Dornier 328-100, G-BWIR

AAIB Bulletin No: 3/2004	Ref: EW/C2002/03/06	Category: 1.1
Aircraft Type and Registration:	Dornier 328-100, G-BWIR	
No & Type of Engines:	2 Pratt & Whitney PW-119B turboprop engines	
Year of Manufacture:	1995	
Date & Time (UTC):	6 March 2002 at 2046 hrs	
Location:	Runway 24, Edinburgh Airport, Scotland	
Type of Flight:	Public Transport	
Persons on Board:	Crew - 4	Passengers - 16
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to forward door attachment and restraint mechanism. Consequent dent in fuselage skin	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	50 years	
Commander's Flying Experience:	3,100 hours (of which 1,000 hours were on type)	
	Last 90 days - 80 hours	
	Last 28 days - 24 hours	
Information Source:	AAIB Field Investigation	

Synopsis

Prior to the planned flight the forward passenger door was closed and locked. The flight crew confirmed the correct positioning of the door during their pre-start checks. During the take-off run, at about 100 kt, the door opened and the flight crew aborted the take off. The door and locking mechanism were undamaged, however, the hinge arms of the integral air stairs were so severely damaged that it is unlikely that the door and the integral stairs would have remained attached had the aircraft continued to accelerate and become airborne. It is concluded that the most probable way in which the door opened was that the door-handle was inadvertently operated during the take-off run. The ergonomic features of the cabin crew station would have contributed to the handle being inadvertently grasped during this phase of flight. A recommendation has been made to the European Aviation Safety Agency regarding the design characteristics of the door.

History of the flight

This sequence of events was compiled from data from the Flight Data Recorder (FDR), Cockpit Voice Recorder (CVR) and from interviews with the crew members involved.

The aircraft was to conduct a scheduled flight from Edinburgh to London (City) Airport as the final sector of a four sector day. Once the passengers were embarked the commander gave permission for the senior cabin attendant to close the forward passenger door. This was accomplished by a combination of a cabin attendant pulling from the inside and a ground crew member pushing from the outside, a common procedure with this operation. The closing process was completed by a spring assisted, upward movement of the internal door handle into the locked position. Correct positioning of the door was confirmed by the flight crew during their pre-start checks by noting a green indication on the Doors system page of the Multi Function Display (MFD) and by the extinguishing of the red 'Doors' caption on the Central Warning Panel (CWP). The CWP is positioned centrally, just below the glare shield.

Once instructed by the commander, the senior cabin attendant took her seat, which is adjacent to the forward passenger door and faces rearwards. The attendant was trained and experienced on the type and had also worked in a similar capacity with another operator. She strapped herself in using the full lap and inertia reel shoulder harness.

The first officer (FO) commenced the take-off roll, on a wet runway, with approximately 10 kt of crosswind from the right, using a decision speed of 107 kt. All appeared normal until 100 kt when the first officer glanced down and saw the red 'Doors' warning caption illuminate. He immediately called "STOP STOP STOP" and rejected the takeoff, bringing the aircraft to a complete halt on the runway. During the deceleration, the audio warning sounded. Once the aircraft was stationary the commander vacated his seat to check the situation in the passenger cabin whilst the first officer contacted ATC to inform them of the emergency. The commander returned to his seat, shut down the left hand engine and taxied to an allocated stand where the passengers were deplaned from a rear door.

The senior cabin attendant commented that her recollection of events was extremely hazy. She recalled that, at some point during the take-off run, she saw the door opening, felt a rush of air and heard a passenger shout that the door was open. She believed that she made a grab for the integral airstairs with her left hand but let go almost immediately as they fell away with the door. Using her right hand to shield her face from the opening, she remembers turning round and giving a 'thumbs up' signal to the commander as he opened the door to check on the situation in the cabin. Shortly afterwards the commander entered the cabin and re-seated the attendant away from the open door where she remained until they arrived on stand. She then organised passenger disembarkation from the rear door of the aircraft.

Once the passengers had disembarked, the operator asked the commander if the crew would operate another aircraft back to London. He agreed this with the crew and they flew the same passengers to London Stansted Airport later the same evening on another aircraft.

Weather

The synoptic situation that evening indicated a strong, unstable, north-westerly air flow over the Edinburgh area. The surface wind had been gusty and the commander recalled significant turbulence during the take-off roll. There had been heavy shower activity throughout the afternoon and the runway was wet in all segments.

Aircraft examination

After the accident the aircraft was ferried to its maintenance base at Cambridge where it was examined by the AAIB; photographs taken immediately after the event were also examined. The damaged door is depicted in Figure 1.

Figure 1
Damaged door on G-BWIR after accident

The door and the latching and locking mechanism were undamaged, and were clearly still capable of correct operation. The channel-section hinge arms of the airstairs, however, were both fractured almost fully through their cross sections, leaving only single flanges securing the two parts of each arm together. Figure 2 shows the damage to the aft hinge arm. The banister mechanism was also heavily damaged, Figure 3.

Figure 2
Damaged aft hinge arm

Figure 3
Damaged aft banister restraint system

It was concluded that this damage was consistent with the effect of the door becoming unlatched and being forced open by very high forces. It is presumed that these were a combination of aerodynamic and pressurisation loads. Rapid and forceful movement in the opening direction had caused high reaction loads to develop in the damping struts leading to buckling and failure of their attachments. This appears to have destroyed the geometry of the banister mechanism and consequently permitted over-travel of the airstairs. The hinge arms supporting the airstairs thus appear to have acted as limit stops, being then subjected to non-design loads leading to severe damage.

Possible consequences of door attachment damage

The hinge arms of the airstairs were so severely damaged that it is unlikely that the door and stairs would have remained attached had the aircraft continued to accelerate and become airborne. The likely trajectory of the separated door and stairs under these circumstances is difficult to estimate. The sequence by which the hinge arms and the elements of the damaged banister / airstair restraint mechanism failed would influence the angle of the door relative to the airflow and hence the path of the separated components. The door aperture is positioned just forward of and adjacent to the No 1 propeller. Clearly this unit would have been at considerable risk of being struck, with very serious consequences. Experience has shown that, on other types, after separation, doors may also strike and become lodged against tail-planes, leading to loss of control and in one case complete break-up of an aircraft.

Description of the door

Door and airstairs

The forward cabin entrance door on this aircraft type opens and closes in conjunction with the associated airstair unit. The door is supported and located in the door aperture when fully closed, but at all other times it is supported only by the airstairs. The airstair unit is mounted on a pair of hinge arms, as shown at Figure 4 (a), pivoted approximately in the plane of the cabin floor and moves in an arc, outwards and downwards, as the door opens. The door itself is articulated from the airstairs and lies beneath the latter once the airstairs are fully deployed with the aircraft ready for boarding as shown in Figure 4.

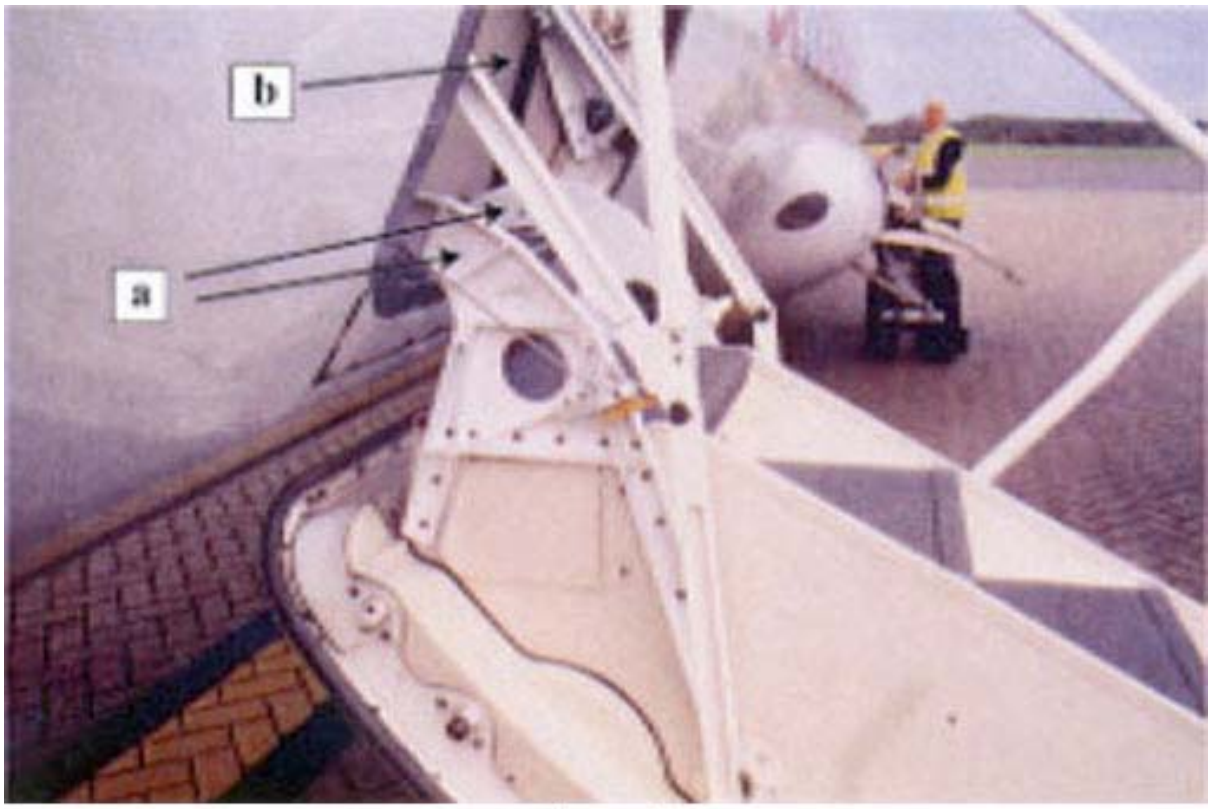

Figure 4
Undamaged example of door fully open,
showing hinge arms (a)
attaching air-stairs to cabin floor.
Damper strut (b) visible within vestibule.

Once the door is closed, the stairs are positioned approximately upright, against the inner face of the door, in the cabin vestibule, as shown in Figure 5.

Figure 5
Vestibule with door closed and locked.
Note aft facing cabin crew seat, retracted
air-stairs and inner door handle (a)

The door is then retained in place within the pressure hull by four rollers, and twelve adjustable stops. Each of the rollers has axes parallel with that of the fuselage. These rollers are mounted on projections from the forward and aft door edge members, two located close to the top and two close to the bottom of the door. (The two rollers and six stops on the forward edge member of the door are visible in Figure 6. A similar set of stops and rollers are mounted on the rear edge member.)

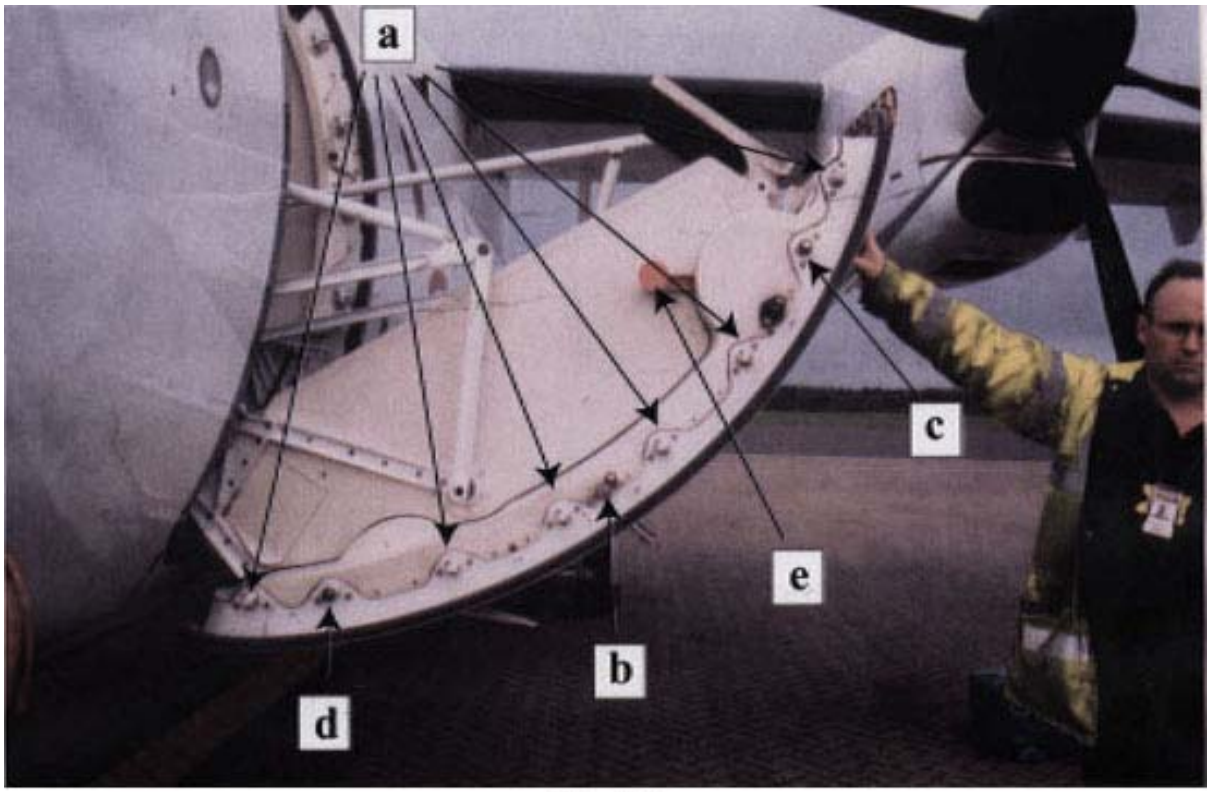

Figure 6
Undamaged example of door partly open.
Six adjustable stops (a), crank (b),
upper roller (c), lower roller (d)
and handle (e) in open position

Each roller engages in a corresponding fixed track mounted at a matching position on the adjacent edge member of the door aperture. The lower tracks are straight and orientated approximately vertically. The upper tracks each incorporate an acute angle turn, allowing the rollers to enter horizontally before changing direction to descend approximately parallel to the local skin contour, as shown at Figure 7(a).

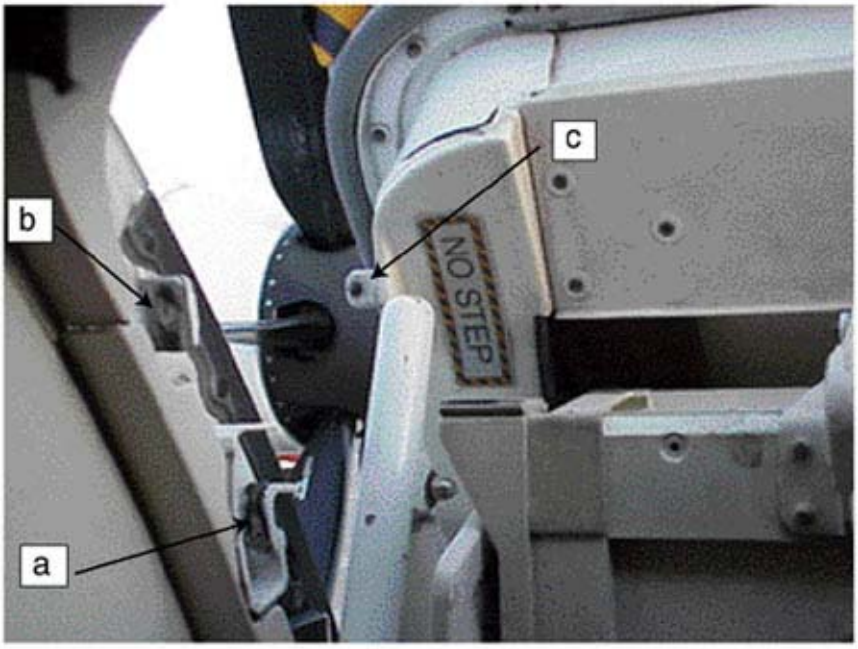

Figure 7
Aft edge of opening door, as upper roller (not visible) moves clear of fixed upper aft track (a) on door aperture. Top fixed abutment (b) visible on aperture above fixed track. Adjustable stop (c) visible on door edge member

When fully closed, the six adjustable stops on each of the door edge members fit behind, and react against, six corresponding fixed abutments mounted on each of the edge members of the door aperture. An abutment (b) and a stop (c) are visible in Figure 7. Pressurisation forces on the door cause the stops to bear firmly against the fixed abutments and force the upper pair of rollers firmly into recesses at the lower end of available travel in the upper pair of roller tracks.

Inner and outer door handles operate a crank mechanism which controls vertical movement of the door relative to the airstairs and the aperture. The mechanism also operates a shoot bolt mounted in the door, orientated fore and aft, which enters a recess in the door aperture as the door reaches the fully closed position.

The geometry of the roller tracks and the operating mechanism ensure that the door is subjected to forces in the closing direction should differential pressure be present with the door not in the fully locked condition.

Door closure

The door reaches the closed position by initially pivoting upwards and inwards from the fully open position in unison with the airstairs. As the door approaches the closed position the upper rollers enter the horizontal sections of the upper fixed tracks. Once those rollers have travelled fully through the available horizontal travel in their tracks, the airstairs cease to move. The upper rollers, however, then change direction as a result of the acute angle of the upper tracks.

Downward motion of the door then takes place relative to the airstairs, allowing the stops on the door to slide behind (ie inboard of), the fixed abutments in the door aperture in the fuselage. During this process, the lower rollers descend within the lower fixed tracks whilst the upper rollers descend within the latter sections of the upper tracks.

The locus of motion of the door during this part of the closure process is controlled both by the path of the door rollers constrained within the fixed top and bottom tracks and by the door operating mechanism. The latter incorporates the crank imparting the vertical movement of the door relative to the airstairs.

Final closure (and initial opening) motion of the door is controlled from within by a handle, mounted on the inside face of the door, with its pivot axis orientated parallel with that of the fuselage, ie fore and aft. The hand grip is similarly orientated, as shown in Figures 5 and 8. The door handle motion to complete door closure is an arc, moving initially upwards and finally outwards.

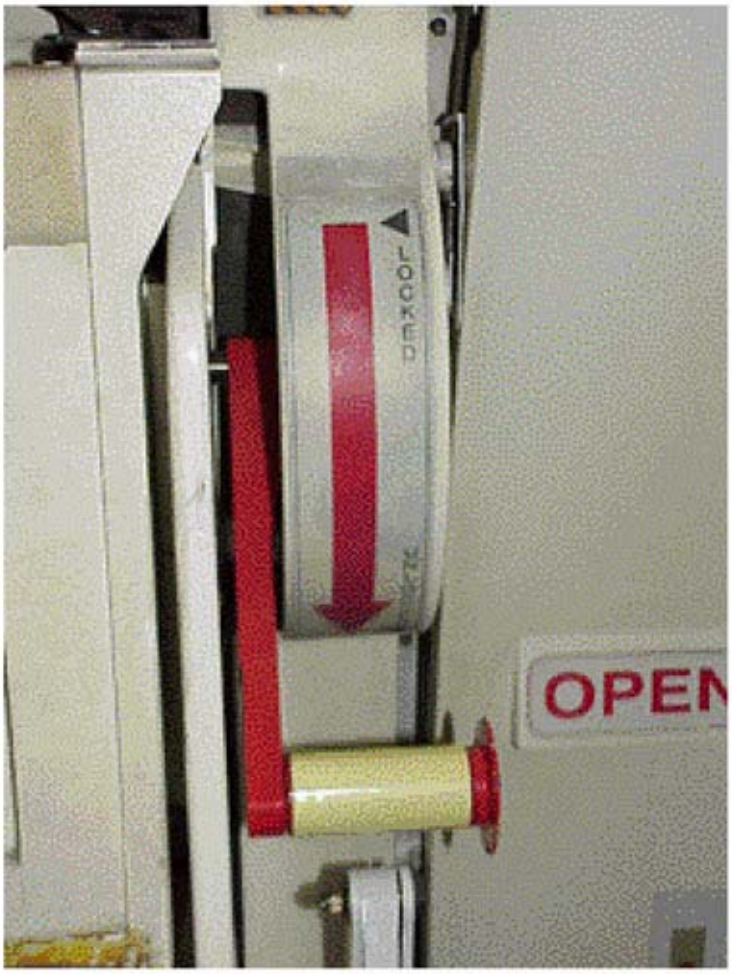

Figure 8
Inner door handle in open position

The shoot bolt enters the recess in the aft edge member of the door aperture as the door handle moves to the fully closed position. Proximity switches, one mounted in the shoot bolt recess in the door aperture and one mounted adjacent to a bell crank within the door operating mechanism, each signal the door warning computer and the pressurisation system.

A striker plate is mounted on the forward edge member of the door aperture. This operates in conjunction with a crank projecting from the forward edge member of the door, depicted at Figure 6 (b). The crank is operated by the door mechanism and prevents the latter from completing its movement should the door not be correctly aligned for closure. Correct alignment requires the door to be positioned with the rollers located in their tracks and the adjustable stops positioned to pass downwards behind the fixed abutments. Thus, the final phase of door movement to the fully closed

condition is prevented unless closure can be completed correctly without contact damage between any components of the door or the aircraft.

Door opening

Door opening from within requires the door handle to be pulled, in a curved trajectory, inwards and downwards, as depicted in Figure 8. This operates the mechanism which first extracts the shoot bolt, then gradually lifts the door relative to the airstairs, as a result of the rotating handle progressively changing the angle of the crank mounted between the airstairs and the door. (The crank is not visible when the door and airstair unit are assembled together.)

Initial upward motion of the door causes the upper rollers on the forward and aft edges of the door to be moved slightly inboard by the profile of the upper roller tracks. This movement acts against any pressurisation forces that may be present and initially causes the 12 door stops to move horizontally, just out of contact with the corresponding fixed abutments. This, in turn, allows the door to translate upwards, permitting the stops to pass the abutments, without friction.

The high mechanical advantage of the inner operating handle and mechanism is such that door movement can be initiated even if a small amount of pressure differential remains in the cabin. Once the upper rollers reach the limit of upward travel available in their tracks, those track directions change, allowing outward movement, away from the fuselage, of the upper part of the door and hence of the airstairs, as depicted in Figure 7. At this point the lower pair of rollers is just leaving the upper end of their tracks and therefore provides no restraint to outward movement of the door.

Control of door travel

Under normal opening conditions, with the aircraft stationary, further natural movement of the door is either slow or does not occur, since restraint is provided by springs, damping struts and friction, acting in conjunction with the mass of the door and the airstairs. The resulting forces produce a closely balanced condition in which light hand pressure enables the door to be slowly moved further towards either the open or the closed position.

A system of banister rails enables the fully deployed airstairs, and hence the door, to be pulled towards the closed position from within the aircraft. It operates in conjunction with the springs within the door mechanism. Damping struts form part of the banister geometry, as shown in Figure 4 (b). This combination controls the rate of movement in both the opening and closing directions. The banister geometry forms the limit stop of deployment of the stairs and door in the open direction.

Door warning and cabin pressurisation systems

When the aircraft is electrically powered and a door is opened, an audio warning sounds, red 'attention getters' flash, a red DOOR caption appears on the CWP and a red door symbol appears on the cabin plan of the MFD. When the attention-getters are cancelled manually, the audio warning stops, the DOOR caption remains on the CWP and the diagram on the MFD retains the red door unsafe indication.

When the door is correctly closed, the two proximity switches signal the door warning computer. Provided all other doors are closed, this causes the CWP caption to extinguish, and the MFD cabin diagram will indicate green 'closed' symbols at all door locations. Once the engines have been started, a short delay occurs before the air conditioning packs are activated but the cabin outflow valve is held in the open position until the takeoff commences. It is signalled to close by movement of the power levers beyond a pre-determined angle. However, the outflow valve will not close unless the two door proximity switches are in the correct position.

Once the airspeed rises above 70 kt the attention-getters and audio system are inhibited. They become active again once airspeed rises above 140 kt. Thus, if a door becomes unsafe above 70 kt during the take-off run the CWP caption will illuminate but no other indication will be given. If, however, the takeoff is then abandoned, the audio system and the attention-getters will come on once the airspeed falls below 70 kt.

Cabin pressurisation increases as the aircraft accelerates, but the rate of increase is relatively slow, since Dornier 328 aircraft accelerate more rapidly than typical turbofan types. Lightly laden examples, such as G-BWIR on this occasion, have a particularly rapid acceleration.

Cabin crew station

The vestibule, shown in Figure 5, incorporates the aft-facing, forward cabin attendant's seat; the crew member's view of the adjacent side of the fuselage being slightly obscured by the close proximity of the retracted airstairs. The cabin attendant has a full harness incorporating an inertia reel system for the shoulder straps: during the acceleration experienced on takeoff this system would not have provided significant upper body restraint.

There are two hand-holds within the reach of a seated cabin attendant which could be used to brace that person against the effects of aircraft acceleration on the upper body. The handrail of the air stair, positioned just above thigh level and to the right of the cabin attendant, could be easily grasped but would provide little upper body restraint. However, the door handle is positioned such that when the door is closed the handle is to the right of the cabin attendant's seat, just above head height, and can be readily grasped by an occupant correctly strapped into the seat. This would provide a more natural bracing mechanism for upper body restraint. Given the rear facing orientation of the seat, the high acceleration rate noted on the flight data recorder (FDR) and the lack of restraint from the inertia controlled shoulder straps, it is entirely possible that, on this occasion, the cabin attendant grabbed the handle.

Other aircraft types

A study of other passenger aircraft types with cabin crew seats adjacent to exit doors was made. This revealed that many have door handles with pivots orientated completely differently from that in the Dornier 328 type, and that those with generally similarly orientated handles have them positioned well out of the easy reach of seated occupants of average size.

The aircraft type having the closest similarity in dimensions and layout of the vestibule area had the inner door handle mounted on the adjacent fixed bulkhead such that it was behind the head of a seated cabin attendant.

No other aircraft type was identified which had a similarly orientated door handle fitted in a comparable position relative to the seat occupant.

Aircraft certification

Design features and certification requirements for doors in pressurised aircraft have evolved and changed over many decades. The earliest pressurised airliners were designed to render impossible the opening of the doors whilst any pressure differential existed. A series of accidents, however, illustrated the difficulty of rapid evacuation of large numbers of passengers via doors built to designs having geometry dictated purely by this requirement.

Later certification requirements led to a generation of door designs having improved evacuation provision at the expense of reduced integrity when subjected to pressurisation loads and an increased tendency to become unsafe during un-pressurised or lightly pressurised flight.

Present day certification of doors recognises that the conflict between the need for total integrity when closed and ease of evacuation in emergency cannot be fully resolved. It is accepted that there may be a period during a typical flight when a door is capable of being opened with the aircraft in motion and /or with a slight pressure differential present. Integrity and the compulsion of warning arrangements, together with the exclusion of all but trained personnel from the vicinity of the doors during takeoff and landing, are factors relied upon to achieve safety during these flight phases.

With regard to the certification process of the 328 aircraft, it is understood that the manufacturer was required to demonstrate that the door and its attachment had sufficient strength to enable the aircraft to fly at a speed of up to 180 kt with the door open, without it becoming detached and striking another

part of the airframe or powerplant. Other tests carried out in support of the certification process required confirmation that if pressurisation began without the door correctly closed but with the rollers engaged in the tracks, the door would move towards the fully closed position. However, it has been deduced that opening of the door at a speed close to rotation, with some cabin pressure differential present, would produce high opening loads on the door restraint system. These loads would differ from those resulting from simply flying with the door in the open position, or commencing a takeoff with the door in an unsafe condition.

Analysis

No evidence of any defect or damage was found other than that observed in the banister mechanism which controls and limits the travel of the door and airstairs in the opening direction, and in the hinge arms supporting and locating the airstairs relative to the fuselage. The second appears to be a consequence of over-travel permitted by the first.

The cockpit voice recorder indicates that the audio warning came on during the deceleration, at a speed just below 70 kt, but was not present at any other time. Given the damage detailed above, and that no defects were found in either the door operating or warning systems, it has not been possible to visualise a set of circumstances in which the aircraft could have initiated this takeoff with the door in an unsafe condition.

The audio warning only came on as the aircraft decelerated below the inhibit speed of 70 kt, and this is consistent with the effect to be expected if the door became unsafe between the time that the aircraft exceeded 70 kt during the acceleration and the time at which it decelerated below that speed, after the takeoff was rejected. Furthermore, the fact that the FO saw the DOOR caption illuminate implies that the mechanism actually moved during that time.

The only way in which this situation could occur would be if the handle had been physically moved inwards and downwards. Although the resulting door movement is initially inwards and would be resisted by pressurisation forces, the rate at which pressure builds during the take-off run, after the outflow valve closes, is low. The precise time history of power lever angles cannot be derived from the FDR information since engine spool-up occurs progressively as the aircraft accelerates. However, it has been judged that the mechanical advantage of the door handle and its associated mechanism is such that the door could have been moved from the locked position against pressurisation forces as high as those which are likely to have been developed by the time a speed of approximately 100 kt was reached.

It is considered highly improbable that the software controlling the warning arrangements would fail to alert the crew to the fact that the door was not correctly latched and locked before the takeoff was started, yet apparently perform correctly from the time the aircraft reached approximately 100 kt until the time it came to a halt. It is also highly unlikely that an unlatched door would have suddenly come open at sufficiently high a speed and with sufficient force to severely damage its attachments had it been unlatched from the start of the take-off run. The geometry of the rollers and tracks is designed to ensure that any pressurisation loads result in the door being forced towards the closed direction.

It is thus concluded that the most probable way in which the recorded data and physical evidence could have been produced was if the door-handle had been grasped during the take-off run and significant downward force exerted. The ergonomic features of the cabin crew station would have contributed to the handle being inadvertently grasped during the take-off run. Under such circumstances, the natural direction of applied loading would have been similar to the normal door opening movement of the handle.

Certification requirements assume that the occupant of the cabin crew seat is appropriately trained. In this instance the senior cabin attendant fully satisfied that requirement. This further emphasises the significance of the ergonomics of the seat and handle orientations in creating this accident.

Although part of the certification compliance was achieved by demonstrating the ability of the aircraft to fly at low speed with the door in the open position, it has been deduced that opening of the door at a

speed close to rotation, with some cabin pressure differential present, would produce high opening loads on the door restraint system. These non design loads are judged to have led to the partial failure of the airstair radius arms.

Other aspects of the investigation

The request for the crew to operate another aircraft later the same evening was reviewed. The company has subsequently sought to resolve this problem by highlighting this relevant section from the operations manual.

> *'After being involved in an accident as defined at the beginning of this paragraph, the crew shall not carry out further flying duties.*
>
> *Crew members shall remain on site, unless to undergo medical treatment or examination, and may not be scheduled for flying duties until authorised by the Chief Pilot after the preliminary findings of the investigation are known or apparent.'*

Conclusions

The most probable cause of the accident was that the senior cabin attendant grasped the inner door handle to restrain her upper body during the rapid acceleration of the aircraft. The ergonomics of the cabin crew seat and door handle made such an involuntary action readily conceivable. Such action lead to the door unlatching and opening rapidly. Failure of the damper attachments and disruption of the banister mechanism then allowed forcible over-travel, leading to failure of the airstair attachment arms.

The remaining attachment strength of the door and airstairs to the aircraft was such that both would almost certainly have separated had the aircraft become airborne. Had separation occurred, the port propeller and other critical parts of the aircraft would probably have been struck. A catastrophic outcome could not be ruled out.

The door and airstair design, though technically complying with the certification requirements, lacked the necessary integrity to prevent a hazardous occurrence to the aircraft.

Safety Recommendation 2003-109

It is recommended that the European Aviation Safety Agency review the design characteristics of the door operating, attachment and restraint mechanisms of the Dornier 328 aircraft type, in order to minimise the possibility of inadvertent door operation and to ensure that there is sufficient residual strength in the door/airstair attachments to prevent separation of the door in the event of a door coming open during takeoff or initial climb.