ACCIDENTS INVESTIGATION BRANCH
Department of Trade and Industry

British Caledonian Airways BAC-1-11 G-AWYS Report on the accident at Corfu Airport, Greece, on 19 July, 1972

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ACCIDENT TO BRITISH CALEDONIAN AIRWAYS, BAC ONE ELEVEN 501 G-AWYS AT CORFU KERKYRA AIRPORT ON 19 JULY 1972

Civil Aviation Report dated 21 August 1973 released by the Civil Aviation Administration, Greece

AIRCRAFT	: BAC One Eleven 501
ENGINES	: Two Rolls Royce Spey MK 512-14 DW
REGISTERED OWNER & OPERATOR:	British Caledonian Airways Ltd.
CREW	: Commander - Captain R Shilton, Acting as Co-Pilot - Uninjured Pilot-in-Charge - Captain W E Mitchell Uninjured Supernumerary-First Officer - P M J Finucane -Uninjured Cabin Staff: Miss M-A MacLennan-Uninjured Miss D Harrison - " Miss L J Adams - "
PASSENGERS	: 79 - Uninjured in the accident but one female passenger collapsed and died after being assisted off the aircraft.
PLACE OF ACCIDENT	: Kerkyra Airport, Corfu, Greece 3936N 1954E
DATE & TIME	: 19 July 1972 at 1315 hrs GMT All times in this report are GMT

SUMMARY

During the take-off run, and at a speed close to take-off decision speed, the aircraft ran through some pools of standing water about mid-point along the runway.
Because of a suspected malfunction of No 1 engine the take-off was abandoned but the crew were unable to stop the aircraft although the emergency stop drill was correctly executed once the decision was taken. The aircraft over-ran the rough ground at the end of the runway at a relatively low speed and came to rest in the nearby lagoon in about 1 metre depth. The 79 passengers and 6 crew were uninjured and left the aircraft in an orderly manner, but an elderly lady who was assisted from the aircraft died of a heart attack whilst being taken to hospital.

1 INVESTIGATION

1.1 History of the flight

1.1.1 The aircraft was on an international passenger charter flight from Gatwick Airport to Kerkyra and was returning to Gatwick with 79 passengers and 6 crew. The pilot in charge (P1), Captain Mitchell, was being given a restricted airfield check into Kerkyra by Captain Shilton who was the aircraft commander but was occupying the right-hand pilot's seat and performing normal co-pilot duties (P2). Before leaving Gatwick Captain Shilton had briefed the crew on their duties and their roles for both outbound and inbound flights. First-Officer Finucane was carried in a supernumerary capacity, having no specific in-flight duties.

1.1.2 The outbound flight to Kerkyra was without incident and the aircraft landed on Kerkyra Airport at 11.58 hours. At Kerkyra Airport the crew carried out the preflight preparation for the return flight and filed an IFR flight plan for Gatwick direct.

1.1.3 For the return flight to Gatwick crew disposition was as before. Because of runway and temperature requirements it was decided that take-off from Kerkyra on Runway 17 would be made with 18^{o} flaps using water injection. After boarding the aircraft the pilot in charge, Captain Mitchell, gave the usual briefing on take-off emergencies which were accepted and understood by the co-pilot, Captain Shilton. Take-off speeds were extracted, taking into account existing conditions, from the tables in the Operations Manual and were written down and placarded in front of each pilot. These speeds were:

V_1 - 135 knots; V_r - 136 knots; V_2 - 143 knots.

NOTE: V_2 speed was placarded as 144 knots instead of 143 knots.

Engines were started normally and before take-off clearance was given Air Traffic Control (ATC) reported that there were some pools of water at mid-distance on Runway 17. On receipt of this information it was decided to switch the ignitors on during take-off and the dry V_1 of 135 knots was amended to 128 knots which was not placarded but it was annotated by the co-pilot with a grease pencil on his airspeed indicator. After lining up for take-off, full power was selected against the brakes and the co-pilot checked that both engines were operating with water injection and the engine P7 gauges, whose Thrust Setting Intex (TSI) counters had been set to 162, were indicating 100%. Both engine Turbine Gas Temperature (TGT) gauges were indicating approximately 600^{o} and brake temperatures were below 200^{o}C. Take-off commenced shortly after 1314 hrs.

1.1.4 The first part of the take-off run was normal but with slight bumpiness on account of surface irregularities. Before reaching 80 knots engine ignitors were switched on by the co-pilot. Shortly afterwards and at a speed of about 100-110 knots, according to Captain Mitchell, the aircraft ran through some pools of standing water and it seemed to hesitate, then recover. At about this speed Captain Mitchell was also aware that the aircraft was deviating progressively to the left and he was conscious of having to increase right rudder. This was also noticed by the co-pilot. Captain Mitchell glanced at the exhaust pressure (P7) gauges and he saw that No 1 P7 gauge was not indicating what it should have been. The co-pilot looked at the airspeed indicator and saw it was indicating approximately 120 knots fluctuating and increasing; he also had the impression of hearing a double bang which he associated with the left engine; he also saw one of the left engine instruments (he believes it was P7) suddenly decreasing. By that time Captain Mitchell called "abandon", closed the throttles and applied the foot brakes. In accordance with the agreed procedure the co-pilot quickly selected full spoiler and applied full reverse power on both thrust levers. The co-pilot estimated that action to abandon the take-off was initiated when airspeed was about 124 knots and increasing; also, whilst selecting spoilers and reverse thrust he had the impression that the aircraft seemed to accelerate slightly but when reverse thrust and braking became effective the aircraft decelerated normally.

1.1.5 As the aircraft decelerated the co-pilot called "speed 80" then at about 60 knots it became apparent to him, from the rate of deceleration and the runway distance remaining, they would not stop. The co-pilot said he could hear the engine or engines roaring in reverse thrust and on checking the engines' instruments the right engine HP rpm was indicating 101 per cent but he did not notice, or expect to see, any indication on the left engine instruments. The co-pilot also applied full foot brakes in order to confirm that they were already in use by

Captain Mitchell; on applying the brakes he did not obtain any sensation of "dumping" such as may be felt or sensed when full anti-skid braking is in use. Captain Mitchell said that he had no difficulty in maintaining directional control during the deceleration phase.

1.1.6 The aircraft overran the rough ground at the end of the runway at a relatively low speed and came to rest in sea water of the nearby lagoon in about 1 metre depth with water up to the level of the mainplanes. Retardation was not violent and there was no injury. According to the co-pilot reverse thrust was not cancelled until the aircraft came to rest.
Evacuation proceeded in an orderly manner via the overwing exits and the port wing. Most passengers were transferred to the shore by small boats which arrived quickly on the scene; some passengers waded ashore. Although no-one suffered physical injury as the aircraft came to rest one elderly lady collapsed after being assisted from the aircraft and died from a heart attack whilst being taken to hospital.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Non-fatal	-	-	-
None	6	79	

1.3 Damage to aircraft

The aircraft was substantially damaged.

1.4. Other damage

Slight damage to airport boundary.

1.5 Crew information

1.5.1 Commander: Captain Rex Shilton, aged 46, holds an Airline Transport Pilot's Licence (ATPL), No 30660 issued in UK on 27 January 1958. He also holds a Flight Navigator's licence and a restricted Radiotelephony licence. His ATPL was valid until 19 May 1973 subject to medical fitness and recency requirements. He was last medically examined on 16 May 1972 and there were no medical restrictions. The following types were included on his licence: Proctor Variant, Dart Herald, Viscount and BAC 1-11. His last periodic competency check on a BAC 1-11 was on May 2, 1972 and his instrument rating was last renewed on 8 February 1972. He held the appointment of a line training captain since 1971 and he had flown a total of 13,126 hours of which 3,223 were in command on BAC 1-11 aircraft. He had landed 8 times at Kerkyra, the most recent of which was July 1972 which was seven days before the accident. During the 96 days preceding the accident he had flown 203 hours of which 64 were during the last 28 days. Before reporting for duty at Gatwick on the day of the accident Captain Shilton had been off duty for over 22 hours and at the time of the accident he had been on duty for 5 hours and 45 minutes. He was uninjured.

1.5.2 Pilot in Charge: Captain William Gordon Mitchell, aged 49, holder of ATPL No 29398 issued in UK on 2 June 1967 when it was upgraded from a Commercial Pilot's licence. His licence was valid until 1 June 1977 subject to medical fitness and recency requirements. He also held a restricted Radiotelephony Licence. His instrument rating was last renewed on 12 April 1972 and he was last medically examined on 4 April 1972. His licence was endorsed with a restriction that glasses should be carried for near vision. His last competency check was conducted on a flight simulator on 12 April 1972 and his last line-check was on 29 April 1972. Captain Mitchell was last examined on emergency procedures on 31 December 1971. At the time of the accident he had flown a total of 13,084 hours, 3,789 of which were on BAC 1-11 aircraft and 826 were in command on this type. During the 96 day period preceding the accident he had flown 159 hours, of which 42 were during the last 28 days. He had landed 5 times at Kerkyra but his most recent landing on this airport was on 13 October 1970; it was for this reason he was being rechecked into Kerkyra.

On the day before the accident he was off duty and at the time of the accident he had been on duty for 5 hours and 45 minutes. He was uninjured.

1.5.3 Supernumerary: First Officer Peter Michael John Finucane, aged 47, holder of ATPL No 54649 endorsed for BAC 1-11 as a co-pilot. He was last medically examined on 18 July 1972 and his last competency check was on May 1972. Mr Finucane took no part in the flight and he was seated on the supernumerary seat behind the pilot in charge during the take-off. He was uninjured.

1.5.4 Cabin Crew: There were 3 female cabin staff.

No 1 Air Hostess, Miss Mc Lennan

No 2 Air Hostess, Miss D. Harrison

No.3 Air Hostess, Miss L. J. Adams.

All 3 had been examined in their knowledge of emergency procedures and cabin safety equipment. They all were uninjured.

1.6 Aircraft Information

1.6.1 The aircraft was a BAC One-Eleven 501, constructed by the British Aircraft Corporation Ltd and was first certificated in the Public Transport (Passenger) category on 12 April 1969. It was equipped with two Rolls Royce Spey MK 512-DW turbo-jet engines using water injection. Its Certificate of Airworthiness No 2993, valid for one year, was last renewed on 23 April 1972 and its Certificate of Maintenance, last renewed on 14 June 1972 following a periodic inspection, was valid for 110 days or 900 flying hours whichever expired first. At the time of the accident it had flown 8,997 hours with 5,626 landings since new and 358 hours since being last inspected.

1.6.2 It had been maintained in accordance with a schedule approved by the United Kingdom Civil Aviation Authority. All mandatory "A" amendments to the schedule up to 26 May 1972 and all Operators' "B" amendments up to 16 June 1972 had been incorporated. There were no outstanding defects.

1.6.3 A load and trim sheet prepared by Olympic Airways at Kerkyra showed that the aircraft's weight when laden for take-off was 42,323 kg and its centre of gravity was approximately mid-range. Included in this figure was a fuel load of 10,540 kg of aviation kerosene and 320 kg of demineralised water which was sufficient for its intended flight and contingency reserves. In the conditions of wind and temperature existing at Kerkyra and because it would be necessary to make an obstacle avoiding turn in the event of an engine failure when committed to take-off, the maximum permissible weight for take-off on Runway 17 was regulated to 42,510 kg. The aircraft was therefore correctly loaded and it has been calculated that a margin of 333 metres was available over and above the runway distance which would be required to stop the aircraft should an emergency arise during the take-off run before the take-off decision speed of 128 knots.

1.6.4 Flight Manual

An approved Flight Manual, carried in the aircraft, included an Appendix which applied when operating from precipitation covered runways. This appendix restricted operations to a maximum depth of slush or water of 12.5 mm; however, this limitation only applied when significantly large areas of the runway are affected and specifically excluded isolated pools such as existed on the Kerkyra runway. The UK CAA have stated there is considerable difficulty in attempting to define the depths of water and runway coverage applicable to isolated pools. It is also understood that this difficulty is recognised by more than one airworthiness authority.

1.7 Meteorological Information

1.7.1 About 40 minutes before the aircraft departed there had been two 10 minute periods of steady rain, each separated by about 5 minutes. At the time of departure it was not raining, the weather was partly cloudy and the runway surface at the northern end of the airport was dry.

1.7.2 Air Traffic Control reported that at the time of the accident the wind was calm, QNH 1011, with some standing water about 2 cms depth at mid point along Runway 17.

1.7.3 An eyewitness, an airport policeman who was located about 700 metres from the end of Runway 17 said that during the take-off, as the aircraft passed his observation post, there was a plume of water following it. After the accident two pools of standing water were located at 1,230 metres from the commencement of the runway. According to the crew, when they lined up for take-off they could see that the first half of the runway was dry but gave the appearance of a shiny surface due to a heat mirage which is normal on this runway.

1.7.4 A special observation made at 13.15 hrs, by the Kerkyra Weather Bureau gave the following:

Surface wind	: calm
Visibility	: 10 kms
Temperature	: +24°C
Humidity	: 73%
Dew Point	: +19°C
Runway Conditions	: wet
QNH	: 1011
QFE	: 1011
Clouds	: 2/8 cumulo-nimbus (CB) cloud at 2,000 ft; 2/8 cumulus at 2,500 ft;

CB 20 kms distant to the east and nortwest of the airport. Light conditions were assessed as fair.

1.8 Aids to navigation

Kerkyra Airport has no aids to navigation except a non-directional beacon (NDB) and a visual omni range (VOR) beacon. These were not a factor in the accident.

1.9 Communications

One frequency, 119.7 MHz, was used for controlling aircraft on the ground and in the air. Speech recording equipment was available and working. A transcript of RT messages was compiled and agreed with the UK Authorities. Communications were generally good and there were no language problems.

1.10 Aerodrome and Ground Facilities

1.10.1 Kerkyra Airport has only one runway (17-35). Runway direction 17 which was used for this take-off has an elevation of 6 ft and the following declared distances:

Take-off run available	- 2,294 metres
Take-off distance available	- 2,334 metres
Accelerate stop distance	- 2,334 metres
Landing run distance available	- 2,294 metres

1.10.2 Runway 17 has a rolled asphalt, smooth texture surface, approximately 10 cm (4 inches) thick. The first 960 metres were recently resurfaced and were clear of tyre rubber. The remaining 1,374 metres were last resurfaced in 1966 and with the exception of the last 250 metres approximately 600 metres were rather heavily contaminated with tyre rubber deposits.
At mid-section of the runway there was a slight upgradient in which there were two depressions of approximately 3-4 metres in diameter and 2-3 centimetres deep astride the centreline. These depressions which were 1,230 metres from the beginning of the runway retained a quantity of water following rainfall. Further along the runway from this point, because of a slight crossfall from right to left, water tended to pond to the left of the centreline over the last 1100 metres of the runway. Drainage from the ponded areas appeared ineffective and dissipation of water was dependent on atmospheric conditions. When required, braking action was qualitatively assessed by a vehicle.

1.10.3 Since there were considerable deposits of tyre rubber over the "braking" section of the runway (ie the last 1,500 metres) an assessment of braking action and of runway conditions generally were made by the Institute of Technology, Cranfield, at the request of the investigation. A "mu-meter" was used to assess runway friction and for test purposes the runway was artificially wetted. A test section commencing 1,580 metres to 2,120 metres from the commencement of Runway 17 was chosen for the trials, the main object of which was to obtain a comparison of the friction meter readings at Kerkyra and known surfaces in the UK. It was found that the differences in friction between the high and low rubber deposits were small and it was concluded from the tests that at water depth of up to .030 inches (approximately .78 mm) the friction of the runway at Kerkyra was good, whereas in water depths of approximately 4 mm friction was poor which is to be expected on any other runway surface of this kind.

1.10.4 Fire Appliances

There were two fire tenders permanently manned by six firemen under the supervision of a Sergeant of the Fire Brigade Service whenever aircraft took off or landed at Kerkyra. The appliances were immediately alerted to the emergency and went to the scene where the firemen assisted in passenger evacuation.

1.11 Flight Recorder

1.11.1 The aircraft was equipped with a Sperry airborne data acquisition system (SADAS) 5000 series which uses a Penny and Giles wire recorder to record the following data:

Parameter	Sampling Rate
Pitch attitude	8 per second
Vertical acceleration	8 per second
Indicated airspeed	1 per second
Altitude	1 per second
Magnetic heading	1 per second
AC frequency	1 per second

1.11.2 The flight recorder and its associated components were recovered intact from the aircraft and returned to the United Kingdom for examination and data processing.

The degree of accuracy of the data was established and the take-off run and accelerate-stop sequence was analysed by experts. The following paragraphs summarise the ensuing report which was prepared by a working group under the chairmanship of the UK inspector of accidents accredited to the inquiry.

1.11.3 Accuracies

At the time of the accident the flight recorder was operating on all parameters within its design limits and the data accuracy obtained was somewhat better than the standard defined by current UK legislation.

1.11.4 The original data was produced in analogue form but significant areas were reduced to digital quantities when maximum accuracy was required for calculation purposes. Transducer calibration corrections and position error corrections were applied. The resultant values are given in analogue form at Appendix 1 to this report. Aircraft speeds are given in equivalent airspeeds (EAS) values; in the circumstances of the take-off, EAS = pilot's ASI reading + 0.5 knots.

1.11.5 Scrutiny of the analogue traces indicated some unusual excursions in pitch between Vmax minus 7 seconds and Vmax minus one second, and in the present case the excursions were almost certainly indicative of large and rapid fluctuations of the flight recorder AC supply occuring during this period. It should be noted that with this type of recorder, pitch readings are sensitive to AC frequency, so to obtain the true values a correction has to be applied to the recorded reading; conversely, if the pitch angle remains constant but the AC frequency varies the pitch readings will vary.

1.11.6 Tests

Tests were carried out at Gatwick Airport on a BAC One-Eleven 500 series using the same flight recorder which had been recovered intact from G-AWYS. The tests were conducted by a British

Caledonian flight crew and by test observers from the airline and the British Aircraft Corporation (BAC) Weybridge. There were two main objectives in carrying out the tests, namely:

(a) to ascertain if the observed AC supply frequency variation could be used as an indication of engine speed changes;

(b) to establish the brake release characteristics of the recorder since the brake release was difficult to identify from the recorder accident data.

The following events and tests were recorded under controlled conditions: engine start-up; abandoned take-off runs using 1 and 2 engines in reverse thrust; normal and fast applications and reductions of take-off power; engine and APU shut-down sequence.

1.11.7 Results of Tests

It was confirmed that large changes in engine speed result in fluctuations of recorded AC supply frequency and the results of the tests when applied to the accident read-out imply that:

(a) engine power was applied 12 to 16 seconds before brakes were released;

(b) wheel brakes were released between 42 and 37 seconds before Vmax;

(c) at approximately 126 knots EAS there was a reduction in No 1 engine HP rpm and this was followed by a period of fluctuating speed on that engine which lasted for about 7 seconds;

(d) at no time during the Corfu incident did No 1 engine lose RPM to sufficiently low a level, and for long enough duration, to cause an automatic changeover of the bus-bar (when the APU alternator would take over from No 1 engine alternator);

(e) action to abandon the take-off was taken before a speed of 135 knots. Reverse thrust was achieved (at least) on No 1 engine and maintained up to the end of the record.

1.11.8 Analysis of Accident Flight Data

The accident data was analysed with the aim of relating its information to the physical evidence determined fron the runway and accident site.

Particular attention was given to:

(a) determining the speeds achieved at significant points during the take-off run;

(b) determining at what stage the decision to abort the take-off was taken;

(c) acceleration and deceleration achieved;

(d) an assessment of the kinetic energy input to the wheel brakes during the braking sequence;

(e) relating the actual performance of G-AWYS to its certificated performance in the conditions prevailing.

1.11.9 Summary of Results

(i) The recording system was working correctly and within its design limits;

(ii) using all the evidence and data available it was not possible to define the time at which brakes were released more precisely than between 42 and 37 seconds before maximum speed (Vmax), but 38.6 seconds has been shown to be the most likely time;

(iii) due to technical limitations of the flight data recorder it was not possible to determine the speed of the aircraft accurately up to approximately 60 to 80 knots;

(iv) acceleration from 60 knots to 126 knots was, apart from a hesitation at 90 knots, equivalent to Flight Manual standards. Since there is no evidence from the crew of a hesitation during this particular phase of the take-off run, it is considered that the recorded hesitation was most likely due to sudden variation in wind speed of the order of 5 knots;

(v) approximately 7 seconds before Vmax there was a reduction in acceleration which could have resulted from a reduction in thrust. The acceleration during the next 6 seconds was equivalent to that which would result from a total thrust of 11,800 lb which is slightly more than the Flight Manual thrust of one engine. There was no recorded evidence to suggest a complete engine failure;

(vi) examination of the recorded parameter of electrical supply frequency to the FDR (supplied by No 1 engine alternator) showed that at Vmax minus 7 seconds there was a sudden decrease in frequency followed by sharp fluctuations in frequency which persisted for about the next 7 seconds;

(vii) accelerate-stop tests carried out on a similar type of aircraft, and using the same FDR carried in G-AWYS, showed similar frequency variations when No 1 engine was throttled back and the take-off abandoned using reverse thrust. Frequency variations which were recorded during the accident have been interpreted as an indication of the state of No 1 engine, starting with a sudden reduction in HP rpm at Vmax minus 7 seconds, followed by fluctuations for about 7 seconds and culminating in increasing HP rpm as reverse thrust was applied;

(viii) coincident with the commencement of the reduction in acceleration the aircraft would have reached two pools, of about 4 metres diameter of standing water which were located 4,035 ft (1,230 metres) from the start of Runway 17;

(ix) application of wheel brakes is identified by a pronounced nose-down pitch at Vmax minus one second and it therefore seems likely that the decision and action to abort the take-off were taken at about Vmax minus 2 seconds at a speed of 132 knots;

(x) when the decision to abandon the take-off was taken the margin of runway distance available above the scheduled accelerate-stop distance had been more than eliminated;

(xi) deceleration from the peak speed of 135 knots was consistent with both engines attaining reverse thrust and all brakes functioning correctly;

(xii) in spite of achieving a deceleration better than assumed in the Flight Manual, the aircraft failed to stop in the distance available because the take-off was not abandoned immediately following a major loss of acceleration just below the decision speed (V_1) of 128 knots. It is estimated that approximately 160 ft (49 metres) more runway would have been required for the aircraft to stop. In the event, when the aircraft left the runway, 144 ft (44 metres) of shingle remained which resulted in the aircraft entering the lagoon.

1.11.10 Performance

The acceleration and braking performance achieved by G-AWYS and the certificated (Flight Manual) accelerate-stop profile are given in graphical form in Appendix 2.

1.12 Wreckage

1.12.1 Inspection at the scene of the accident showed that the aircraft overran the rough ground at the end of the runway and came to rest in a level attitude in approximately 1 metre depth of water in the lagoon with its tailplane trailing edge about 20 ft from the shoreline. The landing gear was down, the wing flaps were at the 18° take-off setting and there was evidence that wing spoilers were deployed as the aircraft entered the water. It came to rest in soft mud and consequently it took six days to complete its salvage.

1.12.2 On recovery it was found to have sustained considerable damage from salt water corrosion as well as some deformation of fuselage structural members.

Brake lines were intact, but during salvage operations, in an attempt to exhaust the brake pressure before towing the aircraft from the water and to ensure wheel rotation, one of the operator's technicians had operated the brake system a number of times; thus evidence of the position of the associated Hytrol braking system components and system status at the time of the accident was lost. However, subsequent inspection and detailed strip examination of the anti-skid braking system revealed no defect. Inspection of the tyres revealed no evidence of scalding or "reverted" rubber and the runway surface revealed no marks suggestive of locked wheel braking or steam aquaplaning. No fault was revealed in the aircraft's controls, instrumentation or ancillary equipment; fuel, oil and demineralised water samples were uncontaminated and up to specification.

1.12.3 Engine thrust pressure gauges (P7 gauges) were calibrated in a laboratory in the UK and were found to be within specified limits of accuracy. The fuel-consumed indicators were also tested and were functioning within specified limits; their readings at the time of the accident were: No 1 engine - 138 kg and No 2 engine-142 Kg. These recorded fuel quantities from start-up to shut-down were consistent with the engines having been run at idle thrust for about 8 3/4 minutes, at take-off thrust for 54 seconds and reverse thrust having been achieved by both engines for 16 seconds. Both engines had used 41 gallons of demineralised water during take-off which would indicate that they were both receiving water at approximately the correct rate for the whole of the time at take-off power.

1.12.4 Engines

On-site inspection revealed that both engines had sustained minor ingestion damage to their first stage LP compressor rotor blades but the LP turbines appeared undamaged. Both thrust reversers were in the fully forward thrust position and were found to be operable. LP and HP rotating systems were completely free to turn. LP fuel filters, LP oil filters and chip detectors were found to be uncontaminated.

1.12.5 Further Investigation

Both engines were returned for testing and strip examination by Rolls Royce in the UK in the presence of a British AIB inspector. On test, No 2 engine was run without water injection and was found to be 1.6 per cent below the minimum acceptable thrust. This deficiency was consistent with LP compressor damage and it was released for overhaul. With the exception of damage due to salt water corrosion no other damage or mechanical defect was subsequently revealed. No 1 engine was test run with and without water injection and was found to be about 2.9 per cent below the minimum acceptable thrust rating. Strip examination of No 1 engine revealed surge clipping in the HP compressor as well as slightly more severe damage to its first stage LP compressor blades than No 2 engine; in addition, a reset push rod in the acceleration control unit (ACU) was found to be seized. The following paragraphs summarise the content of a report by Rolls Royce to the Greek CAA.

1.12.6 Comparison of Damage to Both Engines

There was extensive corrosion damage of a comparable nature throughout both engines, such as would be expected after the ingestion of large quantities of sea water (the Commander said that the reverse thrust was not cancelled until after the aircraft came to rest in the lagoon). Ingestion damage to the LP compressors was nearly identical, consisting mainly of hard body ingestion damage to individual blades and stator vanes such as would be expected by ingestion, into a running engine, of gravel of the type present between the end of the Corfu runway and the sea. This reinforced the view that both engines were still turning at that time and the extent of the damage to the LP sections was so similar as to suggest that both engines were turning at comparable speeds. The other type of damage consisted of a snubber overlap produced by LP1 compressor rotor blades bending in both engines: this type of damage indicated that ingestion of large quantities of water occured at some time during the aborted take-off but it was not possible to deduce whether this particular damage was caused whilst the aircraft was on the runway or when it finally ran into the sea, or by a mixture of both. The only significant differences between the condition of the two engines was the evidence of moderate surge clipping in No 1 engine HP compressor and the seized P3 splitter reset push rod in the No 1 engine ACU. The possible effects and circumstances relating to these last two defects are now considered.

1.12.7 Compressor Surging, Surge Clipping and Flame-out

The possibility that surge clipping in the HP compressor had arisen as a result of a surge at some period in the engine's life since its last overhaul cannot be eliminated but no instance has been reported or recorded. It is, therefore, eminently possible that this damage resulted from ingestion of standing water on the runway during the accident take-off. Such a surge would have caused a sudden loss of thrust to below the water injection cut-off point but, provided flame extinction did not occur, recovery to full thrust would have been equally rapid and the effect of the transient loss of thrust would have been negligible. However, the quantity of water ingested may have been sufficient to result in flame extinction though with continuous ignitors switched "on" the engine should have relit and re-accelerated to full thrust without intervention by the crew; nevertheless, combustion would have to be re-established in all flame tubes before the engine could accelerate again to full thrust.

1.12.8 Effects of Seized P3 Splitter Reset Push Rod

This device enables the ACU fuel datum to be reset and provides for additional fuel to be delivered to the burners as the engine is accelerated to compensate for the additional fuel demand when the water injection system is in use. Examination of this component by the manufacturers leads them to believe that the push rod had seized as the result of ingress of deposits over a period of time rather than through ingress of salt water during the accident itself.

There is, therefore, a distinct possibility that the push rod had seized before the take-off began; previous examples of this minor defect have been revealed during engine overhaul. The effect of this seizure when using water injection is to make the ACU reset system inoperative, reducing the over-fuelling margin available from the fuel control system to that appropriate for acceleration to "dry" take-off thrust; the engine would be slow to accelerate when water is flowing. If slower than normal acceleration is reported in service, the deficiency can be offset and corrected to a large extent by adjusting the ACU towards the top limit of richness. This particular ACU was found to be close to the top limit when rig tested and this may have offset the effects of a seized push rod. Under normal conditions the only effect that a stuck reset push rod can have is during the engine acceleration phase; once full power has been achieved the ACU has completed its function and engine fuel supply is then contolled by the HP speed governor. Thereafter, a seized push rod can only have any effect if, for some reason, the engine loses speed.
Such could have been the case when large quantities of water were ingested from the runway during the take-off run and this, in turn, could have resulted in two possibilities:

(i) it could have effectively raised the engine demand for fuel to above that required for full power under normal conditions. If such a rise took the demand line above the fuel available then a run-down would have occurred;

(ii) it could have caused a compressor surge and possibly flame extinction.

Had (i) occurred then it has been calculated that the time to run down to 10,000 rpm would have been of the order of 10-15 seconds. If, on the other hand, (ii) has occurred, including flame extinction, the expected run-down time to 10,000 rpm would have been of the order of 1 second. At this rpm the water injection system would have been turned off automatically (about 10,850 rpm) and possibly by that time water ingestion would also have ceased.

Under these conditions and with continuous ignition selected "on" the engine should relight and re-accelerate to full power in some 3-8 seconds.

1.12.9 When No 1 engine was test run it showed no tendency to "hang up" (stop accelerating) or run down when water injection was switched on and accelerating to relatively high powers despite the seized ACU P3 splitter reset push rod.

1.13 Medical Reports

A post-mortem examination was conducted on the one passenger who died whilst being taken to hospital after having been assisted from the aircraft. It was revealed that death was due to a heart attack.

1.14 Fire

There was no fire.

1.15 Survival Aspects

The accident was survivable; all passengers were correctly strapped in and retardation forces were low. As soon as the aircraft had come to rest evacuation via the overwing exits and the port wing proceeded in an orderly manner. There was no panic and most passengers were transferred to the shore in small boats.
Some passengers waded ashore.

1.16 Tests and Research

These aspects have already been included in paras 1.10, 1.11 and 1.12.

2 ANALYSIS AND CONCLUSIONS

2.1 Analysis

2.1.1 The calculated accelerate-stop performance at take-off provided a margin of 1,094 ft (333metres) over and above what would have been required to stop the aircraft in the event of a complete failure of one engine at the decision speed V_1 of 128 knots. This speed had been appropriately amended from the dry runway V_1 of 135 knots following ATC's warning over R/T that there was standing water at about mid-distance along Runway 17. In amending the (V_1) to 128 knots the pilots rightly assumed a wet runway condition existed although the first portion of the runway visible to them before commencing the take-off appeared to be dry. Because of the undulating profile of the runway the position of the standing water relative to the centreline could not be seen, but its presence could have merged into the heat mirage which was observed by the crew over the distant section of the runway.

2.1.2 The evidence adduced from the flight recorder shows that there was a large reduction in acceleration at 126 knots EAS about 7 seconds before a maximum speed of 136 knots EAS was achieved. Coincident with this reduction, the fluctuating power supply to the flight recorder indicated a pattern which was compatible with reducing rpm; this pattern was confirmed during tests in another aircraft of the same type using the same flight recorder as fitted to G-AWYS. Calculations, using the recorder data also show that the aircraft would have reached the pools of standing water coincident with a sudden reduction in thrust; this reduction which lasted for 5 to 6 seconds, was almost equivalent to the loss of thrust from one engine. Tests also show that the reduction in engine rpm would not have been sufficient to have caused the electrical bus-bar supplying the flight recorder to switch over automatically to another alternator as would be the case if engine speed fell below its idling value of 7400 to 7800 HP rpm for a significant period of time. There are also indications that engine speed was increasing when braking performance became effective at an EAS of 136 knots (IAS 135).

2.1.3 When the take-off was abandoned there were 2,534 feet (772 metres) of runway remaining: if reverse thrust on both engines is assumed, also that there was a 5 knot tail wind for a proportion of the time, then the net effect would have required a further length of 160 feet runway to have enable the aircraft to stop before running off the end.

For this type of aircraft it is assumed that action to abort the take-off below or at V_1 will be effective in about 2 seconds but in this instance, brakes were not applied until 5 seconds after the reduction in acceleration which occurred at 126 knots EAS. Since the delay time allowed for certification and the equivalent distance travelled during the transition period were more than doubled, this extension of the transition period during the most critical part of the take-off made the overrun inevitable. It may therefore be appropriate to examine the events and circumstances leading up to the abandonment of the take-off. In this respect three main aspects are considered: firstly, the evidence adduced from inspection of the engines, secondly, the runway surface and profile and its contamination with standing water, and thirdly, the circumstances which could have affected the flight crew's reaction time to the engine malfunction.

2.1.4 Engine malfunction

Post-accident engine tests and strip examination revealed no mechanical reason within either engine for a serious loss of thrust during the take-off run. Test running of both engines prior to being stripped showed that they were capable of producing slightly below minimum acceptable thrust. The deficiencies were: 1.6% in the case of No 2 engine and 2.9% in the case of No 1. These small deficiencies were considered to be compatible with the damage sustained by the ingestion of water either whilst on the runway or after leaving the runway. The pattern of damage to both engines' LP compressors was similar but relatively more severe in the case of No 1: this engine also bore signs of surge-clipping in its HP compressor. A further aspect was revealed during the strip examination of No 1 engine in that its ACU water reset push-rod was seized; this was found as a defect of relatively minor importance which is not new in the history of this type of engine; however, its relevance to an engine malfunction is now considered together with other possible reasons for the loss of thrust.

For the loss of thrust three hypotheses are considered. The first one assumes that no water was ingested on the runway and that the malfunction of No 1 engine might have been due to the defective ACU reset mechanism. According to the manufacturer's systems engineers the effect of a stuck ACU reset push-rod would only be apparent in the acceleration phase and the engine would not accelerate to its maximum power speed. Once full power has been achieved (and it was in this instance and maintained for something like 54 seconds) the ACU would have fulfilled its function and the engine fuel supply would thereafter be controlled by the HP speed governor. Consequently, a large and rapid reduction in rpm would not have resulted from a defective ACU reset mechanism alone and this aspect is therefore discounted as a reason for the malfunction of No 1 engine.

The next two hypotheses assume a quantity of water was ingested during the take-off run. The first possibility is that because water injection was already in use it could have effectively raised the engine demand for fuel to above that required for full power under normal conditions. If such a rise took the demand line above the fuel available, then a run-down would have occurred, but it has been calculated that a run-down to 10,000 rpm due to the foregoing would have taken plade gradually (about 10 to 15 seconds). The second possibility is that ingestion of a quantity of water could have caused a compressor surge with possible flame extinction. Had this happened, then a run-down to 10,000 rpm would have taken place in about one second and, at these rpm, the water injection system would have been automatically turned off. It is also possible that during this time water ingestion from the runway would have ceased and under these conditions, with the ignitors set to "on" it would be expected that the engine would relight and then re-accelerate to full power again in some 3-8 seconds.

2.1.5 From the extent and rapidity of the run-down indicated by AC power fluctuations on the flight recorder, the calculated amount by which total thrust was reduced and the length of time at which total thrust appeared to remain depressed, it would thus seem that the last hypothesis is more consistent with the available facts and physical evidence. The likelihood that the defective ACU reset rod delayed engine acceleration at its maximum rate following a relight cannot be regarded as more than a remote possibility since there are indications that the engine speed was increasing as the braking devices became effective six seconds after the malfunction occurred.

2.1.6 <u>Runway Surface and Water Contamination</u>

Appendix E of the Flight Manual provides guidance when there are significant amounts of water or slush on the runway and it also contains a limitation that the aircraft must not be operated when the depth of water exceeds 12.5 mm. However, this limitation only applies when significantly large areas of the runway are contaminated and this was not applicable to isolated pools of standing water. In the case in question there were two pools of water 4 metres in diameter which were in the direct path of the aircraft during its take-off run. Although it was not possible to measure accurately the depth and quantity of water existing at the time, the transcript of the R/T messages from Corfu ATC contains a reference to both the existence of the pools and their approximate depth of 2 cm. During investigation some days later, when six hours after rainfall had ceased, it was found that the approximate depth of water in the centre of the same depressions was somewhat deeper than 2 cm. The centre of the left-hand pool which was about 4 metres in diameter, was 5 metres from the runway centreline and was more likely to have been traversed by the left main undercarriage and thereby water was thrown up to the rear-mounted engines as they are on BAC One-Eleven aircraft. It is understood from the manufacturer that in such a case an engine malfunction could occur. Airworthiness authorities are aware of the difficulties of including in the Flight Manual appropriate limitations concerning maximum depths of water in isolated pools which can be safely traversed during take-off; it is understood that the UK authorities are already studying this problem in conjunction with the manufacturers and the operators.

2.1.7 The possibility of aquaplaning having occured during the braking run is discounted because there was no evidence of steam or viscuous aquaplaning on the tyres or on the runway surface. Moreover the retardation rates achieved were totally inconsistent with this particular phenomenon.

2.1.8 Crew's reaction time

In discussing the reaction time of the crew after the engine malfunctioned the circumstances which are thought to be relevant are now considered. The evidence shows that the take-off run was commenced with full thrust having been selected and obtained before the brakes were released. Engine acceleration during this phase was normal; although there were fluctuations in the rate at which airspeed increased between 80 and 90 knots, these are consistent with the effect of a light variable wind and there is no reason to suppose that the take-off was anything other than normal until the aircraft passed through standing water. This is supported from an eye-witness, an airport policeman, who was standing in his observation post at the side of the runway. According to the crew, at about 90-100 knots, in other words before reaching the water, engine instruments were

checked and there were no abnormal indications. According to the pilot in charge (P1) the aircraft seemed to hesitate and recover when it passed through the standing water, but he was aware of having to progressively apply right rudder to counteract a deviation to the left and he was also conscious of a noise which could have been due to water impinging on the aircraft. At this particular stage the pilot in charge, Captain Mitchell, had no reason to believe that an engine had malfunctioned and probably attributed his control difficulties to the uneven retarding effect which the pools could have had. The co-pilot was aware that his colleague was having some difficulty in maintaining directional control, having also heard a noise which he associated with an engine and because he was aware that the aircraft's speed was probably approaching the critical value, he immediately scanned the airspeed indicator to check its reading in relation to V_1. He saw the ASI fluctuating at about 120 knots and increasing but at this stage V_1 had not been achieved. Whilst the co-pilot was checking the ASI the pilot in charge noticed that No 1 thrust indicator (P7) "was not where it should have been" and he abandoned the take-off.
It would appear that this chain of events spanned about five seconds' time following which the abandon decision was taken but the margin allowed for in an accelerate stop had thus been eroded. Although neither pilot could recall the exact indicated speed when the take-off was abandoned, they were quite certain in their minds that V_1 had not been called and the last impression remaining with the co-pilot was that airspeed was about 125 knots and increasing. Thereafter the drill was quickly and correctly carried out once the decision was taken. The flight recorder showed that take-off was abandoned at 132 knots which was 4 knots more than the wet runway V_1 of 128 knots and 3 knots lower than the dry runway V_1 of 135 knots. Airframe vibrations would have made precise interpretation of indicated airspeed difficult and fluctuations of the ASI needle could well have exceeded a spread from 1 to 5 knots in the circumstan-

ces. Based on the available evidence, calculations show that the runway distance remaining when brakes were applied, precluded a safe pull-up although the braking performance achieved was in fact slightly better than would be expected on a wet runway. The performance achieved was consistent with both engines operating in reverse thrust and would thus indicate that any temporary loss of engine power prior to the abort, had been restored by the time reverse thrust was selected and obtained on both engines; this deduction is also supported by the recorded quantity of fuel used by both engines.

It is generally accepted that an aborted take-off following an engine failure close to or at decision speed is a critical operation and even when done precisely there will be little or no margin above the available stopping distance; in this instance however, because the take-off weight was less than the maximum permitted in the circumstances, such a margin did exist before the take-off commenced but by the time wheel brakes were fully applied, following the malfunction, that margin had been more than eroded because of a few seconds delay in identifying the conditions and taking the appropriate action. It is thought that had there been a complete engine failure at 126 knots as opposed to a limited spin-down , as in this case, the malfunction would in all probability have been detected earlier and the aircraft could have been stopped within the confines of the runway.

2.2 Conclusions

2.2.1 Findings

1. The aircraft was correctly documented and it had been maintained in accordance with the relevant approved maintenance schedule.
2. Its loading and centre of gravity were within the limits prescribed in the Flight Manual and its take-off weight of 42,323 kg was correctly restricted to comply with net flight .

path climb-out requirements when taking off on Runway 17 at Kerkyra.

3. The pilots were correctly lisensed and adequately experienced.

4. Fuel, oil and demineralised water were uncontaminated and up to specified standards.

5. Take-off speeds were correctly extracted by the crew from their Operations Manual (V_1 135, V_r 136 and V_2 143) and the dry V_1 speed of 135 knots was correctly amended to the wet runway value of 128 knots.

6. After having been informed by Air Traffic Control that there was standing water about the mid-point on the runway the co-pilot marked the revised V_1 value in grease pencil on his ASI. Take-off was performed with water injection in use and with engine ignitors switched on in due time during the take-off run.

7. The flight recorder system recorded all the parameters within its design limits and the derived data provided an accurate profile of the accelerate-stop sequence.

8. At about 126 knots IAS (wet V_1 = 128 knots) the aircraft ran into one or both pools of standing water which were astride the centreline and each approximately 4 metres in diameter and about 2 cm deep.

9. Entry into the standing water resulted in directional control problems, a hesitation in the aircraft's rate of acceleration and a temporary loss of thrust probably from No 1 engine.

10. There was an interval of about 5 seconds between running through the water at about 126 knots IAS and the initiation of action to abandon the take-off. By this time the engine malfunction had ceased and it was probably accelerating again towards full thrust rpm.

11. The aircraft was also accelerating again and attained a maximum speed of 135 knots IAS about 2 seconds after the action to abandon take-off was initiated at about 132 knots IAS.

12. Deceleration from the peak speed of 135 knots IAS was consistent with both engines operating correctly in reverse thrust and wheel brakes functioning properly and being correctly used. There was no aquaplaning effect during the deceleration and spoilers were used correctly.

2.2.2 Cause

The accident sequence originated when the aircraft ran into a pool of standing water at a speed very close to V_1 causing a temporary reduction of engine thrust from water ingestion and a momentary loss of aircraft acceleration.

This situation, apparently, delayed the crew's identification of their problems and the initiation of action to abandon the take-off was taken about 3 seconds too late for the aircraft to be stopped within the runway distance remaining.

Observations

It is observed that there is no limitation procedure or provision in the operator's Flight Manual in reference to isolated pools with standing water along the runways. -

The Investigation Committee

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