



## A340 Crew Conducts Emergency Landing With Left-main Gear Partially Extended

*The report said that a wheel-brake torque rod detached and prevented the left-main gear from extending fully. The aircraft was substantially damaged during the emergency landing at London Heathrow Airport. Seven occupants received minor injuries during evacuation.*

FSF Editorial Staff

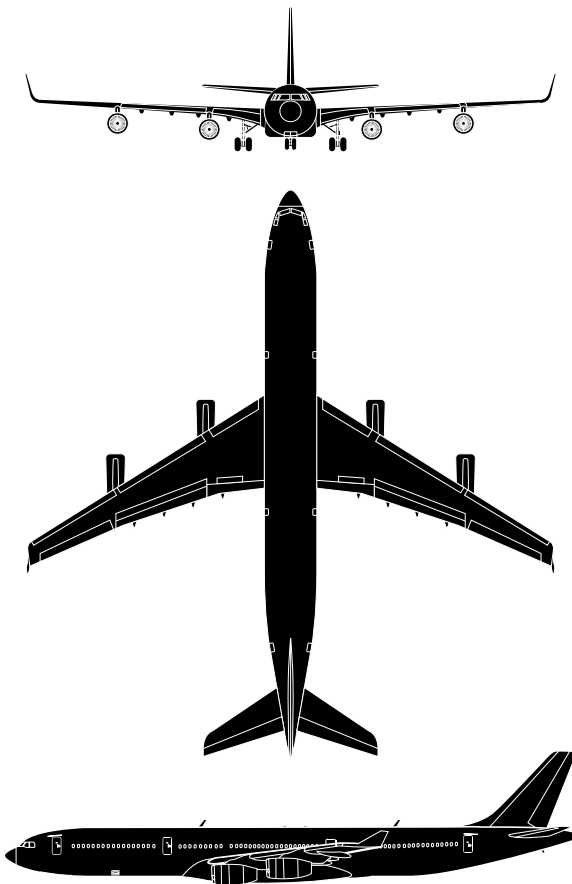
At 1620 local time Nov. 5, 1997, the flight crew of a Virgin Atlantic Airways Airbus A340-311 conducted an emergency landing on Runway 27L at London (England) Heathrow Airport with the aircraft's left-main landing gear partially extended. The aircraft was substantially damaged. Five passengers and two crewmembers received minor injuries during evacuation.

The U.K. Air Accidents Investigation Branch (AAIB) said, in its final report, that the accident investigation identified the following causal factors:

- "Full deployment of the left-main landing gear was prevented by the unrestrained end of the no. 6 brake torque rod having become trapped in the keel-beam structure within the gear bay, jamming the landing gear in a partially deployed position;
- "The torque pin which had connected [the] no. 6 brake torque rod to that wheel-brake assembly had disengaged during landing gear retraction after takeoff from Los Angeles [California, U.S.], allowing the unrestrained rod to pivot freely about the retained end;



- "The torque pin and its retaining assembly had been subject to higher axial [loads] and torsional loads than predicted during aircraft braking in service. These loads were the result of elastic deformation of the wheel axle, brake and torque rod, and [of] assembly without the correct axial clearance as a result of prior undetected displacement of the associated bushes. [Elastic deformation means that an object's dimensions change when stress is applied to the object and that the object's dimensions return to normal when stress is removed from the object.] The precise mode of failure of the retaining-assembly bolt, nut and cotter pin could not be ascertained in the absence of these parts; [and,]
- "This design of wheel-brake assembly had satisfactorily passed the related certification wheel-brake structural torque test to the requirements of TSO [technical standard order] C26c paragraph 4.2(b). However, the [TSO] contained no requirement to use a representative axle or other means to reproduce the axle deflections which occur during aircraft braking in service and did not require post-torque-test strip-assessment of brake



### Airbus A340-300

The Airbus A340 wide-body, medium-/long-range transport first flew in October 1991. The 200-series model and the 300-series model began service in 1993. The A340-200 accommodates 263 passengers or 303 passengers. The A340-300 has a longer fuselage and accommodates 375 passengers or 440 passengers.

The A340-300 has four CFM 56-52C turbofan engines, each producing a maximum of 138.8 kilonewtons (31,200 pounds thrust). Maximum fuel capacity is 138,600 liters (36,618 gallons).

The aircraft has three main-landing-gear assemblies. Each of the two wing assemblies has four wheels; the fuselage assembly has two wheels.

Maximum standard takeoff weight is 257,000 kilograms (566,582 pounds). Maximum long-range takeoff weight is 271,000 kilograms (597,447 pounds). Maximum standard landing weight is 186,000 kilograms (410,056 pounds). Maximum long-range landing weight is 190,000 kilograms (418,874 pounds).

Maximum operating speed is 0.86 Mach. Typical operating speed is 0.82 Mach. Typical standard range with fuel reserves is 12,223 kilometers (6,600 nautical miles). Typical range with fuel reserves (long-range model) is 13,242 kilometers (7,150 nautical miles).

Source: *Jane's All the World's Aircraft*

assemblies for resultant evidence of overstressing deformation which did not produce component failure.”

The aircraft was manufactured in 1993 and had accumulated 19,323 service hours and 2,104 flight cycles. The report said that no known abnormalities existed when the flight began.

The three flight crewmembers had received more than 48 hours rest before they reported for duty at 0330 (1930 Los Angeles time).

The commander, 40, had an airline transport pilot (ATP) license and 14,486 flight hours, including 2,920 flight hours in type.

The first officer, 32, had an ATP license and 4,655 flight hours, including 301 flight hours in type.

The cruise relief pilot, 28, had an ATP license and 4,650 flight hours, including 289 flight hours in type.

The flight crew had received simulator training on procedures related to abnormal extension of A340 landing gear.

“This simulator training had not gone as far as to practice any landings with any main-landing gear not deployed, as QRH [quick reference handbook] procedures current at the time were considered to be adequate to ensure that satisfactory deployment of a non-fully extended landing gear would occur as a result of the crew carrying out the QRH ‘L/G [landing gear] Gravity Extension’ procedure,” the report said.

The aircraft was pushed back from the gate at 0455. Thirteen cabin crewmembers and 98 passengers were aboard the aircraft.

“The [flight] crew later recalled that several tight turns had been made during the push-back and taxi phases, but this was not considered abnormal,” the report said.

The flight crew conducted the takeoff from Runway 24L at 0509.

The flight crew said that, during the departure from Los Angeles, landing gear retraction appeared to require more time than normal, but the instruments showed no abnormal indications. The report said that, because the aircraft was below 1,500 feet above ground level (AGL) when the gear were retracted, landing gear abnormal-condition indications were suppressed.

“By the time the aircraft had climbed through this height, the abnormal-condition indications had cleared, and so no subsequent warnings were generated,” the report said.

When the flight crew later conducted a routine check of aircraft-system status indications on the electronic centralized aircraft monitor (ECAM) during cruise flight, they observed a fault temperature indication (“XX”) for the no. 6 brake, which is on the left-main landing-gear inboard-rear wheel.

“This had been experienced with other brake units on previous occasions and was considered to be merely a fault associated with the indication system rather than any real landing gear anomaly,” the report said.

No other abnormal indications were observed until the aircraft was on final approach to Runway 27R at Heathrow. The aircraft was about 15 kilometers (eight nautical miles) from the runway when the crew extended the landing gear and observed a “L/G NOT DOWNLOCKED” indication on the ECAM and the “UNSAFE” annunciator light for the left-main landing gear.

The crew decided to go around. The first officer (pilot flying) began the go-around maneuver at 1504. Daylight visual meteorological conditions prevailed. The surface wind was from 190 degrees, variable between 150 degrees and 210 degrees, at 13 knots. Visibility was 25 kilometers (16 statute miles). There were scattered clouds at 1,900 feet and a broken ceiling at 7,000 feet.

Air traffic control (ATC) issued radar vectors to a holding fix. At this time, the aircraft had about 10,350 kilograms (22,818 pounds) of fuel — sufficient for about two hours of holding. After establishing the aircraft in a holding pattern at 8,000 feet, the crew conducted the QRH “L/G Gravity Extension” procedure. Nevertheless, the left-main gear abnormal indications remained.

The crew discussed the situation with company fleet-management specialists and engineering specialists.

“The crew attempted to rectify the landing gear problem by various means, including resetting the landing gear control-and-interface units (LGCUIs) and relevant circuit breakers (nosewheel steering and landing gear), both on the flight deck and in the underfloor electronic equipment bay,” the report said. “However, all attempts to lower and lock down the left-main landing gear were unsuccessful.”

The crew also discussed with company management the possibility of diverting to Kent International Airport in Manston. The commander was told that Manston already had been alerted and was prepared for an emergency landing there.

The flight crew decided to conduct a low pass over Heathrow, so that a company engineer in the control tower could make a visual inspection of the landing gear. The flight crew briefed the cabin crew about the landing gear abnormality and their plans for the low pass.

“The cabin crew carried out their duties efficiently and effectively,” the report said. “Passenger briefings were given regularly as updated information was passed from the flight deck.”

The commander assumed pilot flying duties before the low pass was conducted.

“The aircraft was given radar vectors for an instrument landing system (ILS) approach to Runway 27R, and the aircraft was then flown over the airport central area in order to fly past the tower with the underside of the aircraft exposed to view,” said the report.

The commander banked the aircraft right as it flew by the tower at 300 feet AGL. The company engineer told the crew that the left-main landing gear was “hanging in the bay” and asked the crew to conduct another low pass.

The commander decided not to conduct another low pass because the ECAM displayed a low-fuel-quantity alert, indicating that 5,400 kilograms (11,905 pounds) of fuel remained. The commander also decided not to divert to Manston.

“However, it was decided to attempt to maneuver the aircraft in order to apply some additional ‘G’ [gravity] loading to the aircraft in an attempt to assist the left-main landing gear to deploy fully,” the report said.

The crew conducted the maneuver northeast of the airport.

“The aircraft’s flight control system is, however, designed to limit the additional G loading and angle-of-attack that may be applied in flight by pilot input, in order to keep the aircraft within the allowable flight envelope,” the report said. “The maximum 1.46 G loading applied during the maneuvering and the maximum angle-of-attack of 10 degrees were both within normal operating limits.”

The maneuver did not correct the landing gear problem. The crew then discussed whether they should conduct a touch-and-go landing on the right-main landing gear, which might force the left-main gear to extend.

“However, because of the relatively low fuel state and the fact that the commander had never practiced this type of maneuver in a simulator, it was not attempted,” the report said.

The commander decided to land the aircraft at Heathrow. He declared a “Mayday” at 1608.

Airport personnel and ATC personnel already had discussed which of Heathrow’s three runways was best suited for the emergency landing. Runway 23 was aligned more closely with the prevailing wind than Runway 27L or Runway 27R, but Runway 23 could not be used immediately because aircraft were parked off the departure end. The airport personnel and

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ATC personnel decided that Runway 27L was better suited than Runway 27R for the emergency landing.

“Runway 27L was offered [to the flight crew] so that the potential contact by the left-engine pods on the runway after the landing would tend to cause the aircraft to veer away from the [airport] central area and terminal buildings,” the report said. “It was also suggested to the commander by the operator’s fleet manager that the aircraft be landed on the right side of the runway in order to provide the maximum available runway surface to the left of the aircraft for use in the event of the anticipated swing to the left as the aircraft decelerated.”

The crew agreed to conduct the emergency landing on Runway 27L, which was 3,658 meters (12,000 feet) long and 45 meters (150 feet) wide.

“Full emergency services deployment was rapidly achieved, and the area on each side of the landing runway was rapidly cleared of other aircraft, personnel and mobile equipment,” the report said.

The commander requested and received ATC clearance to conduct several 360-degree turns on base leg. The crew retracted the landing gear and again conducted the QRH “L/G Gravity Extension” procedure. The left-main gear remained partially extended.

The commander then briefed the first officer and reserve pilot on the QRH procedure for landing with a landing gear abnormality. The commander decided, however, to use a different engine-shutdown procedure than that recommended by the QRH.

“The manufacturer’s procedure called for the crew to shut down all [four] engines just prior to touchdown,” the report said. “However, the commander elected to modify this procedure and briefed the crew to shut down engine no. 1 and [engine no.] 4 on initial touchdown (by selecting the engine master switches to ‘OFF’), then to shut down engine no. 2 on his command, and then finally to shut down engine no. 3 as the aircraft settled down onto its left side during the landing roll. The [reserve pilot] was briefed to perform this task on the commander’s instruction.”

The report said that the commander’s decision to modify the QRH procedure was prudent and ensured that hydraulic power and electrical power were retained as long as possible. (The aircraft’s ram-air turbine cannot power the emergency generator at airspeeds below about 100 knots, and use of the auxiliary power unit is not recommended because of the risk of fire.)

“The decision to shut down the no. 1 [engine] and no. 4 engine on touchdown was to ensure that symmetric thrust was

maintained,” the report said. “Use of reverse thrust was not an available option. No. 2 engine was to be shut down as the aircraft’s left wing dropped, to reduce the risk of fire. Operation of the no. 3 engine was retained for as long as possible to provide power for the flight-control computers and related systems.”

(The report said that, after the accident, the manufacturer revised the QRH to include the commander’s engine-shutdown procedure.)

The crew retracted the center-main landing gear. The report said that the center-main gear, which is mounted on the fuselage, was not designed for the asymmetric loads generated during a landing with an outboard-main landing gear retracted or partially retracted; the center-main gear could collapse and damage the fuselage.

The right-main landing gear and the nose landing gear remained extended fully for the emergency landing. The report said that the left-main landing gear was “only slightly extended, with the outboard wheels and tires clearly visible.”

The commander hand-flew a stabilized approach with full flaps. Indicated airspeed (IAS) was 129 knots when the aircraft touched down near the touchdown zone and to the right of the Runway 27L centerline. The commander ordered the no. 1 engine and the no. 4 engine shut down.

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***As the aircraft decelerated, all four tires on the right-main landing gear burst, and the wheels fractured.***

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“During the commander’s attempt to keep the left wing raised for as long as possible, the aircraft banked to the right, pivoting about the right-main landing gear,” the report said. “As a result, the no. 4 engine

pod scraped the runway briefly, emitting a short burst of sparks, before the aircraft began to settle down on its left side.”

The no. 2 engine was shut down 10 seconds after touchdown, at 111 knots IAS; the no. 3 engine was shut down 16 seconds after touchdown, at 105 knots IAS. As the aircraft decelerated, all four tires on the right-main landing gear burst, and the wheels fractured. A brief fire occurred when the no. 1 engine nacelle and the no. 2 engine nacelle struck the runway.

During the landing, the aircraft drifted to the right, but the fuselage remained aligned with the runway centerline until the last 200 meters (656 feet), when the nose turned 20 degrees left.

Aircraft rescue and fire fighting personnel extinguished two small fires under the left wing and spread foam on the areas around the left-engine nacelles and the outboard main landing gear. The crew activated, as a precaution, the fire extinguishers for the no. 1 engine, the no. 2 engine and the auxiliary power unit. The commander then told the cabin crew to evacuate the passengers.

Most cabin doors and evacuation slides operated normally. The left-forward door, however, required an “extra push” by a cabin crewmember, and the right-rear door (door 4R) was opened by a cabin crewmember with assistance from several passengers. The left-forward (L1) evacuation slide and the right-mid-forward (R2) evacuation slide required manual inflation.

The report said that postaccident inspections of the L1 and R2 evacuation slides showed “no significant defects other than those arising from the deployment of the slides.” The investigation did not establish the cause for the failure of the slides to inflate automatically.

Postaccident tests of door 4R showed that the door opened unassisted in the required time (eight seconds). The door weighs 124 kilograms (273 pounds). Opening is assisted by pneumatic pressure from a gas-charged cylinder. The door does not open at a steady rate; a pause occurs after evacuation-slide deployment, while cylinder pressure is replenished. The report said that manual force applied to the door at this time can prevent cylinder pressure from building normally and slow the door from opening further.

“It was observed that by pushing on the door in this condition, it was possible to prevent the gas pressure from building up sufficiently to assist the door, giving the impression of a failure of the assist system,” the report said.

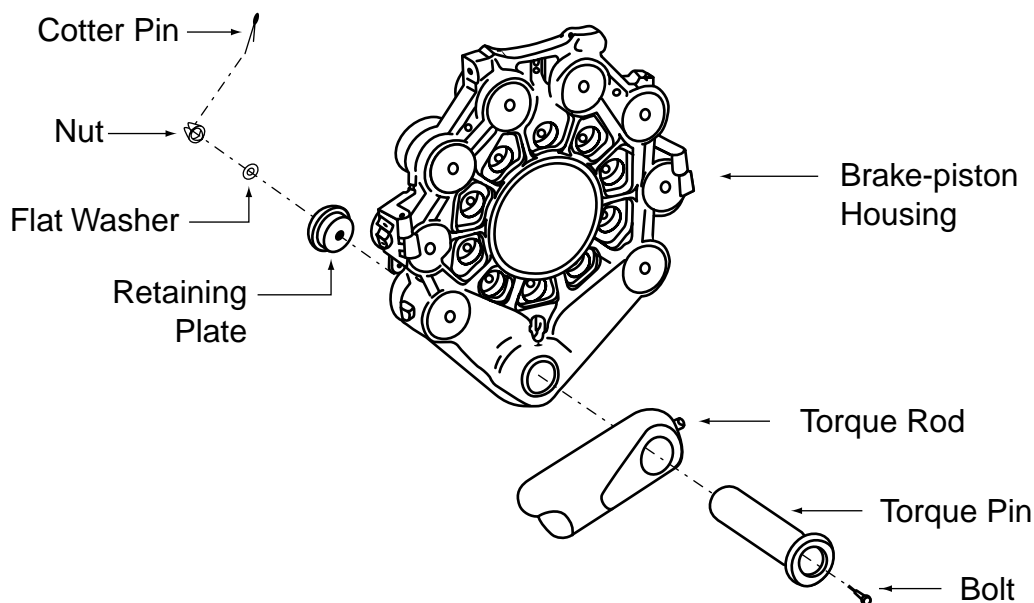
Nevertheless, the report said that the cabin crew manual recommends pushing the door at the first sign of any difficulty in opening and that Virgin Atlantic Airways’ A340 training-simulator door opened at a steady rate. Furthermore, the airline’s flight attendants acquired very little experience opening the doors during line operations; the doors normally were opened from the outside by ground crewmembers.

Postaccident examination of the aircraft showed that the no. 6 brake torque rod had disconnected from the brake-piston housing but had remained connected to the left-main landing gear strut. The disconnected end had moved from its normal alignment and had become trapped in the keel-beam structure inside the wheel bay.

“It was apparent that this landing gear could neither be lowered nor retracted once the rod had become so trapped,” the report said.

The torque rod is designed to resist torque forces generated during braking and, thus, to prevent the brake-piston housing and related components from rotating. The torque rod normally is attached to the piston housing by a torque pin (Figure 1). The torque pin is installed through a slot in the torque rod and a bore in the piston housing. Two bushes (metal linings) are installed between the torque pin and the piston-housing bore. The torque pin is retained by a bolt, retaining plate, flat washer, nut and cotter pin.

### Brake-piston Housing and Torque-rod Assembly; Virgin Atlantic Airways Airbus A340; London, England; Nov. 5, 1997



Source: U.K. Air Accidents Investigation Branch

Figure 1

The no. 6 brake torque pin from the accident aircraft was found off the end of Runway 24L at Los Angeles. The torque-pin retaining hardware was not found.

“There was no evidence of damage in the associated area of the [torque] rod, and it appeared that the torque pin and retainer had become separated in operation,” the report said.

The report said that metallurgical examinations of the torque pins from the accident aircraft and from other A300-series aircraft in the operator’s fleet provided no conclusive findings to explain why the no. 6 torque pin detached from the accident aircraft.

Examination of the bushes in the accident-aircraft’s piston housing showed that the bush closest to the torque rod had moved slightly from its normal position. One side of the bush had moved 0.58 millimeter (0.023 inch); the other side of the bush had moved 0.48 millimeter (0.019 inch).

The piston-housing bore, normally round, had an oval indentation of 0.23 millimeter (0.009 inch). The indentation extended about one-third of the way along the bore.

“Compression, not wear, was responsible for the dimensional change,” the report said. “Furthermore, the void thus created between the bush and the bore had become contaminated with debris . . . . This indicated that the damage was ‘old’ and had occurred long before the accident flight.”

The report said that the bore damage showed that “the braking loads transmitted through the torque rod in service had been greater than [the braking loads] anticipated during the design of the attachment assembly.”

During certification, A340 wheel brakes were shown to meet the minimum performance standards in U.S. Federal Aviation Administration (FAA) TSO C26c [*Aircraft Wheels and Wheel-Brake Assemblies*].

“The certification test was conducted, as is customary, with the brake assembly fitted to a solid axle which had external dimensions that were representative of that fitted to the aircraft,” the report said. “The certification structural torque test of the brake assembly was completed satisfactorily, without component failure.

“However, this solid-axle test could not correctly reproduce the associated deflections which the real axle would experience in service and did not, therefore, generate realistic axial loads in the torque pin and its retaining assembly.”

The report said that tests by the brake manufacturer showed that torque-pin tensile (i.e., stretching) loads were higher than predicted during braking because of elastic deformation of the wheel axle, brake housing and torque rod.

“The increased tensile loading on the torque pin retaining assembly could have overstressed or fatigued the associated

bolt, or possible additional torsional [i.e., twisting] loads due to brake-rod rotation during bogie [wheel-assembly] articulation could have sheared the cotter pin and permitted the unsecured nut to disengage from the bolt,” the report said.

Actions taken after the accident included a redesign of the torque pin and retaining hardware, and the introduction of a secondary restraint system to prevent the torque rod from coming in contact with the aircraft structure after detachment of a torque pin.

During the accident investigation, the AAIB asked Airbus Industrie to conduct a study of aircraft controllability during an emergency landing with an outboard main landing gear partially extended. The study showed that an adverse crosswind — i.e., a crosswind striking the aircraft on the side where the main landing gear is not down and locked — can have a substantial effect on directional control.

“The study concluded that the aircraft is controllable initially due to aerodynamic forces,” the report said. “After the [engine] nacelles contact the runway, the significant forces are mechanical. In zero-crosswind conditions, directional control is, in most cases maintained.

“For crosswind conditions, the speed at which a deviation of 15 meters [49 feet] from the runway centerline occurred was taken [for study purposes] as the limit of controllability. For a 25-knot crosswind which was from the side with the main landing gear normally extended, the aircraft would come to rest before reaching 15 meters deviation in every case.

“If the 25-knot crosswind were from the side with the nacelles on the runway, then the 15-meter deviation would be attained while the aircraft was still moving at significant speed, the exact value depending on the weight, coefficient of friction of each nacelle and load distribution. In a worst case, this speed could be in excess of 50 knots.”

The report said that the results of the Airbus study are “of considerable importance” in selecting a runway for an emergency landing with an abnormal gear configuration.

“A favoring crosswind will allow directional control to be maintained, while an adverse crosswind will present potentially serious lateral deviation problems,” the report said. “Zero-crosswind conditions will still lead to directional [control] problems if the friction on the nacelles is high and the landing weight is close to the maximum permitted.

“In this case, the commander succeeded in keeping the aircraft on the runway, despite an adverse crosswind component of some 13 knots.”

The report said that flight data recorder (FDR) and cockpit voice recorder (CVR) electrical power ceased when the engines were shut down during the emergency landing.

“There has been discussion within regulatory bodies as to whether FDRs and CVRs should be equipped with independent power supplies to enable recording to continue if electrical power is lost,” the report said. “For the FDR, however, many of the data sources are from the aircraft data bus itself or from electrical sensors; therefore, if electrical power is lost, so are the inputs to the FDR.

“It would, however, be feasible to fit an independent power source to a solid-state CVR. The new-technology recorders have a much lower power requirement than the older tape-based systems. An independent power source could provide sufficient electrical power to the CVR and cockpit area microphone for a period of 10 minutes when normal aircraft power was not available.”

European Joint Aviation Requirements – Operations (JAR OPS 1) requires aircraft with maximum takeoff weights over 5,700 kilograms (12,500 pounds) certified after April 1, 1998, to be equipped with CVRs that can record for at least two hours. The accident aircraft was required to be equipped with, and was equipped with, a CVR that can record for 30 minutes.

“A normal descent, approach and landing would require at least 30 minutes recording duration,” the report said. “Abnormal situations which require the aircraft to go around, enter a holding pattern or to substantially extend its normal flight time will invariably result in the loss of the recording of the initiating event.

“In the case of this accident, a two-hour CVR recording would have provided the investigation team with a complete record of crew communications during the events leading up to the emergency landing.”

Nevertheless, the available CVR recording showed that the three pilots “worked well together” and adhered to crew resource management principles.

“Each pilot was able to make a valuable contribution to the team and displayed a high degree of initiative and motivation,” the report said. “The presence of the third pilot on the flight deck ... provided a useful alleviation of workload for the two ‘operating’ pilots.”

Based on the accident-investigation findings, AAIB made the following recommendations:

- “Airbus Industrie should consider providing a revision to the QRH ‘Landing with Abnormal Landing Gear’ procedure to include reference to the considerations of crosswind and choice of landing runway;

- “The CAA [U.K. Civil Aviation Authority], FAA and JAA [European Joint Aviation Authorities] should review the requirements for public transport aircraft cabin door simulators used for crew training to require that they accurately simulate any nonlinear characteristics of the associated aircraft doors and to require that full instruction is given to cabin crews regarding the door-operating characteristics to be expected when operating the doors in an emergency;
- “The CAA, FAA and JAA in consultation should amend the aircraft wheel-brake certification structural torque test requirements in TSO C26c, paragraph 4.2(b), to require the use of representative wheel axles or other means to reproduce the expected axle deflections and associated brake-assembly loads arising in service, and a postcertification torque test strip examination of such assemblies to check for yielding deformation to verify loading behavior;
- “The CAA, FAA and JAA in consultation should amend the requirements for the integration of the failure mode analysis (FMA) of new-design wheel-brake assemblies by the aircraft manufacturer to take into account the potential secondary effects of torque-rod disconnection upon landing gear operation, in order to assess the related risk of gear jamming due to torque-rod fouling on adjacent parts. Where a potential for such torque-rod fouling is identified, appropriate design action should be required to eliminate this possibility so that landing gear operation is protected;
- “In order that the maximum air safety benefit may be obtained from [CVRs] during incident and accident situations where associated aircraft electrical power supplies may be prematurely lost, the FAA and the CAA should commission a study to investigate the feasibility of fitting limited-duration independent power supplies to solid-state CVRs; [and,]
- “The JAA should extend the existing JAR-OPS 1.700 requirement, for aircraft above 5,700 kilograms and certificated after April 1998 to have a two-hour-duration CVR-recording capability, to include a requirement to retrofit the same weight category of aircraft certificated on, or before, April 1998 with similar recording-duration CVRs.”♦

[This article, except where specifically noted, is based on the U.K. Air Accidents Investigation Branch Aircraft Accident Report 4/2000: *Report on the accident to Airbus A340-311, G-VSKY, at London Heathrow Airport on 5 November 1997*. The 148-page report contains photographs, diagrams and appendices.]

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