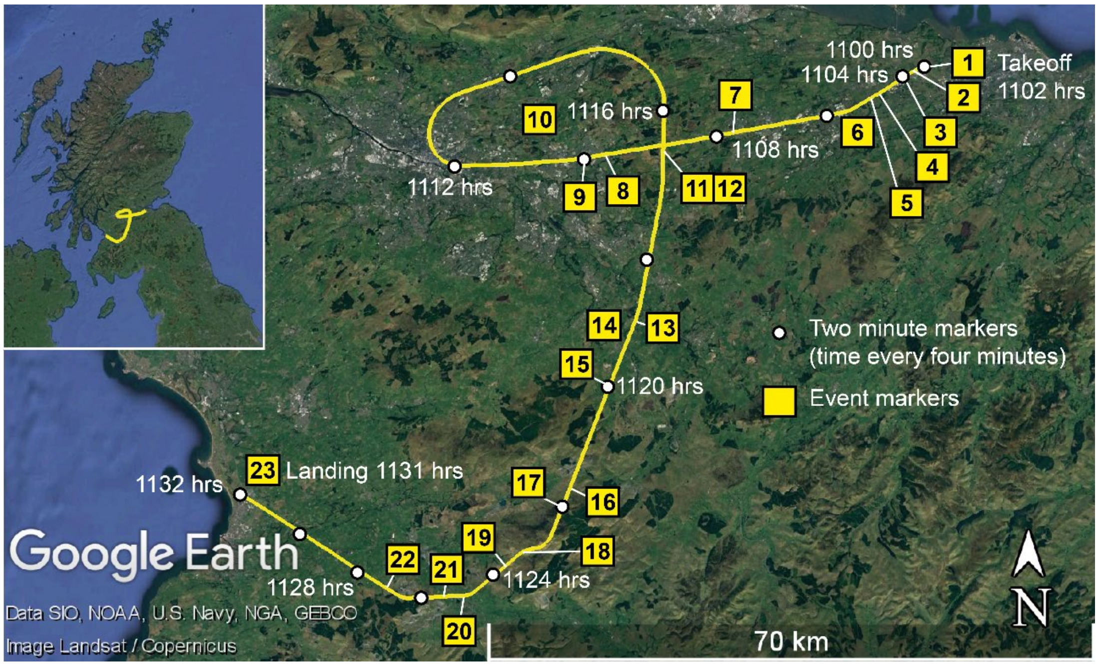


Figure 6

Flight path with marked events (see report text)

The following highlights key points during the flight, with numbering associated with Figures 5 and 6:

1. Overall vibration parameter and N2 vibration parameters of the right engine significantly higher than for the left engine but not at any trigger level.
2. Right oil quantity reduced.
3. Right engine EPR parameter became invalid, control switched from EPR to N1 and the autothrottle disengaged.
4. An ACARS engine exceedance report was generated. This was triggered by the right EGT exceeding the 654° C limit. The peak value was recorded as 667.5° C.
5. An ACARS maintenance message was generated indicating an issue with an engine P2 or EPR pneumatic tube.
6. Rise in right engine oil temperature.
7. The aircraft levelled off at FL100.
8. Vibration level of right engine exceeded 2.5 units. 10 seconds above 2.5 units changes the crew indication of the vibration value on the upper EICAS display to amber.
9. ACARS maintenance messages were generated regarding an engine temperature probe.
10. The aircraft headed back east and then south.
11. Engine power reduced for the descent from FL100 to 6,000 ft amsl.

12. Right engine oil pressure dropped and an associated alert was generated.
13. The same ACARS maintenance messages were sent.
14. Aircraft levelled at 6,000 ft amsl.
15. An additional ACARS maintenance message was sent relating to the EEC control of the air/oil heat exchanger valve.
16. Right engine throttled back.
17. Flap deployment sequence started.
18. Approximate location of passenger video showing flames.
19. Start of descent from 6,000 ft amsl.
20. ACARS messages were generated. One related to a degraded EEC channel capability, but with sufficient control for time-limited dispatch. Another related to the air/oil heat exchanger and a further two related to a temperature probe.
21. Right engine N2 stopped.
22. Gear down.
23. Landing.

The recorded engine fire parameters did not indicate a fire at any point during the flight or taxi. The passenger video (Figure 2) shows fire evident in flight. This was recorded approximately 8 minutes before landing, as the aircraft was levelling from a left turn with flaps deploying. No evidence of fire was found after this time.

The aircraft was shadowed by the AFS vehicles for the taxi and arrived at the final parked location of Stand 5 on a heading of about 260° approximately 2 minutes 20 seconds after touchdown.

Figure 7

CCTV snapshot showing fuel leak location, disembarkation and AFS attendance

The presence of the fuel leak can be identified when a CCTV camera was zoomed in to the relevant location after the aircraft came to a halt. The first passengers started disembarking via steps at the front left door within 5 minutes of the aircraft coming to a stop, and the last less than 6 minutes later. Figure 7 shows a snapshot from one of the CCTV recordings.

Figure 8 shows the vibration levels of both engines for the most recent flights, including the event flight. The values are not calibrated or in specific units but serve to highlight large changes in vibration levels. The difference between left and right engine vibration values before the event flight were not considered relevant to the investigation. The plot shows that the overall and N2 vibration levels dramatically increased at the start of the event flight. The N1 vibration values decreased.

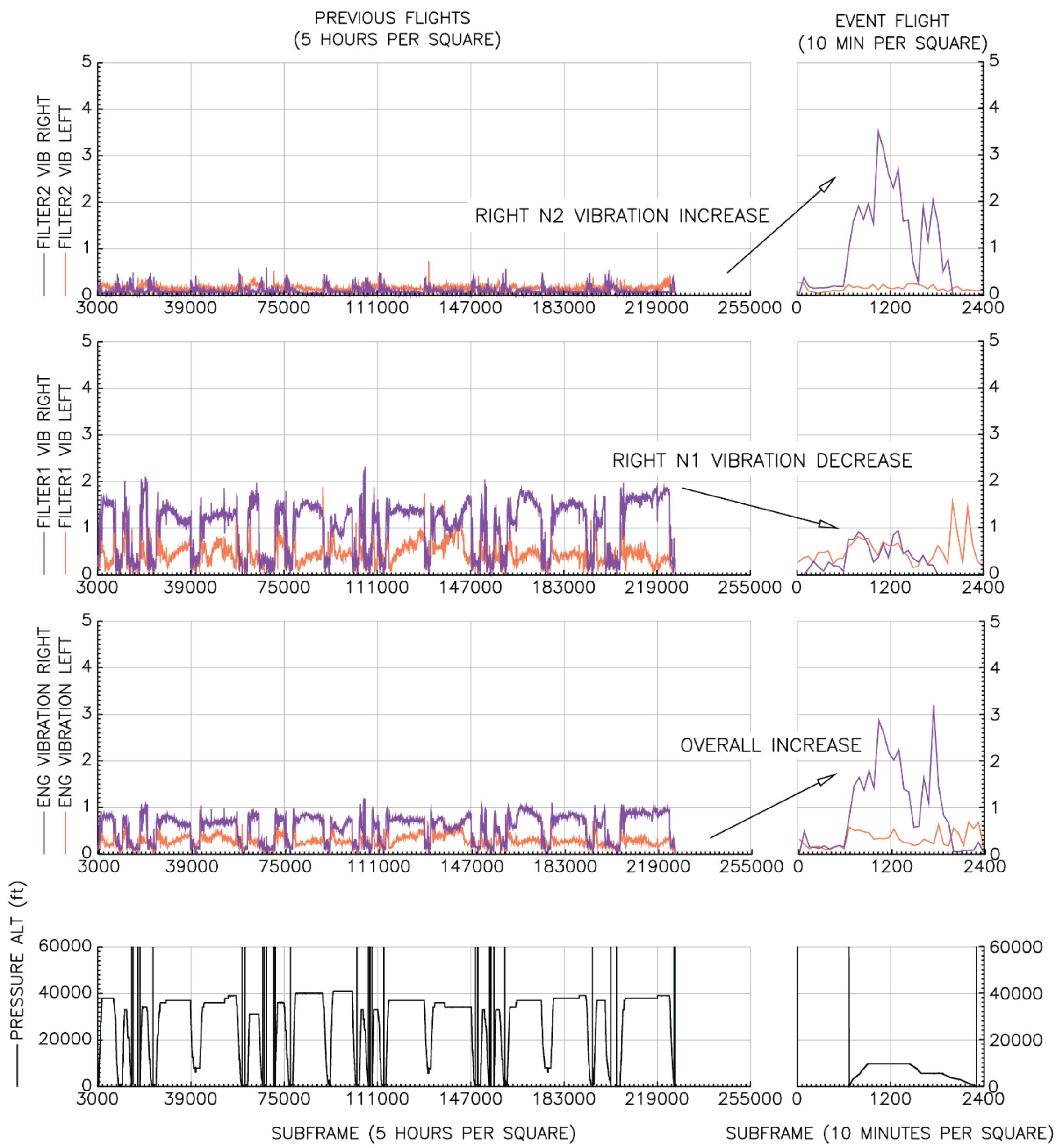


Figure 8

Vibration data trends

Aircraft information

N197DN is a Boeing 767-332 aircraft that is ETOPS certified and powered by two Pratt & Witney PW4060 turbofan engines. It was delivered to the operator in December 1997 and had completed 15,843 flight cycles and 106,760 flight hours by the time of the serious incident.

Fuel tanks

The internal wing structure forms three aircraft fuel tanks: a left and right wing tank with a capacity of 40,000 lbs each and a centre wing tank of 80,000 lbs. The wing fuel tank boundaries are the front and rear spar, upper and lower wing surfaces, and Rib 3 (Figure 9). Located above the engine pylon within the fuel tank boundary is a separate zone called the dry bay, which is sealed and does not contain fuel. It spans from Rib 6 to Rib 9 and is a safety feature in case of an uncontained engine rotor failure. Analysis has identified that high energy engine fragments could penetrate the wing in this area and therefore it is kept free of fuel to prevent a fuel leak. It has a drain hole at the lowest point to remove any condensation or other fluids that may collect in the bay and a removal access panel to facilitate inspections (Figure 10).

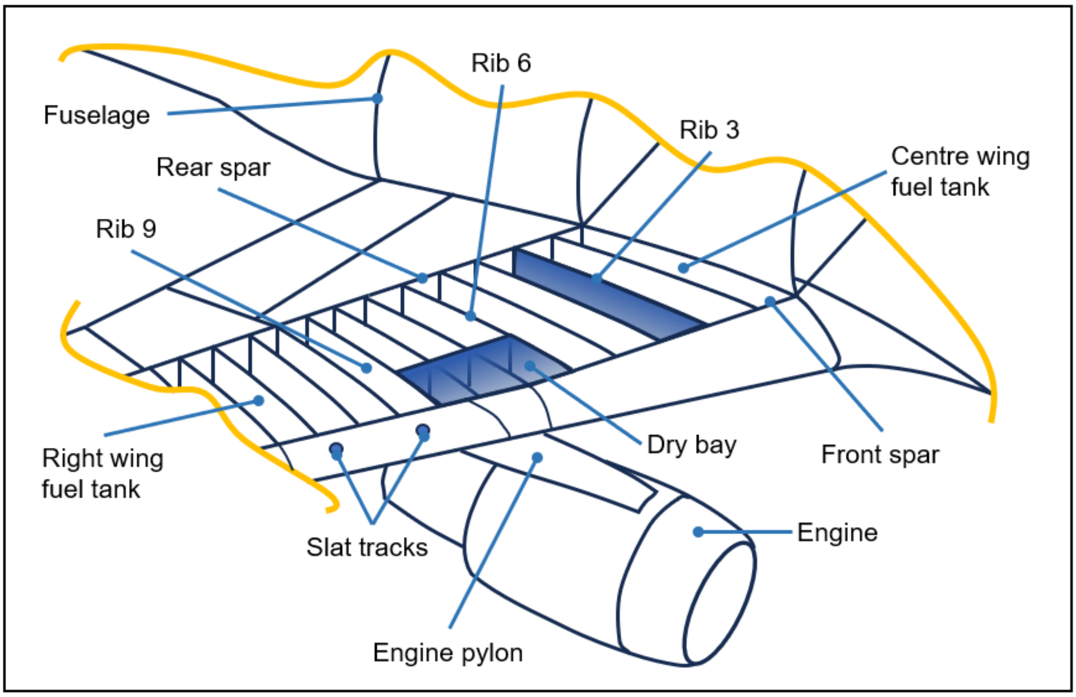


Figure 9

Wing scheme showing dry bay location.
(Upper and lower wing surfaces not shown for clarity)

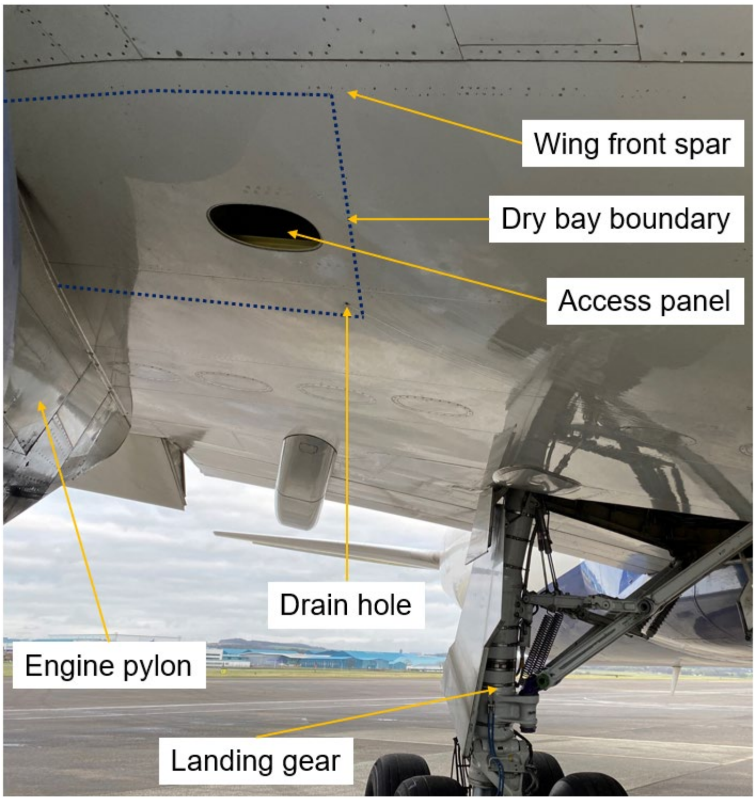


Figure 10

Dry bay viewed from outside the aircraft looking aft
(Note: Access panel removed after flight)

Slat track system

The wing leading edge slats extend and retract on tracks supported on rollers (Figure 11). In the retracted position the slat track protrudes through the front spar into the fuel tank. To maintain the fuel tank boundary, a slat track housing is attached to the inside of the front spar into which the track retracts. It is fitted with a drain tube to allow any fluids from the environment to drain out of the housing. If water were allowed to accumulate in the bottom of the housing and then freeze, there is a risk that the slat tracks could damage the housing, resulting in a fuel leak.

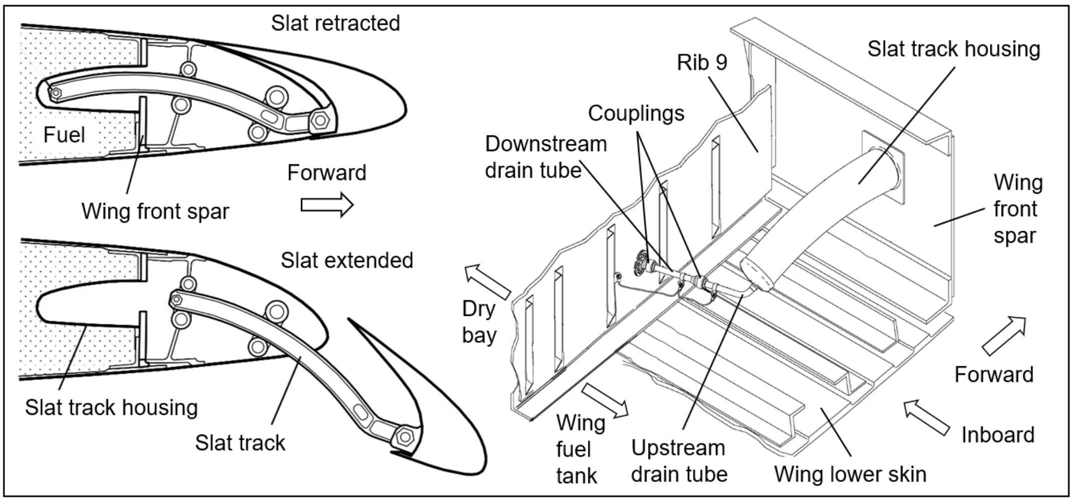


Figure 11

Generic slat track function (left) and the B767 inboard slat track housing (right)

The inboard slat track housing for Slat 8 is located just outboard of Rib 9 (the outboard rib of the dry bay). The drain tube connects the housing at the lowest point to a fitting on Rib 9. Any water that accumulates in the housing will flow through the drain tube into the dry bay and then out of the wing via the drain hole at the lowest point in the dry bay.

Slat track housing construction

The slat track housing, including the upstream section of the drain tube, is a welded aluminium assembly. The upstream and downstream drain tube sections are manufactured from ½ inch (12.7 mm) diameter 6061 aluminium alloy tube with a typical wall thickness of 0.035 inch (0.89 mm). After the slat track housing has been welded, it is heat treated[17] and a conversion coating (current process is to use Alodine 600[18]) is applied to the whole assembly. The assembly is then painted with two coats of zinc chromate primer, and a corrosion inhibiting compound is applied to the internal surfaces. During manufacturing the components are visually inspected for surface defects and the minimum wall thicknesses must remain greater than 0.032 inch (0.80 mm). The investigation did not identify the specific supplier or any manufacturing records for the slat track housing, and downstream drain tube, fitted to N197DN.

Slat track housing design evolution and other related events

The design of the drain tube for the Slat 8 inboard track has changed since the aircraft type first entered service. This has been managed by Airworthiness Directives (ADs) and Service Bulletins (SBs). The first change moved the drain tube exit from the lower wing skin over the engine to discharging into the dry bay through Rib 9. The change was mandated as it was identified that if fuel leaked into the drain tube and then onto the hot engine or exhaust nozzle, there was a risk of a fire when the aircraft was stationary or during low-speed taxiing.

Footnote

[17] From O condition to the T6 condition.
[18] Alodine 600 is a chemical formulation for the treatment of aluminium alloys to provide corrosion protection and as a surface preparation for paint and adhesives.

Both drain tubes (original and post SB) comprised a flexible steel tube to connect the rigid drain tube welded to the slat track housing to either the lower wing skin or Rib 9 with two flexible O-ring couplings between the individual parts. Since the publication of the SBs there were two in-service occurrences that caused the flexible steel tubes to crack due to vibration following an engine event. AD 2011-12-11[19], which mandated SB 767-57A0094[20], was issued to restore the continued airworthiness, and change from a flexible steel tube to a rigid aluminium tube.

The background information for this change is stated as: '*Accomplishment of this service bulletin prevents cracks in the number 5 and number 8 slat track housing drain tubes. Cracks in these drain tubes could let fuel drain from the main fuel tanks into the dry bay area of the wings. Fuel from the dry bay areas could subsequently drain on to hot Main Landing Gear (MLG) brakes and possibly result in a fire*.'

SB 767-57A0094 was embodied on N197DN in December 2012 at 5,864 flight cycles and 36,857 flight hours.

The drain tube fitted to N197DN was an assembly of several components; two sections of aluminium tube joined together with flexible O-ring couplings. The first section of tube is welded to the slat track housing and the second tube is attached to a machined fitting on Rib 9 with the same O-ring coupling. The flexible O-ring couplings are made up of several components and allow for angular movement of the tubes in the fore/aft and vertical directions, and small lateral movements to accommodate build tolerances.

Fatigue analysis by the aircraft manufacturer during certification of the rigid drain tube demonstrated that the fatigue life was greater than the design goal even when artificial damage was introduced to replicate manufacturing defects. The new design was vibration tested for five hours both laterally and vertically without failure and the system had a first mode resonant frequency response at 170 Hz and a second mode at 260 Hz. Analysis of the drain tube at 165 Hz demonstrated that with a 5g or 10g input load, the drain tube would fracture after either 200,000 or 21,000 fatigue cycles respectively, at the bend adjacent to the slat track housing. This equates to approximately either 20 minutes or 2 minutes of operation.

Engine vibration monitoring system

Vibration sensing is carried out using a single accelerometer mounted to the engine. This, along with other engine parameters, is processed by the Airborne Vibration Monitor unit using algorithms tailored to give a value of between 0 and 5 for N1, N2 and overall vibration levels. The processes are different for each, and no specific units are associated with these values. The values cannot be linked to any engine issue or level of damage or provide precise timing for the change in actual vibration. In the lower left corner of the secondary EICAS display the value and name of the highest vibration parameter are indicated to the crew. If a vibration level exceeds 2.5 for more than 10 seconds, the displayed value changes from white to amber (Figure 5, point 8). There are no other cockpit effects.

Footnote

19 Issued in July 2011.
20 Originally issued in June 2005, current revision 3 issued in October 2015.

Engines

N197DN was fitted with two Pratt & Whitney PW4060 turbofan engines, and the engine installed on the right wing was serial number ESN 724314. It had accumulated a total of 90,814 hours and 15,560 cycles in operation with 1,862 hours and 331 cycles since its last maintenance shop visit. It is a conventional two shaft turbofan with a two-stage high-pressure turbine (HPT) section (Figure 12). The second stage HPT disk (HPT 2) has 82 blades and a 100% rotation speed of 9,900 rpm.

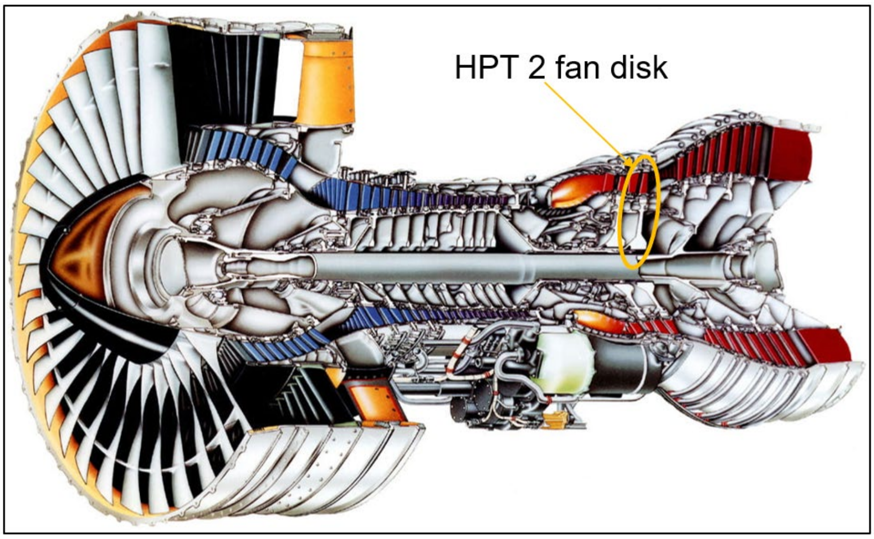


Figure 12
Section view of PW4060 engine showing HPT 2 disk (used with permission)

Aircraft examination

Initial assessment of the fuel leak

The aircraft was inspected by the AAIB at Prestwick Airport with support from the operator's maintenance personnel and a detailed visual inspection of the dry bay confirmed that it was structurally intact, with no evidence of fuel leaks through joints or sealant. The components of the fuel system which passed through the dry bay were confirmed to be satisfactory with no leaks present. It was noted that after the event the leak was stopped by moving fuel out of the right wing tank into the centre fuel tank. A test was undertaken where fuel was transferred back to the wing tank, and during the transfer the dry bay was monitored for fuel leaks. When the fuel quantity reached approximately 17,000 lb in the wing tank, fuel was seen coming through a fitting on Rib 9 (Figure 13). The flow rate was estimated at approximately 1.5 gallons per minute.

Figure 13

Fuel coming through the fitting on Rib 9. View from inside the dry bay looking outboard.

The wing fuel tank was drained, and a qualified mechanic inspected the area outboard of Rib 9. The inspection revealed that the drain tube from the slat track housing to the rib had fractured and had allowed fuel to enter the drain tube (Figure 14). The two pieces of the upstream drain tube section were removed from the aircraft for further examination.

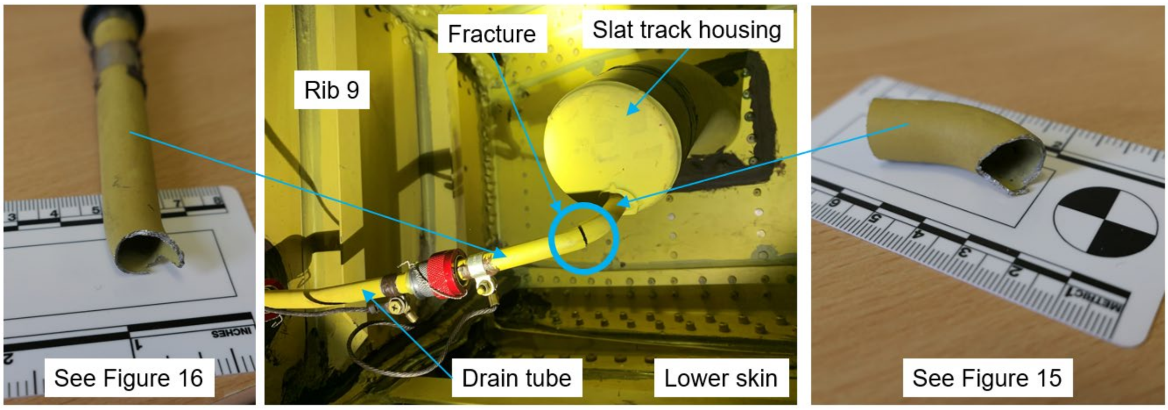


Figure 14

View looking forward of the slat track can showing the drain line fracture (centre)

Drain tube examination

The two pieces of the upstream drain tube (Figure 15 and 16) were examined at a specialist forensic laboratory using an optical microscope and a Scanning Electron Microscope (SEM). Initial examination of the fracture surfaces identified extensive mechanical damage consistent with rubbing between the opposing halves of the fracture. Areas of the fracture surface also exhibited deposits which masked the underlying fracture surface. Energy Dispersive X-ray (EDX) analysis of the deposit found that it was consistent with the primer paint on the inner and outer surfaces. It appeared that once the crack had developed, fragments of paint from the surface had migrated into the crack and had been ground between the opposing fracture faces.

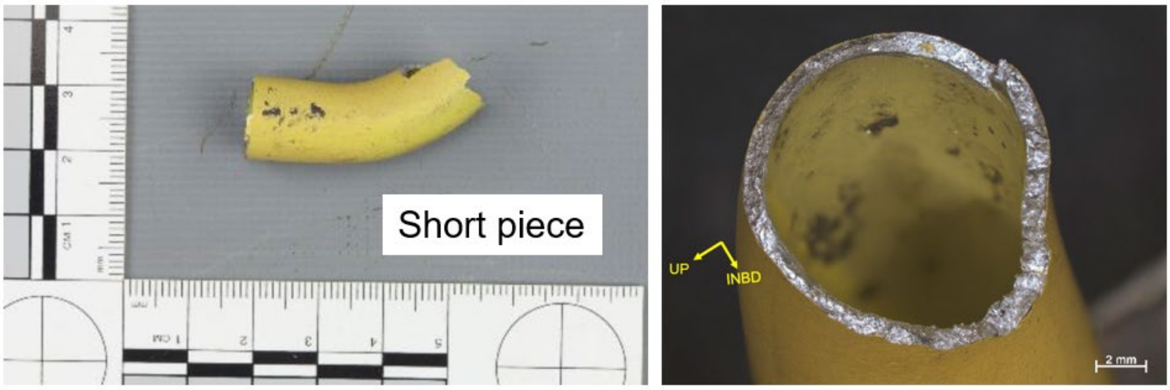


Figure 15
Short piece of drain tube (adjacent to slat track housing)

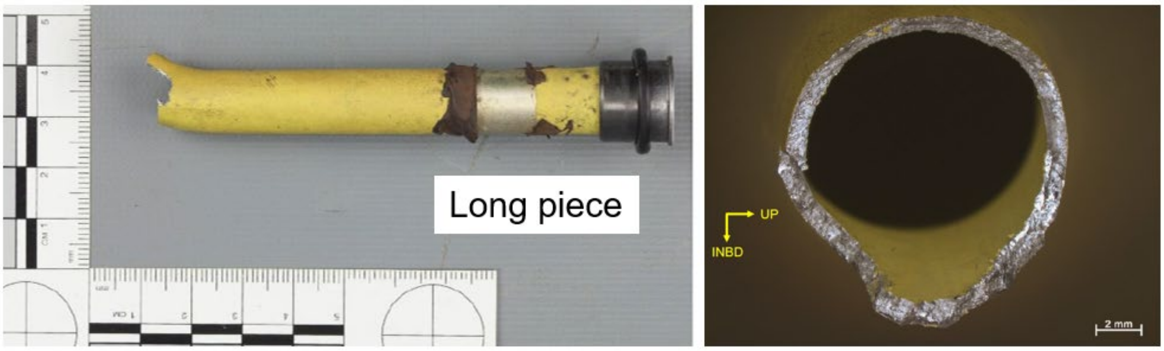


Figure 16
Long piece of drain tube (adjacent to the coupling)

Striations were visible at discrete areas across most of the fracture surface indicating that crack growth was the result of fatigue. The orientation of the striations suggested that fatigue cracks had initiated on the upper surface of the tube and propagated in both directions around the circumference (Figure 17). Although the main crack growth suggested initiation in an area at the top of the tube, it was apparent that multiple cracks had initiated at both the inner and outer surfaces of the tube ahead of the main crack front. These secondary cracks propagated for short distances before joining the main crack. Towards the inboard edge, the fracture turned downstream towards Rib 9 and propagated for approximately 7 mm in an axial direction before returning to a circumferential orientation. At the bottom of the tube, the two converging crack fronts were on different planes approximately 1.7 mm apart. At this point an overload crack propagated between the two cracks causing the two pieces of the tube to separate.

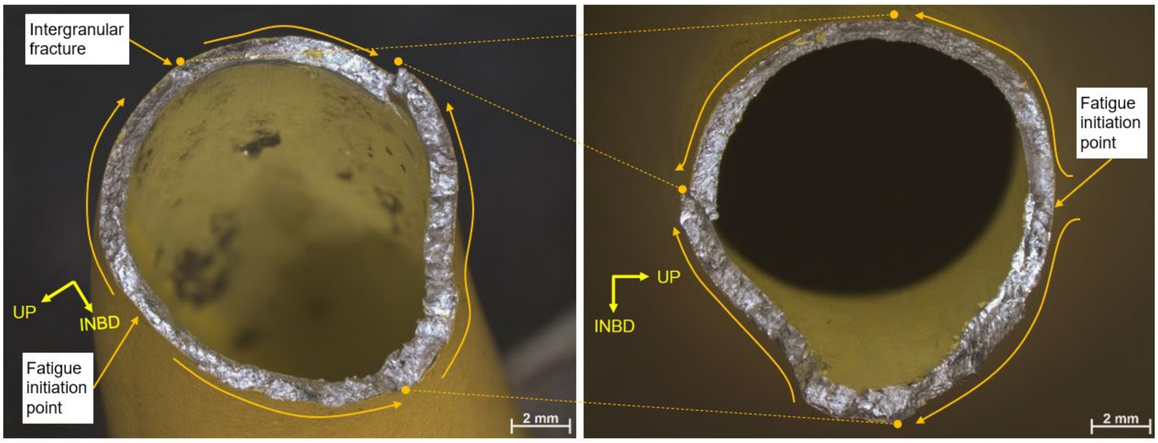


Figure 17

Left - Short piece fracture face showing crack propagation direction
Right - Long piece fracture face showing crack propagation direction

It was noted at the fatigue initiation point on the outer edge at the top of the tube, that an area of intergranular fracture approximately 100 µm deep was present (Figure 18 left). Further instances of intergranular fracture were observed on the fracture surface at both the inner and outer edges. At the outboard side of the fracture an area of intergranular fracture was observed on the outside edge which extended approximately 180 µm in from the outboard edge (location identified in Figure 17 left, shown in Figure 18 right).

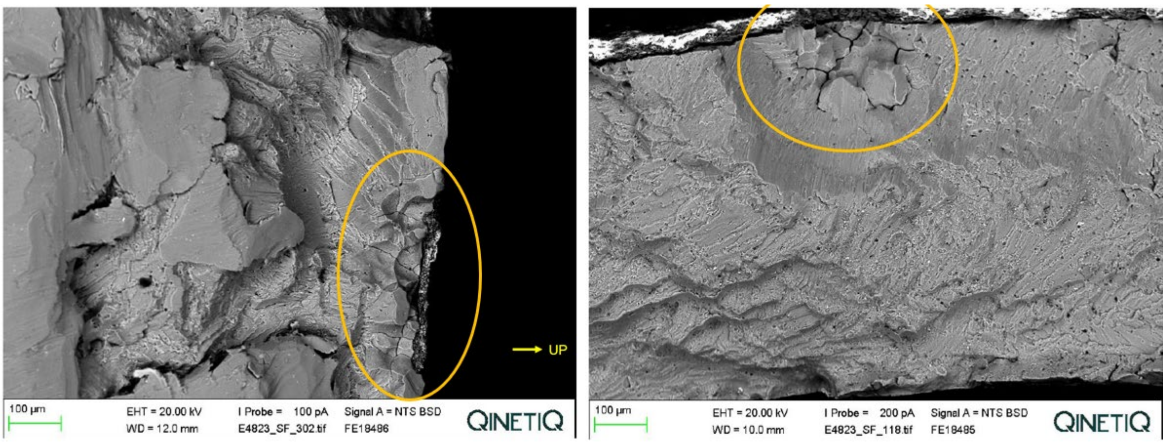


Figure 18

Left - Intergranular fracture at the initiation point
Right - Intergranular fracture at the outboard edge of the fracture

A series of micro-sections were removed from both pieces of the tube away from the fracture face. All the sections highlighted further intergranular cracking present on both the inside and outside of the tube, although it was more prevalent on the outer surface. In some cases, the micro-section showed the intergranular fracture breaking onto the surface (Figure 19), and it appeared to have initiated from a small pit approximately 5 µm deep on the surface of the tube. Further analysis using EDX mapping (Figure 19 right) showed that the surface breaking feature was covered with a chromium rich layer consistent with the Alodine process applied during manufacturing.

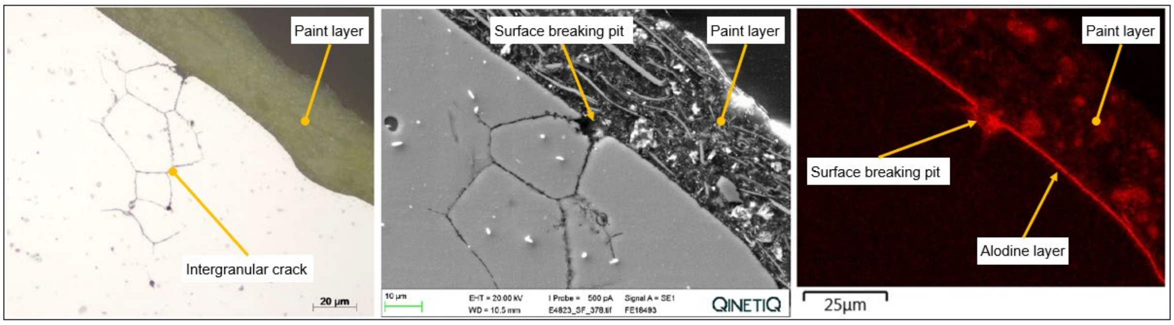


Figure 19

Example surface breaking intergranular fracture

It was observed that the chromium rich layer had formed around the bottom of the pit and had partially extended along the grain boundaries which indicated the pitting and intergranular cracking was present before the application of the chromate conversion coating. It also showed that it was present before the part was painted. The pitting and intergranular cracking was therefore not a result of in-service degradation and had been present since the drain tube was manufactured.

Additional analysis using EDX techniques confirmed the material alloy composition to be consistent with the aluminium-magnesium-silicone alloy 6061, and the hardness demonstrated that the temper condition was T6. The average paint thickness on the inner surface was 12 µm and 31 µm on the outer surface. Wall thickness measurements were taken from the micro-sections away from the fracture face and showed an average thickness of 0.89 mm (0.035 inch). Wall thickness measurements taken from the fracture face indicated that the wall thickness on the inside of the bend was approximately 0.96 mm (0.038 inch) but 0.75 mm (0.030 inch) on the outside of the bend. A further measurement was taken near the initiation point which was 0.90 mm (0.035 inch).

Engine examination

A preliminary external inspection revealed no evidence of soot or heat damage to the engine cowlings, or other external surfaces of the aircraft. An inspection of the engine identified a significant quantity of loose metal items and fragments in the cowlings and the exhaust. Further examination revealed many broken system mounting brackets, component chaffing damage and the oil scavenge line for bearing No 3 had become detached. All the components liberated from the engine had remained within the casing or cowls and was therefore considered a 'contained engine failure'.

The engine was subsequently stripped at the operator's engine maintenance facility, and it was found that six blades on the HPT 2 disk exhibited transverse fractures (Figure 20). These blades were identified as Blades 2 through 7. Further damage was noted to the turbine section downstream of the HPT 2 disk consistent with turbine blade loss.

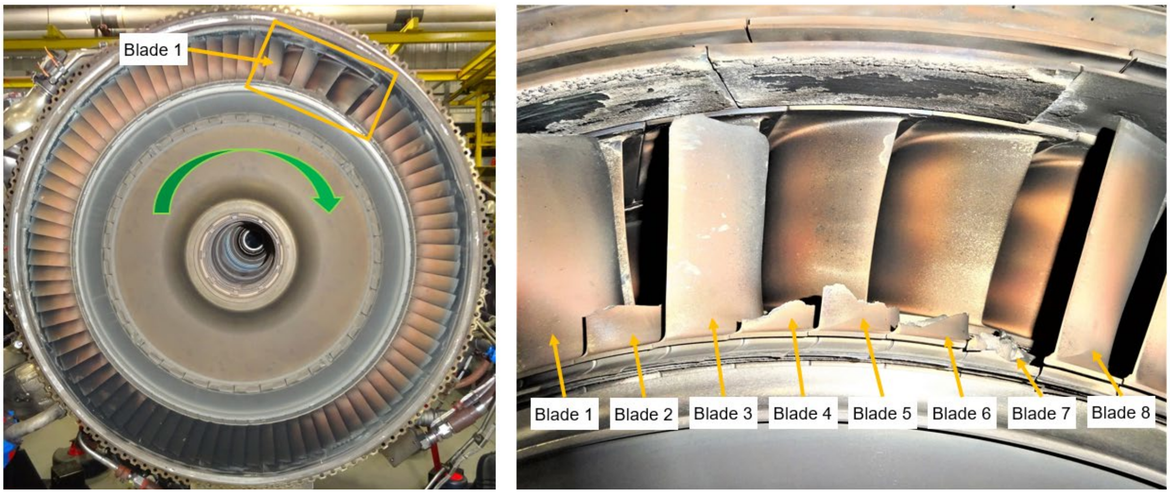


Figure 20

Left - View on HPT 2 disk looking forward showing rotation direction
Right - Detail view of Blades 1 to 8

High-Pressure Turbine examination

The blade set was examined by the engine manufacturer which revealed that the facture face of Blades 2 to 6 exhibited jagged non-directional fracture features indicative of rapid tensile overstress due to secondary impact. Blade 7 exhibited fracture features consistent with fatigue, indicating that it was the first blade to detach (Figure 21). The level of imbalance in the subject event exceeded the level of imbalance observed in two prior B767 events that resulted in the fracture of the slat track housing drain tube.

Detailed examination indicated that the fracture initiated from two Stress Corrosion Cracks (SCC) at the forward rib external convex wall (identified in green in Figure 21), which measured 3.96 mm (0.156 inch) wide by 2.06 mm (0.081 inch) deep and 3.00 mm (0.118 inch) wide by 1.12 mm (0.044 inch) deep. SEM examination of these areas revealed these cracks extended from multiple origins along the external convex wall surface, but the exact origins could not be determined due to oxide scale and rubbing damage. EDX mapping of the fracture surface and exterior convex wall surface revealed it was composed primarily of mixed nickel-based alloy oxides and aluminium-platinum based coating oxides. The regions of pitting and oxide scale also exhibited silicon, which could have originated from dirt ingested during engine operation. EDX mapping of the crack attack front of a pit, paired with Wavelength Dispersive Spectroscopy revealed the presence of sulphur, indicative of sulphation attack, otherwise known as hot corrosion. Further evaluation of the fracture surface found evidence of fatigue on both the convex and concave side walls. The fatigue progressed from the extremity of the cracks (identified in red in Figure 21) and exhibited arrest features indicative of high cycle fatigue. Final blade fracture was by overload stress, identified in blue in Figure 21.

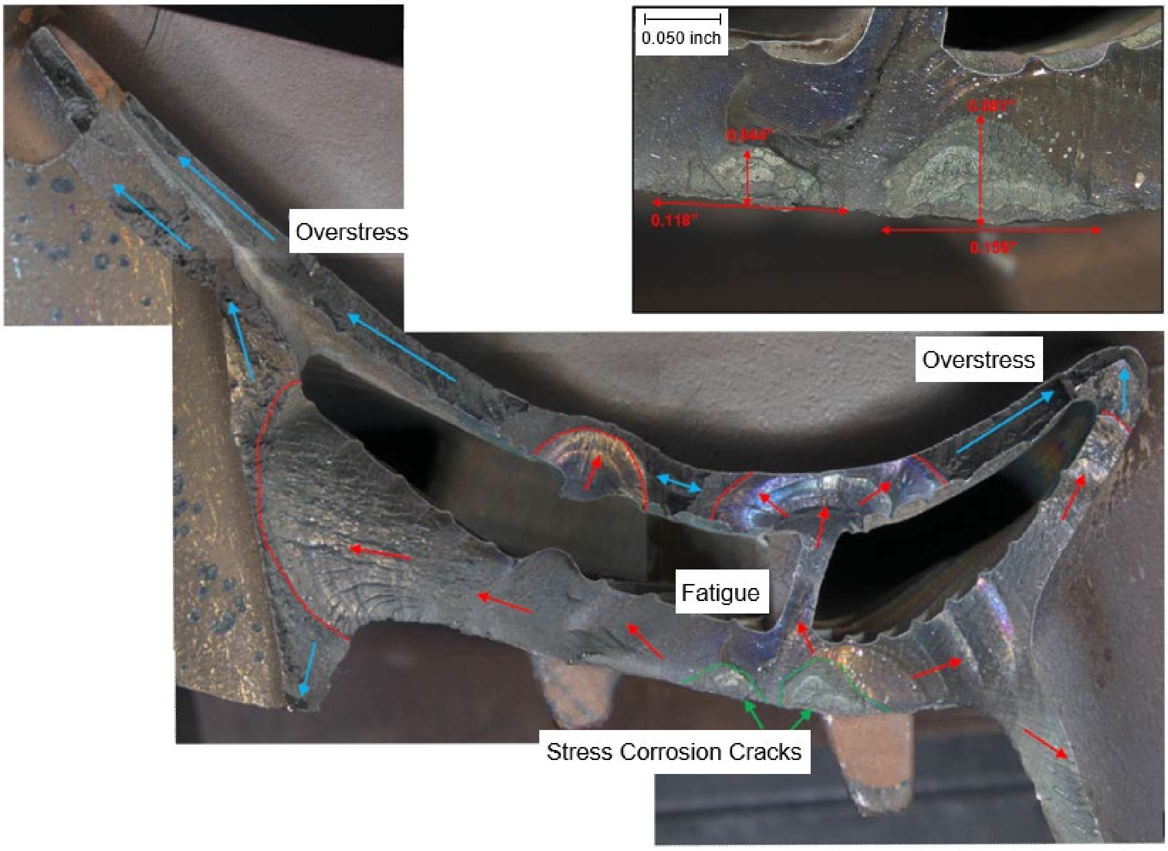


Figure 21

Detail of the Blade 7 fracture face (Used with permission)

Although not all the HPT 2 blades were examined in detail, there were some small surface cracks similar to those in Blade 7, identified in the adjacent blades to the cluster loss.

Additional information from the operator’s operating manuals

Quick reference handbook

The QRH procedure for ‘*Engine Limit or Surge or Stall*’ is contained in Appendix 1. It specified ‘*one or more*’ of the following conditions for applying the procedure: ‘*Engine fire warning… Airframe vibrations with abnormal engine indications…Engine separation*’. It included steps to select idle thrust on the affected side, start the APU, then shutdown of the affected engine.

The QRH *‘Overweight landing considerations’* procedure is contained in Appendix 2.

The QRH’s guidance on *‘Checklists directing engine shutdown’* stated:

> *‘Checklists directing an engine shutdown must be evaluated by the captain to determine whether an actual shutdown or operation at reduced thrust is the safest course of action. Consideration must be given to the probable effects of running the engine at reduced thrust.*

There are no non-normal checklists for the loss of an engine indication or automatic display of the secondary engine indications. Continue normal engine operation unless an EICAS message shows or a limit is exceeded.'

Flight crew training manual

The Flight crew training manual (FCTM) section on *'Airframe vibration due to engine severe damage or separation'* stated:

'Certain engine failures, such as fan blade separation, can cause high levels of airframe vibration. Although the airframe vibration may seem severe to the flight crew, it is extremely unlikely that the vibration will damage the aircraft structure or critical systems. However, the vibration should be reduced as soon as possible by reducing airspeed and descending. In general, as airspeed decreases vibration levels decrease. As airspeed or altitude change the airplane can transition through various levels of vibration. It should be noted that the vibration may not completely stop.

…Vibration will likely become imperceptible as airspeed is further reduced during the approach.

Once airframe vibration has been reduced to acceptable levels, the crew must evaluate the situation...'

The FCTM *'Evacuation'* section' stated:

'…Crew members must make the decision as to which exits are usable for the circumstances…the captain has to choose between commanding an emergency evacuation using the emergency escape slides or less urgent means such as deplaning using stairs, jetways, or other means…'

Flight operations manual

The operator's Flight Operations Manual described a *'yellow emergency'* as one where *'The landing will be successful'* and '[AFS] *equipment may be required'*. It advised cabin crew *'Do not anticipate an evacuation…'* but *'Prepare for dynamic circumstances which may require an evacuation after landing'.*

Additional operational aspects

The investigation did not establish what engine vibration levels the flight crew might have seen on the EICAS display[21]. The commander encouraged input from other crew members throughout the event. The flight crew could not answer every interphone call made by cabin crew members, and some resulting conversations were inaudible on the CVR. They expressed the view that Prestwick handled the incident effectively.

Footnote

21 The EICAS secondary engine indications – N_2, fuel flow, oil and vibration – are displayed using a switch on the EICAS control panel, or they automatically appear when (for example) a parameter is exceeded.

Several cabin crew members described high workload after the 'yellow emergency' call, instructing passengers to read their aircraft safety cards and re-briefing those seated at emergency exits. They checked one another were prepared, then assumed their jump seat brace positions while mentally reviewing their evacuation procedures.

The operator reported it does not specify a 'rapid disembarkation'[22,23] procedure. It had previously simplified its cabin crew emergency procedures to encompass unanticipated emergencies at the gate, and evacuation scenarios.

Information from the airport

Airport fire service

Prestwick's *'Airport fire service aircraft incident report'* stated the AFS was *'originally called out by ATC to a Local Standby Air*[24]*, for an inbound Boeing 767 with vibration problems. On route to standby positions, ATC upgraded incident to a Full Emergency*[25,26]*, and advised the pilot was landing heavy and was concerned about hot brakes'.*

The report stated the AFS vehicles positioned at the front of the parked aircraft because of *'heavy nose to tail winds'*. They *'deployed* [two] *hoses at this point to guard the aircraft against ignition as the fuel was running near hot engine and braking surfaces. AFS crews were also instructed to monitor the brake assembly temperatures using thermal imaging equipment. The brakes were not over hot but were still a concern due to the leaking fuel*[27]*'.*

The AFS Officer in Charge reported that had possible flames been reported, he would have requested the aircraft to stop on the runway for an inspection. Also, had the aircraft's fuel leak been discovered earlier, he would have required it to park away from the airport buildings.

ATC

The on-duty ATC watch manager reported upgrading the airport's response after the commander requested AFS attendance for the overweight landing. She said aspects of their communication indicated they were under pressure. She reported that six people in the control tower watched the aircraft's approach and landing (some using binoculars), and none saw anything abnormal.

Footnote

22 Referred to as 'rapid deplanement' in the USA.
23 Some operators specify precautionary rapid disembarkation procedures to address scenarios where an evacuation may not be necessary. They usually involve passengers expeditiously vacating the aircraft using normal means, without baggage.
24 Response category for an aircraft in flight which has, or is suspected to have, a defect which should allow it to land safely.
25 Response category for an aircraft which is, or is suspected to be, in danger of an accident.
26 The full emergency was announced at around 1118 hrs.
27 The first recorded temperature was approximately 180°C and they decreased thereafter.

Stress and plan continuation bias

Authors of a model on pilot stress, startle and surprise[28] wrote *'…stress is thought to cause a shift from analytical skills toward intuitive judgement, making one susceptible to biases'.* Plan continuation bias means continuing with the original plan despite cues indicating a different plan might be preferrable. It often occurs in dynamically changing conditions. An *'FAA aviation safety'* publication[29] stated it *'can appear stronger the closer* [a person] *gets to accomplishing an activity.*

Analysis

Introduction

A high-pressure turbine blade fractured in the right engine, probably during takeoff, which damaged a further five blades, but the engine was still capable of producing thrust.

A passenger recorded a video of flames coming from below the wing, however the fire extinguished before the landing. Extensive CCTV recordings of the landing and taxi, and eyewitness accounts, did not indicate the presence of fire whilst on the ground. As the aircraft arrived on stand the AFS noticed the fuel coming from the wing and put provisions in place to capture the fuel and prevent it igniting on the hot engine or brakes. Thus, there was the potential for a more significant event to have occurred. The crew actions and the engineering aspects are analysed below.

Initial crew actions

Flight deck indications of a failure began during the airborne acceleration segment of the takeoff with the autothrottle disconnecting and right engine EEC mode alerts, neither of which were resolved using the applicable QRH procedure. While considering the effect of those on continuing the flight, reports of abnormal vibration in the cabin raised the commander's awareness of a bigger, yet unidentified, problem. That, combined with abnormal EGT indications, prompted his decision to divert, probably realising such indications would preclude an overwater crossing anyway. While the extent to which crew members perceived the vibration varied, the commander, appearing aware it could vary with altitude and airspeed, preferred landing promptly. As no urgent assistance was required, declaring an emergency with ATC was probably not necessary.

The flight crew managed the overweight landing according to the associated QRH guidance; they used the longest runway nearby, with FLAPS 25, autoland, maximum autobrake, and requested AFS attendance on arrival.

Footnote

28 Referenced in: Frontiers | A narrative review of the interconnection between pilot acute stress, startle, and surprise effects in the aviation context: Contribution of physiological measurements (frontiersin.org) [accessed 1 March 2024].

29 CFIT and Plan Continuation Bias (faa.gov) [accessed 14 March 2024].

Engine management and procedural implications for the approach

Vibration became evident in the flight deck during the base leg, especially when FLAPS 1 was set. More than one QRH procedure, along with other guidance, was applicable. The *'Engine fire or engine severe damage or separation'* procedure directed engine shutdown, while the *'Engine limit or surge or stall'* procedure contained options to shut down the engine or operate it at reduced thrust settings (depending on specified engine indications). The flight crew's actions aligned with aspects of the *'Engine limit or surge or stall'* procedure and, consistent with other aspects of QRH and FCTM guidance, they considered whether an *'actual shutdown'* was necessary. Aside from the *'Engine EEC mode'* procedure, they did not appear to reference the QRH manual itself.

The relief pilot made several references to engine failure considerations but the commander, appearing keen to land, preferred continuing with the approach, and operating the engine at reduced thrust. Supporting that decision, the relief pilot continued making effective suggestions to encompass single engine operating aspects. The *'Engine limit or surge or stall'* QRH procedure specified using the single engine landing flaps setting. Although the commander briefed the single engine go-around, he continued with the overweight flaps setting for the approach. He might have assessed landing performance as the more immediate threat and wished to avoid the distraction of re-setting speeds, while he perceived time pressure to continue with the approach. The right engine subsequently running down was not apparent to the crew until after landing, therefore did not feature in those decisions.

The arrival and disembarkation

The ATCO ensured a full emergency response because of the intended overweight landing, and there were indications the flight crew were under pressure. After the flight crew declared an onboard 'yellow' emergency, the cabin crew had limited time to make landing preparations, and the short period of flames seen from the cabin was not reported to the flight crew. Such a report may not have significantly changed the approach and landing but might have caused the AFS to inspect the aircraft immediately after landing and/or keep it away from the terminal building.

Because the right wing's fuel leak was discovered after parking, the commander could make the pragmatic decision of deplaning the passengers quickly using the normal (left) exits, without baggage. The fuel leak's proximity to hot brakes from an overweight landing increased urgency. However, prompt actions by airport staff and assertive cabin crew passenger management helped fulfil a 'rapid disembarkation'. Had the fuel leak been discovered before parking; or had the stairs been delayed to the stand and/or the fuel been leaking from the left wing, an evacuation (using relevant exits), with the inherent risk of injuries, may have been necessary.

Other crew resource management aspects

The commander's openness to input, combined with assertive communications by the relief pilot and cabin crew, manifested some effective information sharing while the co-pilot focussed on the flying task. However, high workload for all the crew during the last ten minutes of the flight, along with natural limitations of communicating using interphone, might have impeded certain cabin information reaching the flight crew. The flight crew remained unaware of the flames which had been seen from the cabin during the approach.

The commander exhibited natural signs of stress during the event. The insidious, complex, and dynamic nature of the failure might have increased the potential for plan continuation bias, as the commander felt time pressured to land the aircraft. Consequently, some decision making, for example, in relation to engine operating considerations for the approach, appeared more intuitive, rather than structured, in nature.

Delaying commencing the approach, for example, after the vibration became evident while at 6,000 ft amsl, could have allowed time for the flight crew to reference the QRH together; agree on engine operation and aircraft configuration for the landing and go-around; and make additional communications with the cabin. Nevertheless, the affected engine ran down, the flames curtailed, and the aircraft landed promptly.

Engine failure

An HPT 2 blade in the right engine fractured and the detached blade then damaged a further five HPT 2 blades, the majority of which were subsequently liberated from the disk. The initial fracture was a result of fatigue cracks initiated from two SCCs on the exterior convex face of the blade. Similar cracks were also seen on the adjacent (non-damaged) blades. Detailed metallurgical examination revealed the presence of sulphur, indicative of a sulphation attack, hence pitting of the blade surface during normal engine operation, rather than a specific blade problem.

The vibration created by the rotating out of balance HPT 2 disk resulted in many engine systems being damaged, and the vibration was transmitted into the airframe. Engine control modes, engine oil parameters and the automatic ACARS messages relating to the engine showed multiple issues with the engine as the flight progressed under high vibration. Significantly higher levels of vibration from the right engine were evident during and after the takeoff than had been recorded during N197DN's previously recorded flights. For a short period in flight, the vibration values were sufficiently high to have changed the displayed vibration values from the normal white to amber. It is not evident whether the crew noticed this change, however they were aware of a problem anyway. The engine maintained a capability to create thrust until the throttle was reduced to idle during the descent and it is considered that a short time after this, the engine ran down and the N2 shaft ceased rotating.

It is the opinion of the engine manufacturer that the magnitude of imbalance from the damaged HPT 2 disk exceeded the level of imbalance observed in the two prior B767 events. All three events resulted in the fracture of the slat track housing drain tube, and the time to shut down the engine after the blade loss was of a similar order of magnitude. The engine was at takeoff / climb power from 1103 hrs until the aircraft reached FL100 at 1108 hrs, with the peak vibration level sustained for one minute starting at 1110 hrs. The engine ran down and the N2 stopped rotating at 1125 hrs. Based upon the N2 rotation speed the frequency of the vibration would have been between 150 to 160 Hz for the climb, dropping to 130 to 140 Hz during the period at FL100. This is discussed further in the fracture of the drain tube section below.

It should be noted that the certification specification for aircraft engines, CS-E 810 Compressor and Turbine Blade Failure, states that any single turbine blade will be contained after failure. Furthermore, no hazardous engine effect can arise because of other engine damage that is likely to occur before the engine is shut down following a blade failure. During the event flight the failed blade was contained and no hazardous engine effect was identified.

Fracture of the drain tube

The investigation did not determine the exact vibration spectra that was applied to the Slat 8 inboard track housing drain tube, but it was concluded that the sustained high level of vibration from the engine caused the drain tube to oscillate and fail in fatigue. Detailed analysis of the fracture faces concluded that the fatigue cracks initiated from intergranular cracking. A literature survey in conjunction with the forensic materials laboratory was undertaken to determine the source of this intergranular cracking and it was deemed most likely to have come from accidental acid splash[30]. This may have occurred during the early stages of the tube manufacture as there was a layer of chromate conversion coating as well as paint that covered the cracks. A fatigue analysis by the aircraft manufacturer demonstrated that the intergranular cracks on the surface of the drain tube would not have significantly reduced the fatigue life of the component. Analysis of the fracture face of the drain tube showed regular striation spacing and there was no evidence of arrest features; it was therefore concluded that a crack started and fully fractured within this single flight.

During certification testing of the modified drain tube design that was fitted to N197DN, it was determined that the first mode resonant vibration response of the system was approximately 170 Hz. From the recorded data for most of the incident flight the N2 speed was between 120 and 150 Hz. It was not possible to determine how the out of balance forces from the HPT 2 disk were attenuated, amplified or modified by the structural elements between the engine and the drain tube. However, the aircraft manufacturer was able to demonstrate the drain tube would have fractured in less than 20 minutes of operations in a similar manner to N197DN if it were subjected to an input load greater than 5g at 165 Hz. It was deemed probable that the drain tube would have been subjected to loads such as these and hence provide conditions conducive to crack propagation during the incident flight.

The rotation axis of the engine is orientated in the fore/aft direction (Figure 22) and therefore out of balance HPT 2 disk loads are transmitted in the vertical and lateral directions. The slat track housing and Rib 9 prevent the drain line from moving laterally, but it is unrestrained vertically. The vertical vibration loads act upon the centre coupling causing it to be displaced. This movement is absorbed at Rib 9 by the other coupling but creates a bending moment in the drain tube near the slat track housing. The upper and lower surfaces are cyclically placed into tension and compression thereby applying a fatigue load to the drain tube. The analysis of the drain tube fracture faces showed the crack initiated from the upper surface at the point furthest laterally from the centre coupling.

Footnote

30 The Identification and Prevention of Defects on Anodized Aluminium Parts / Ted Short, Metal Finishing Information Service, 2003.

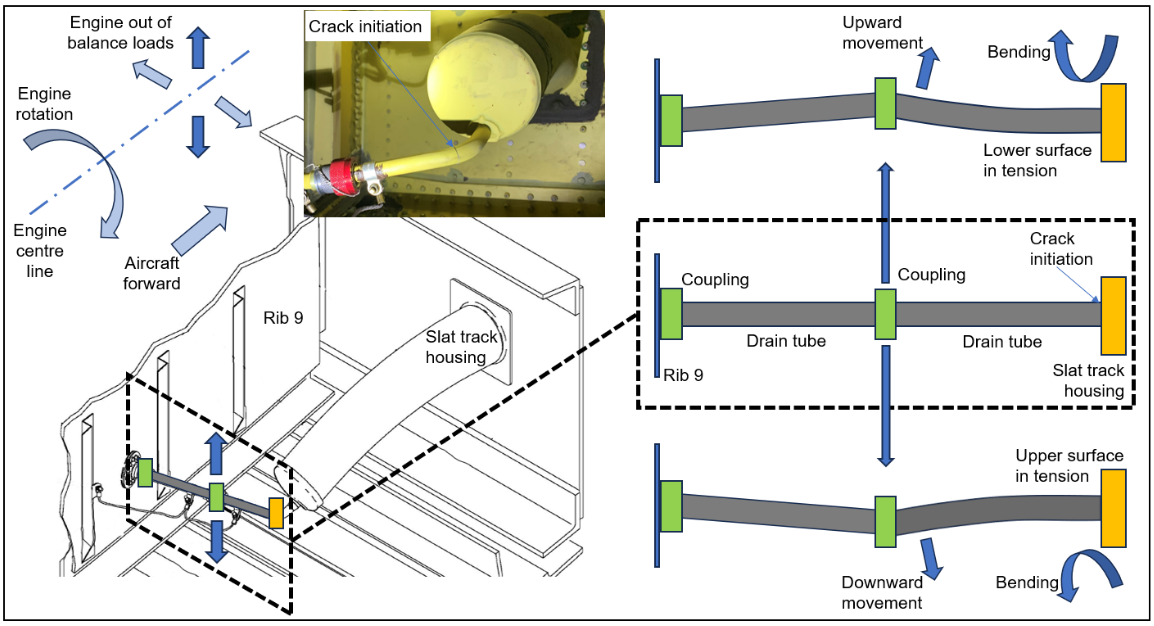


Figure 22
Drain line fracture mechanism

The fracture of the drain tube opened a leak path from the right wing fuel tank into the dry bay which allowed fuel to travel from the tank into the slat track housing drain tube, through the dry bay and out of the water drain. It was estimated that approximately 1,100 lb of fuel were lost from the aircraft during the period from the fracture of the drain tube to the completion of the fuel transfer after the aircraft was on stand. Approximate flow rate calculations suggest that the fuel leak started shortly after takeoff and continued until the fuel transfer was completed at approximately 1300 hrs with about a quarter of the total quantity of the fuel lost through the drain tube being lost in flight.

The passenger video of flames coming from the rear of the wing was likely to be the fuel streaming from the dry bay drain hole into the air flow and being ignited in the hot jet efflux. The absence of soot or heat damage on the engine cowlings suggests that the flames were behind the engine rather than being an engine fire. None of the witnesses on the ground reporting seeing any flames during the approach, and the fuel leak was first noticed by a ground marshaller as the aircraft taxied to the stand. The wind direction and the orientation of the aircraft on stand resulted in fuel being blown aft towards the landing gear. The brake temperatures were monitored when the aircraft was on stand and the initial readings were in excess of the fuel ignition temperature. No ignition took place, but this did present significant potential for a fuel fire.

As a result of this serious incident the aircraft manufacturer has taken safety action to launch a project to review the design of the drain tube for potential reliability improvements. At the time of publication of this report, the manufacturer had found that there was no increased risk to a catastrophic[31] outcome from a failed drain tube. The Federal Aviation Administration review of the analysis was pending. To provide visibility of the outcome, the following recommendation is made:

Safety Recommendation 2024-015

It is recommended that the Federal Aviation Administration requires the Boeing Airplane Company to demonstrate that following this serious incident, the design of the slat track housing drain tube on the Boeing 767 family of aircraft continues to comply with the certification requirements for large transport aircraft.

Conclusion

During the early stages of the event flight a high-pressure turbine blade fractured through fatigue cracking. The fatigue crack was initiated by a possible combination of hot corrosion and pitting from external contamination. The detached blade caused damage to a further five blades resulting in an engine imbalance. A drain tube in the right fuel tank fractured, probably as a result of the vibrations transmitted from the out of balance engine. This resulted in fuel escaping from the right fuel tank out of a wing drain hole and igniting in flight. The flight crew landed the aircraft promptly at Prestwick. They were unaware of any flames, or the right engine running down, until after landing.

The fuel coming from the wing was noticed by the ground crew as the aircraft parked near the terminal buildings. The wind was blowing the fuel towards the hot brakes and there was a risk of a fuel fire. The passengers were rapidly disembarked, and actions were taken to contain and stop the fuel leak.

As a result of the vibration-driven fatigue fracture of the drain tube, the aircraft manufacturer has launched a project to identify potential reliability improvements to the design while the Federal Aviation Administration reviews the manufacturer’s finding that the risk of a catastrophic outcome from a failed drain tube is not elevated. This project is ongoing and so a Safety Recommendation has been made to the Federal Aviation Administration to ensure the aircraft continues to meet the certification requirements for large transport aircraft.

Footnote

[31] Airworthiness definition of a ‘catastrophic event’ – Normally a full aircraft hull loss with multiple passenger fatalities and possible crew incapacitation or fatality. Statistically improbable with less than one occurrence happening in $1x10^9$ flying hours.

Appendix 1 - QRH *'Engine Limit or Surge or Stall'* procedure

Engine Limit or Surge or Stall

Condition: One or more of these occur:
- Engine indications are abnormal
- Engine indications are rapidly approaching or exceeding limits
- Abnormal engine noises are heard, possibly with airframe vibration
- There is no response to thrust lever movement or the response is abnormal
- Flames in the engine inlet or exhaust are reported

1 A/T ARM switch . . . . OFF

2 Thrust lever (affected side) . . . Confirm . . . . .Retard until engine indications stay within limits or the thrust lever is at idle

3 ENG START selector (affected side). . . . . FLT

Note: If an engine compressor surge/stall occurs during ground operations, or takeoff is rejected due to an engine compressor surge/stall, a maintenance inspection is required prior to flight.

Note: Do not initiate an over-water crossing when a surge or stall has occurred.

Note: EGT may take up to two minutes to recover to normal range.

▼ Continued on next page ▼

▼Engine Limit or Surge or Stall continued▼

4 Choose one:

◆Engine indications are **stabilized and** EGT is **stabilized or decreasing**:

►►**Go to step 5**

◆Engine indications are **abnormal or** EGT continues to **increase**:

►►**Go to the Engine Failure or Shutdown checklist on page 7.16**

■ ■ ■ ■

Check that RPM and EGT follow thrust lever movement.

5 ⚠ Thrust levers (affected side) . . . Advance slowly

6 Choose one:

◆Engine RPM and EGT follow thrust lever movement:

Run the engine normally or at a **reduced thrust setting** that is surge and stall free.

►►**Go to step 11**

◆Engine RPM and EGT **do not** follow thrust lever movement:

►►**Go to step 7**

▼ Continued on next page ▼

▼Engine Limit or Surge or Stall continued▼

7 Choose one:

◆EGT is **normal**:

►►**Go to step 8**

◆EGT is **not** normal:

►►**Go to the Engine Failure or Shutdown checklist on page 7.16**

■ ■ ■ ■

8 ENG bleed air switch (affected side) . . . . Off

9 Choose one:

◆Engine **responds**:

Operate engine normally or at a **reduced thrust level** which is surge and stall free.

►►**Go to step 10**

◆Engine does **not** respond:

Operate engine at idle.

►►**Go to step 10**

10 ENG bleed air switch (affected side) . . . . On

▼ Continued on next page ▼

▼Engine Limit or Surge or Stall continued▼

11 Choose one:

◆Engine operates **normally**:

■ ■ ■ ■

◆Engine operating **at idle** or at a **reduced thrust level** which is surge and stall free:

Note: Do not use FMC performance predictions.

►►**Go to step 12**

12 GND PROX FLAP OVRD switch . . . . OVRD

Note: Monitor fuel balance.

13 Transponder mode selector . . . . TA ONLY

14 Use flaps 20 and VREF 20 for landing.

15 Use flaps 5 for go-around.

16 Check the Abnormal Configuration, Actual Landing Distances and Approach Speeds tables in the ODM.

17 **Checklist Complete Except Deferred Items**

▼ Continued on next page ▼

▼Engine Limit or Surge or Stall continued▼

Deferred Items

Descent Checklist

Altimeters . . . . ___, xckd		C&F
■Minimums . . . . ___, ___, xckd		C&F
■Landing data . . **flaps 20, Vref 20, xckd**		C&F
■Approach briefing . . . . complete		PM
■Autobrakes . . . . as reqd		PM
Seat belt signs . . . . ON		PM
Pressurization panel . . . . set		PM
Recall . . . . ckd		PM

Approach Checklist

■Flight & nav instruments . . . . verified	C&F
Cabin notification . . . . complete	C
Altimeters . . . . ___, xckd	C&F

Landing Checklist

Landing gear . . . . .down	C&F
Flaps **20, 20**	C&F
Speedbrake . . . . ARMED	PM

■ ■ ■ ■

Appendix 2 - QRH *'Overweight landing considerations'* procedure

Overweight Landing Considerations

Condition: A decision is being considered or has been made to land over the maximum landing weight limitation.

Note: Exercising captain's emergency authority does not require the declaration of an emergency with air traffic control. Refer to FOM - Flight Ops Manual 2.3 Operational Irregularities.

Note: When considering an immediate return to the takeoff runway, the landing distance is generally less than the takeoff distance at all gross weights when landing with flaps 25 or 30 and the runway is dry.

Approach:

- Consider landing on the longest available runway.
- Review landing distance required in the Approach/ Landing or Abnormal section of the ODM (normal or reduced landing flap configuration).
- If landing distance is a concern, consider jettisoning fuel or holding to reduce weight.

▼ Continued on next page ▼

▼Overweight Landing Considerations continued▼

- If landing distance is not an issue, jettisoning fuel or holding to reduce weight is not necessary.
- Use an autobrake setting commensurate with runway length and conditions. Refer to the Operational Landing Distances table in the ODM.
- If approach VREF (including additives) is within 10 KIAS of the flaps 30 placard speed, use flaps 25 and VREF 25 (plus additives) for landing.
- The aircraft is not certified to autoland at greater than maximum landing weight. If the captain determines that an autoland is the safest course of action, the approach, flare, and landing must be closely monitored at all times.
- The vertical speed required to maintain glidepath may be significantly higher than normal. The captain should brief contingencies if "SINK RATE" cautions are received on short final.

▼ Continued on next page ▼

▼Overweight Landing Considerations continued▼

Landing:

- Do not hold the airplane off waiting for a smooth landing.
- Fly the airplane onto the runway at the normal touchdown point.
- Attempt to touch down at approximately 200 - 300 fpm. If able, note the vertical speed at touchdown.
- If a long landing is likely to occur, a go-around should be accomplished.
- Apply reverse thrust commensurate with runway length and conditions.

After Landing:

- Be alert for the possibility of tire, grease, or hydraulic fire and the possibility of wheel fuse plugs melting. Advise the ground crew of the hot brake hazard.
- Make a logbook entry including the phrase "overweight landing." Include actual landing weight, maximum landing weight, and vertical speed at touchdown, if known.

■ ■ ■ ■

Published: 18 July 2024.