



Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT

**BAe Avro 146-RJ85, EI-RJW
Near CDG Airport, Paris, France**

1 July 2016



**An Roinn Iompair
Turasóireachta agus Spóirt**

**Department of Transport,
Tourism and Sport**

FINAL REPORT

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13¹ to the Convention on International Civil Aviation, Regulation (EU) No 996/2010² and Statutory Instrument No. 460 of 2009³, safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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¹ **Annex 13:** International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.

² **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

³ **Statutory Instrument (SI) No. 460 of 2009:** Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.



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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 4 July 2016, appointed John Owens as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report.

Aircraft Type and Registration:	BAe Avro 146-RJ85, EI-RJW
Number and Type of Engines:	4 x Honeywell LF 507
Aircraft Serial Number:	E2371
Year of Manufacture:	2000
Date / Time (UTC):⁴	1 July 2016 @ 14.10 hrs
Location:	Near Paris CDG (LFPG), France
Type of Operation:	Commercial Air Transport, Scheduled Passenger
Persons on Board:	Crew - 4 Passengers - 89
Injuries:	Crew - Nil Passengers - Nil
Nature of Damage:	Nil
Commander's Licence:	Airline Transport Pilot Licence (ATPL), Aeroplanes (A) issued by the Irish Aviation Authority (IAA)
Commander's Age:	51 years
Commander's Flying Experience:	11,322 hours, of which 10,156 were on type
Notification Source:	Occurrence Report submitted by the Operator to the IAA
Information Source:	AAIU Report Form submitted by the Pilot Correspondence with the Operator

⁴ **UTC:** Co-ordinated Universal Time. All times in this Report are UTC (local time minus two hours on the accident date).

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SYNOPSIS

During climb out from Paris Charles De Gaulle Airport (LFPG), France, on a scheduled passenger flight to Newcastle (EGNT), United Kingdom, the Flight Crew noticed that the cabin rate of climb and cabin altitude had increased rapidly, and that a white PRESSN advisory light (pressurisation fault) had illuminated on the Central Warning Panel (CWP). This was followed by a pressurisation system caution light (pressurisation failure). As the Flight Crew were completing the abnormal operation checklist, a CABIN HI ALT (cabin high altitude) warning was generated. This resulted in the Flight Crew declaring an emergency (Mayday) to Air Traffic Control (ATC), donning their oxygen masks and performing an emergency descent. During completion of the cabin high altitude checklist, they discovered that a ram air switch on the overhead panel, which controls the position of the ram air valve, was in the OPEN position instead of the normal SHUT position. The Flight Crew moved the switch to the SHUT position, which closed the ram air valve and restored normal system operation. The flight was continued to EGNT without further incident.

It was subsequently found that a non-return valve in the aircraft's ram air system had been installed the wrong way round. This incorrectly installed valve, in combination with the ram air valve being in the open position on the occurrence flight, prevented the aircraft from pressurising correctly.

NOTIFICATION

The AAIU became aware of this serious incident following the Operator's submission of an Occurrence Report to the IAA on 4 July 2016⁵. The AAIU notified the *Bureau d'Enquêtes et d'Analyses* (BEA) in France, where the event occurred. The BEA delegated the Investigation to Ireland as the State of Registry. Neither the Cockpit Voice Recorder (CVR) nor the Flight Data Recorder was preserved by the Operator. However, the Operator provided the Investigation with data for the occurrence flight from its Flight Data Monitoring (FDM) system.

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1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft departed from LFPG at approximately 13.55 hrs. During the climb, at approximately FL100⁶, the Flight Crew completed a standard pressurisation check. They noted that the differential pressure⁷ and cabin rate of climb⁸ were normal (3.8 psi⁹ and 500 feet (ft) per minute respectively), but observed that the airflow coming from the cockpit air vents was "quite weak".

⁵ **Occurrence Reporting Requirements:** Regulation (EU) 376/2014 on 'the reporting, analysis and follow-up of occurrences in civil aviation' requires operators to submit occurrence reports for certain occurrences as soon as possible and in any event no later than 72 hours after becoming aware of an occurrence. SI No. 460 of 2009 on the 'notification and investigation of accidents, serious incidents and incidents' requires operators to inform the AAIU directly of any serious incident or accident as soon as practicable by the most rapid means available.

⁶ **FL100:** Flight Level 100, a three digit representation of aircraft altitude (10,000 feet (ft/FT) in this case) referenced to standard pressure (1013.25 hPa).

⁷ **Differential Pressure:** In this case, the difference between the air pressure in the aircraft cabin and the air pressure outside the aircraft. Also known as ΔP (The Greek letter 'Delta' (Δ) is used to signify difference or change).

⁸ **Cabin rate of climb:** The rate at which the air pressure inside the aircraft cabin is decreasing.

⁹ **PSI/psi:** Pounds per Square Inch – Unit of pressure.



When the aircraft was passing FL160, the Flight Crew noticed that the cabin rate of climb and cabin altitude¹⁰ had increased rapidly, and that a white PRESSN (pressurisation) advisory light was illuminated on the Central Warning Panel (CWP) in the cockpit's main instrument panel. The Flight Crew reported that the [*Pressurization Controller Fault*] "*abnormal checklist*"¹¹ was followed and that PRI and SEC faults (**Section 1.5.2**) were observed on the pressurisation panel/controller located in the overhead panel in the cockpit. The Flight Crew continued with the aircraft climb.

The Crew stated that when the aircraft was passing FL200, an amber PRESSN caution—indicating a pressurisation system failure—illuminated on the CWP. They also stated that the cabin altitude was continuing to climb rapidly. The aircraft was levelled off at approximately FL220. The '*Pressurization Controller Failure*' checklist (to be followed when an amber PRESSN caution illuminates) requires the pressurisation system to be selected to MAN (Manual). The Flight Crew reported that the system was selected to MAN, but that control of the system could not be regained. They said at this stage, the cabin altitude had reached 9,500 ft¹² and that a CABIN HI ALT (cabin high altitude) warning was displayed on the CWP. They declared a Mayday to ATC Paris, donned their oxygen masks and carried out an emergency descent to FL100.

The Flight Crew was now following the '*Emergency Descent after Pressurization Failure*' checklist, which included the requirement to select the ram air switch to OPEN when the cabin differential pressure was less than 1 psi. When the Flight Crew looked at the ram air switch, they discovered that it was already in the OPEN position. Because the differential pressure was 0.5 psi at this stage, they selected the ram air switch to SHUT. The pressurisation mode was then reselected to AUTO and control of the pressurisation system was regained. The Flight Crew reported that they briefed the Cabin Crew, carried out a DODAR¹³ check and decided to continue to EGNT. The Flight Crew stated that they made a PA¹⁴ to the passengers and that the rest of the flight was uneventful. Following arrival in EGNT, the Flight Crew made an entry in the aircraft's technical log book describing the occurrence. Maintenance personnel carried out a test of the pressurisation system. No anomalies were noted and the aircraft was returned to service.

Subsequently, the Flight Crew did not recall touching the switch at any stage before the occurrence and could not explain how the ram air switch came to be in the OPEN position. A different crew had operated the aircraft on the previous flight on the day of the occurrence. The Operator informed the Investigation that the crew who operated the previous flight did not experience any problems with the pressurisation system. The Operator also advised that no maintenance was carried out during the turnaround in LFPG and that Ground Servicing personnel would normally not have entered the cockpit at this time.

1.2 Cabin Crew Observations

The Operator reported that following the occurrence, the Cabin Crew stated that the '*Emergency Descent*' announcement the Flight Crew made while wearing their masks was "*not readily understandable by those in the cabin*".

¹⁰ **Cabin Altitude:** The air pressure inside the aircraft cabin expressed in terms of altitude (in feet).

¹¹ **Appendix A** contains extracts from the relevant checklists.

¹² The Cabin Altitude would normally be approximately 3,600 feet at FL220.

¹³ **DODAR:** An acronym used during abnormal operations: Decision, Options, Decide, Act or Assign, and Review.

¹⁴ **PA:** Public/Passenger Address.

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In addition, the Operator reported that the Cabin Crew were expecting the oxygen masks in the cabin to drop down because that was their understanding of what would occur during an emergency descent. The masks did not drop down nor should they have (**Section 1.5.2**).

1.3 Injuries to Persons

No injuries were reported to the Investigation.

1.4 Personnel Information**1.4.1 Aircraft Commander**

Age:	51 years
Licence:	ATPL, issued by the IAA
Total all Types:	11,322 hours
Total on Type:	10,156 hours

1.4.2 First Officer

Age:	29 years
Licence:	ATPL, issued by the UK Civil Aviation Authority (CAA)
Total all Types:	406 hours
Total on Type:	246 hours

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1.5 Aircraft Information**1.5.1 General**

The aircraft, a BAe Avro 146-RJ85, was manufactured in 2000. Its Certificate of Airworthiness was issued by the IAA on 18 October 2007. The Airworthiness Review Certificate (ARC) in force at the time of the occurrence was issued on 16 February 2016 and was valid until 17 February 2017. The aircraft had operated for a total time of 26,411 hours from the date of manufacture until the occurrence date.

1.5.2 Aircraft Pressurisation System

The aircraft's engines and/or the Auxiliary Power Unit (APU) supply air to the air conditioning system. The aircraft is pressurised by air from the air conditioning system to maintain the cabin altitude (air pressure) at a comfortable level for its occupants. Pressurisation is controlled by a pressurisation panel/controller located on the overhead panel in the cockpit (**Figure No. 1**). When the pressurisation panel/controller is in the AUTO (normal) mode, it automatically adjusts the open-shut position of a fuselage-mounted cabin air outflow valve (the No. 1/master valve). This regulates the outflow of pressurised air and thereby controls the air pressure within the aircraft. The position of an identical valve (No. 2/slave valve) is controlled by the position of the No. 1 valve.



A three-line display on the panel/controller indicates the RATE of change of cabin altitude in ft per minute (FPM); the ΔP (differential pressure) between the cabin and the outside air (in PSI), and the cabin ALT (altitude) (in FT). If the system detects a fault, the relevant fault code(s) will be displayed on the middle (ΔP) line of the display. These can be cleared by a CLEAR DISPLAY FAULT button on the pressurisation panel/controller. The fault code PRI indicates that the primary electronic control channel has failed. SEC indicates that the secondary channel has failed (PRI and SEC were observed by the Flight Crew).

The system can also be set to MAN (manual) mode. In this mode, the positions of the outflow valves are controlled by a 16-position MAN RATE rotary selector. If the outflow valves are fully open, PRIMARY FULL OPEN and/or SECONDARY FULL OPEN will illuminate in green on the pressurisation panel/controller.

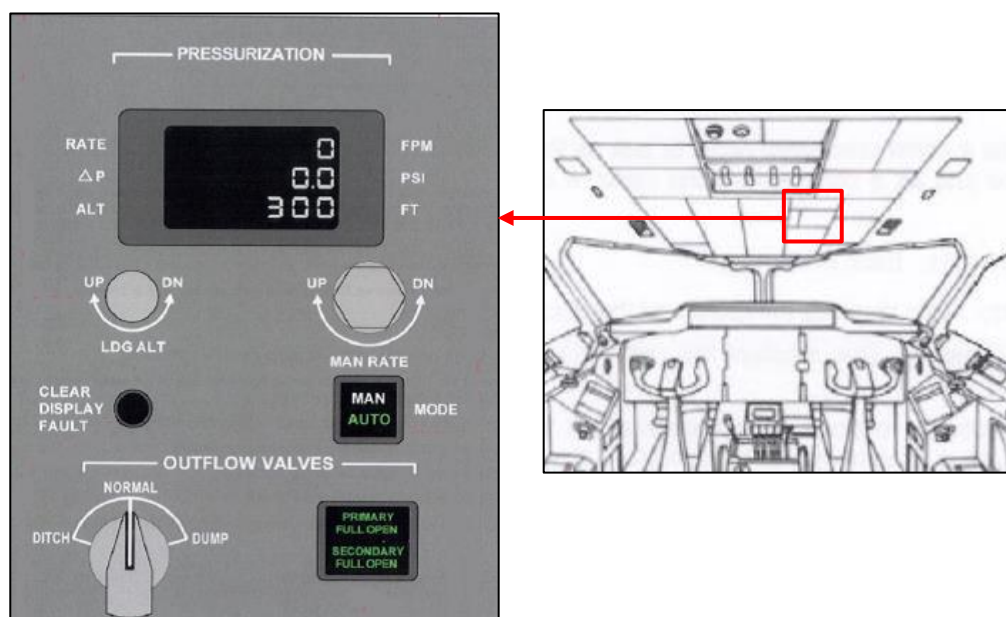


Figure No. 1: Pressurisation panel/controller (adapted from Flight Crew Operating Manual)

A quad indicator (**Figure No. 2**) is fitted to the first officer's instrument panel, which utilises a four-line display to indicate the RATE of change of cabin altitude (in FPM), the ΔP between the cabin and the outside air (in PSI), the CAB ALT (cabin altitude) in FT, and the LDG ALT (altitude of the landing airfield), also in FT.

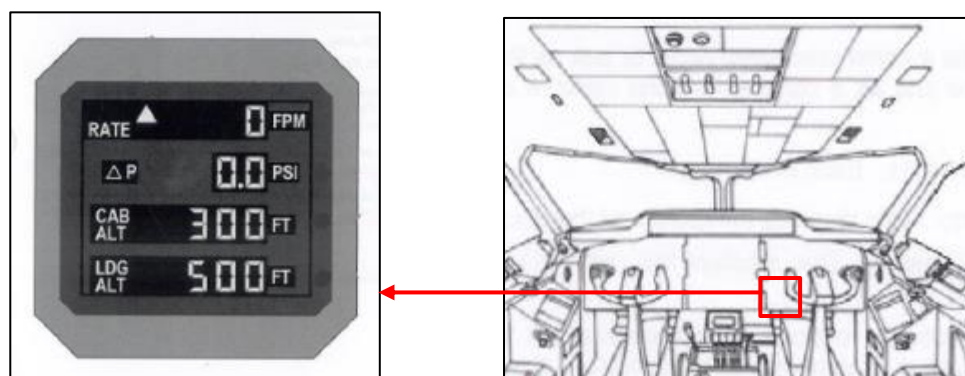


Figure No. 2: Quad Indicator (adapted from Flight Crew Operating Manual)

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The aircraft's CWP, which is located in the centre of the cockpit's main instrument panel, contains white and amber PRESSN captions. The white caption indicates that an abnormal system selection has been made or that a minor system failure has occurred. According to the Flight Crew Operating Manual (FCOM), "*a minor system failure is one that does not require pilot action*". The amber caption indicates that the differential pressure is outside the range -0.5 to 7.6 psi or that "*a major system failure has occurred requiring pilot action*".

If the cabin altitude exceeds 8,700 ft, the CAB ALT display on the quad indicator and the ALT display on the pressurisation panel/controller will flash. If the cabin altitude reaches 9,700 ft (± 200 ft), a CABIN HI ALT warning will illuminate on the CWP, accompanied by a triple chime aural alert. The cabin oxygen masks will automatically drop if the cabin altitude reaches 13,250 ft ± 250 ft.

1.5.3 Ram Air System Description

An optional ram air system (**Figure No. 3**) is fitted to all RJ aircraft in the Operator's fleet. When activated, it provides aircraft ventilation during unpressurised flight or when the air conditioning packs are off. It can also assist with the clearing of smoke or fumes from within the aircraft and its activation is included in the checklists to be followed for such events.

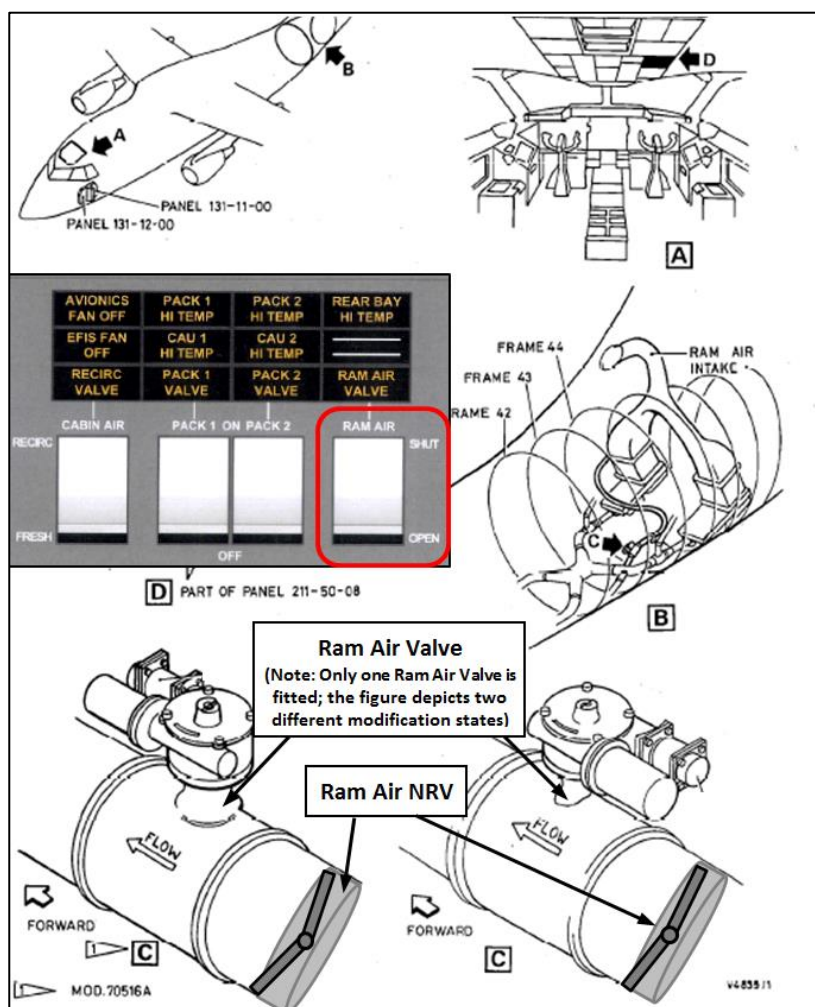


Figure No. 3: The ram air system (adapted from AMM 21-51-00). The direction of the airflow is embossed on the ram air valve's housing.



Ram air is supplied from the ram air duct (which is connected to the ram air intake), through a non-return valve (NRV) and a ram air valve to the flight deck supply duct. This duct is connected to the cabin air supply duct (**Section 1.7, Figure No. 4**). The direction of airflow is embossed on the ram air valve's housing. The position of the ram air valve is controlled by an unguarded two-position (OPEN-SHUT) switch fitted to the AIR SUPPLY panel, which is located on the bottom right of the overhead panel in the cockpit. The correct position for the switch during normal aircraft operation is SHUT. The AIR SUPPLY panel contains several other switches relating to air supply and air conditioning, which are the same shape and size as the ram air switch. Neither the aircraft's Flight Data Recorder (FDR), nor the Operator's FDM system, records the position of the ram air switch or the position of the ram air valve.

When the ram air valve is being switched from SHUT to OPEN or vice versa, a RAM AIR VALVE amber annunciator above the switch will briefly illuminate when the ram air valve is in motion, i.e. '*Not in the Position Selected*' (NIPS). The annunciator will only remain illuminated if the valve fails to open or shut as selected. If this occurs, an associated amber AIR COND caution light will illuminate on the CWP, in conjunction with a Master Caution light on the cockpit glare shield panel and an associated single chime aural alert.

The ram air NRV consists of a circular housing (four inches in diameter), which contains two spring-loaded flaps and a spigot, about which the flaps hinge (**Photo No. 1**). The flaps are spring-loaded to the closed position. The purpose of the NRV is to ensure that when the ram air valve is open, air can only flow into the aircraft cabin from the ram air duct and not from the cabin to the duct and therefore to atmosphere.



Photo No. 1: A removed ram air NRV (Source: *Aircraft Operator*)

1.5.4 Aircraft Checklists

The Operator utilises a two-page (single leaf) '*Normal Checklist*' during routine operations. The '*Before Start*' section states the following in relation to air supply and air conditioning:

AIR CONDITIONING..... AS REQD

The '*After Start*' section states:

APU/ENG AIR.....AS REQD

PACKS/CABIN AIR..... AS REQD

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The 'After Take-Off' section states:

ENG AIR..... ON
 APU AIR..... OFF
 PACKS..... ON, ΔP "..."

The 'Flight Deck Safety' section of the checklist is required to be completed in full for the first flight of the day. For other flights, a reduced version is used. The 'AIR CONDITIONING AS REQD' item is included in the full 'Flight Deck Safety' checklist and in the reduced version.

Expanded checklists are contained in the Flight Crew Operating Manual (FCOM) carried on board the aircraft, which contain details of the 'AS REQD' items referred to in the 'Normal Checklist'. In accordance with the FCOM, the flight crew is required to confirm the switch positions of the 'AS REQD' items. The Operator's Operations Manual requires all checklists to be used. The 'Before Start' Air Conditioning 'AS REQD' items are as follows (emphasis added):

FLT DECK TEMP CTRL switch..... AUTO
 CABIN TEMP CTRL switch AUTO
 AUTO rotary selectors As Required
 FLT DECK FAN switch As Required
 CABIN FAN switch..... ON
 CABIN AIR switch..... As Required
 PACK 1 & 2 switches..... As Required
RAM AIR switch..... SHUT
 APU AIR switch.....OFF, unless conditioning from the APU
 APU VLV NOT SHUT annunciator..... Out
 ENG AIR switches (4)..... OFF

Extracts from the abnormal and emergency checklists are included at **Appendix A**. The checklists do not contain a requirement for Flight Crews to level off if a white PRESSN advisory light or an amber PRESSN caution light is illuminated on the CWP. The Investigation asked the aircraft Manufacturer why there is no requirement to level off if an amber caution is received. The Manufacturer stated that:

...the philosophy behind the drill...is to try and regain control of cabin pressurisation as quickly as possible and levelling off, with the necessary ATC interaction, would delay its commencement. Furthermore, the problem might be solved when carrying out the drill whilst continuing to climb, requiring no change to the flight profile...

Regarding the possibility of reduced oxygen levels adversely affecting the Flight Crew, the Manufacturer stated that:

In the event of reduced oxygen levels arising from pressurisation difficulties, the aircraft's master warning system provides prompts and the emergency checklist [provides] instructions to ensure flight crews don their oxygen masks...



1.6 Operator's Initial Follow-Up Action

Following the occurrence, the Operator was initially of the opinion that the ram air switch inadvertently being in the OPEN position caused the failure of the aircraft to pressurise. Therefore, the Operator requested the aircraft Manufacturer to review the Abnormal and Emergency checklists with a view to including a check of the position of the ram air switch earlier in the checklists for pressurisation-related events.

The aircraft Manufacturer advised the Operator that an open RAM AIR valve should not, on its own, allow cabin air to escape to atmosphere due to the system's NRV. However, the Manufacturer also stated that it was aware of a previous similar event, which occurred in 2004 and that subsequent investigation of that event found the ram air NRV to have been installed the wrong way round. As a result of this communication, the Operator inspected the ram air NRV on EI-RJW on 9 July 2016 and found it to be fitted the wrong way round. An inspection of the ram air NRVs on the rest of the Operator's RJ fleet (an additional 14 aircraft) was also carried out and no further anomalies were identified.

1.7 Scheduled Maintenance Requirements

1.7.1 General

A list of all scheduled maintenance tasks to be performed on the aircraft is contained in the Operator's Approved Maintenance Programme (AMP). This programme is based on the aircraft Manufacturer's maintenance requirements (outlined in its Maintenance Planning Document/MPD), combined with the specific requirements of the Operator. The AMP is approved by the IAA. Each scheduled maintenance task is normally issued to maintenance personnel in the form of a work order, which contains the Part Number (P/N), Serial Number (S/N) and location of the component on which the work is to be performed and a description of the work required. A task card, containing more detailed instructions and the appropriate AMM section to be used, is normally issued with each work order.

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1.7.2 Non-Return Valves

There is no scheduled inspection requirement for the ram air NRV in the Manufacturer's MPD or in the Operator's AMP. Two other NRVs, which have the same P/N and are identical to the ram air NRV, are fitted to the recirculating air supply ducts, which form part of the recirculating system on the aircraft. There is a task in the MPD/AMP regarding these two NRVs (MPD ref 215000-RAI-10030-1), which is scheduled to be performed every 20,000 flight cycles¹⁵. The maintenance task states:

REMOVE, CLEAN, INSPECT AND CHECK OPERATION OF COOLING SYSTEM 4 INCH NON-RETURN VALVE RECIRCULATING AIR SUPPLY TO CAU¹⁶ OUTLET JET PUMP.

The instructions on how to perform this task are contained in section 21-50-64 of the Aircraft Maintenance Manual (AMM): *VALVE (RECIRCULATING DUCT) – NON-RETURN VALVE MAINTENANCE PRACTICES*.

¹⁵ **Flight Cycle:** A flight cycle is a take-off and landing.

¹⁶ **CAU:** Cold Air Unit – A unit in the aircraft's pressurisation system that provides cold air.

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This AMM section is referred to on the work order and task card issued for each of the two NRVs fitted to the recirculating system. The locations of the valves are specified on each work order as "RJW L/H" and "RJW R/H". A detailed post-installation operational and leak check is prescribed in the AMM.

NRVs are also fitted to the cabin and flight deck supply ducts emanating from the rear pressure bulkhead located at Frame 44 (**Figure No. 4**). The two NRVs are the same type as the recirculating NRVs and the ram air NRV, but are five inches in diameter. The NRV fitted to the flight deck supply duct (left hand side) is in close proximity to the ram air NRV and ram air valve. The duct coming from the ram air valve is connected to the flight deck supply duct, which in turn is connected to the cabin air supply duct.

The MPD/AMP contains a similar maintenance task for the cabin and flight deck supply NRVs (MPD ref 215000-RAI-10040-1), which is also scheduled to be performed every 20,000 flight cycles. The maintenance task states:

REMOVE, CLEAN, INSPECT, AND CHECK OPERATION OF COOLING SYSTEM 5 INCH NON-RETURN VALVES, CABIN MAIN SUPPLY AND FLIGHT DECK MAIN SUPPLY.

The instructions on how to perform this task are contained in section 21-50-54 of the AMM:

VALVE – NON-RETURN (CABIN AND FLIGHT DECK SUPPLY DUCTS) MAINTENANCE PRACTICES.

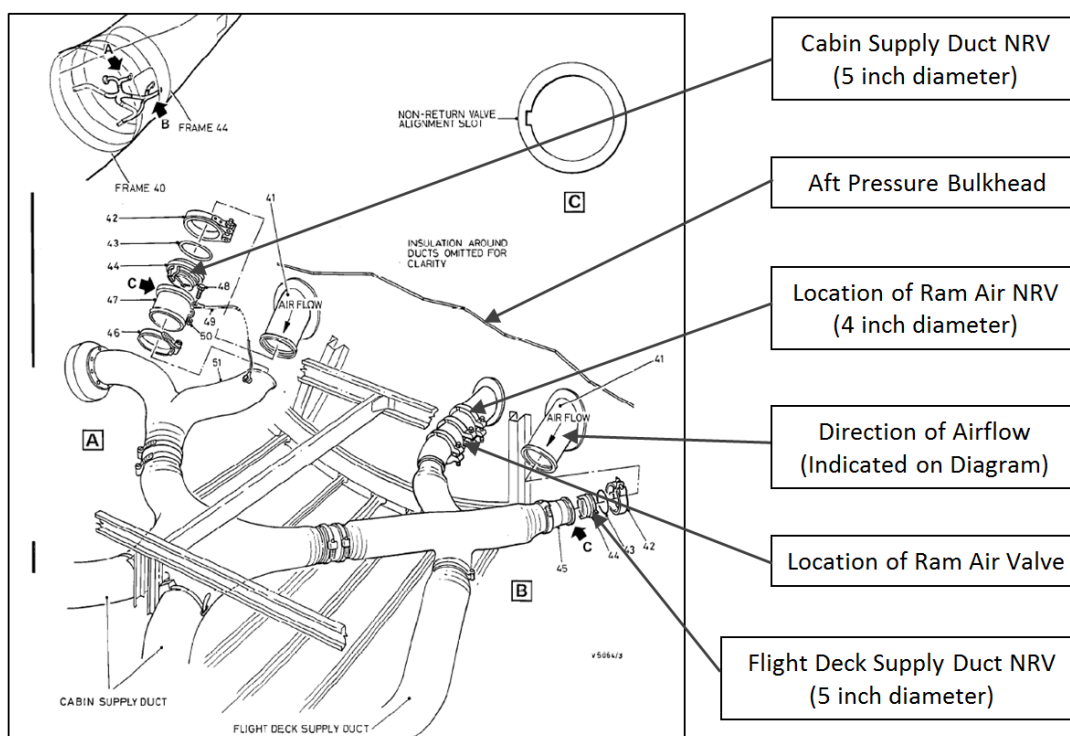


Figure No. 4: AMM 21-50-54 Fig. 201 (Cabin and Flight Deck Supply Ducts and NRVs)

The AMM procedure instructs to "align pin on non-return valve (valve) (44) with slot in flange of duct (47), with valve flaps operating in direction of airflow and insert valve in duct". This slot ensures that the NRV is fitted with the spindle in the vertical position; it does not ensure that the valve is installed the right way round.



The post-installation testing requirements include operating the aircraft's air conditioning system from either the engines or the Auxiliary Power Unit (APU) and ensuring that air can be supplied to the aircraft's cabin and also performing a leak check at all duct joints that were disturbed during the inspection of the valve.

The Investigation asked the aircraft Manufacturer why there was no scheduled maintenance inspection/cleaning requirement for the ram air NRV, which is identical to the recirculating air NRVs and for which there is such a requirement. The Manufacturer stated that this was for economic reasons, i.e. the economic impact on the air conditioning system if a recirculating air NRV fails justifies regular maintenance activity, whereas according to the Manufacturer:

The ram air system does not serve a safety function; rather it provides cabin ventilation at non-pressurised altitudes in the event of total failure of the air conditioning system. Indeed, the ram air system is an optional modification that, by design, is not installed on all AVRO RJ aircraft.

1.7.3 Operational Check of Ram Air Valve

The MPD/AMP contains a requirement to perform an “*OPERATIONAL CHECK OF [the] RAM AIR VENTILATION ON/OFF VALVE AND INDICATING SYSTEM*” (MPD ref 215100-OPT-10000-1) which is scheduled to be carried out every 10,000 flight cycles. Part of this task involves selecting the ram air switch to OPEN and ensuring that the ram air valve actuator moves the valve to open. The RAM AIR VALVE annunciator should come on while the valve is in motion and then go off. This task would not identify an incorrectly fitted ram air NRV.

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1.8 Non-Return Valve Maintenance History

The most recent heavy maintenance check on the aircraft prior to the occurrence was performed by an approved Maintenance/Repair Organisation (MRO) in July-August 2011. The maintenance tasks regarding the recirculating air supply NRVs (four inch diameter) and the cabin and flight deck supply duct NRVs (five inch diameter) were scheduled to be carried out during this visit. However, according to the Operator, its aircraft maintenance computer system automatically scheduled an inspection of the ram air NRV due to its part number being the same as the part number of the NRVs fitted to the recirculation ducts.

The work order that was issued for this task referred to the S/N of the NRV fitted to the ram air system (922867-7, which had been fitted since aircraft manufacture). The work order described the NRV's location as “*RJW AFT*”¹⁷. However, the instruction and the AMM section to use (21-50-64), as included on the work order, related to the originating task (outlined earlier and repeated below):

*REMOVE, CLEAN, INSPECT AND CHECK OPERATION OF COOLING SYSTEM 4 INCH NON-RETURN VALVE **RECIRCULATING AIR SUPPLY TO CAU OUTLET JET PUMP** [emphasis added].*

¹⁷ **RJW AFT:** The Operator advised that this description was selected from a pre-set list of positions in its aircraft maintenance computer system, when the P/Ns for the aircraft's components were being loaded into the system.

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The associated task card explained that the task was an “RAI¹⁸ scheduled maintenance task” which required “the removal (for discard, restoration, cleaning, testing or inspection) and subsequent installation of an equipment [sic] or a component identified by a Part Number”. The task card also explained that it was applicable “to the component p/n ser/no & position as defined on the associated workorder”.

This task was completed during the heavy maintenance check and was certified on the task card and work order on 28 August 2011. The aircraft’s total operating hours and total flight cycles at the time were 20,856 and 18,715 respectively. The following text was entered in the action taken section of the work order:

AFT NRV (CABIN AND FLIGHT DECK SUPPLY DUCTS) REMOVED, CLEANED, INSPECTED AND REFITTED. SATIS [satisfactory]. REF AMM 21-50-54-201.

Maintenance records indicate that the same maintenance technician performed the maintenance task on the two 5 inch NRVs (cabin and flight deck supply ducts) and two of the three 4 inch NRVs (the left hand recirculating NRV and the ram air NRV). This technician no longer works for the MRO. Due to the length of time that has elapsed since the maintenance task was performed, the technician was unable to recall any details when contacted by the Investigation. Records indicate that a different technician performed the task on the right hand recirculating NRV.

The Operator reported that the only defect recorded in relation to the ram air system from the July-August 2011 heavy maintenance check until the occurrence date, was on 3 December 2011, which stated that the RAM AIR VALVE NIPS light [remained] illuminated when the ram air valve was operated. It was reported that the fault was traced to FOD¹⁹ which was removed. The Operator stated that there is no record of the ram air NRV having been removed at this time. Following the removal of the FOD, a ram air valve operational test was performed. The test is to ensure that the RAM AIR VALVE annunciator (NIPS light) illuminates while the ram air valve is in motion and extinguishes when the ram air valve reaches the selected position. It would not identify if an NRV was incorrectly fitted.

The Operator advised that there were no reported problems as a result of the maintenance inspections performed on the other NRVs during the July/August heavy maintenance check.

1.9 Ram Air NRV Removal, Installation and Test Procedures

1.9.1 Aircraft Maintenance Procedures

Section 21-51-14 of the AMM, included at **Appendix B**, describes the installation procedure for the ram air NRV. **Figure No. 5** below is from this AMM section.

¹⁸ **RAI:** Removal and Installation.

¹⁹ **FOD (Foreign Object Damage):** The acronym FOD is used to describe damage attributed to foreign objects and the foreign objects themselves.

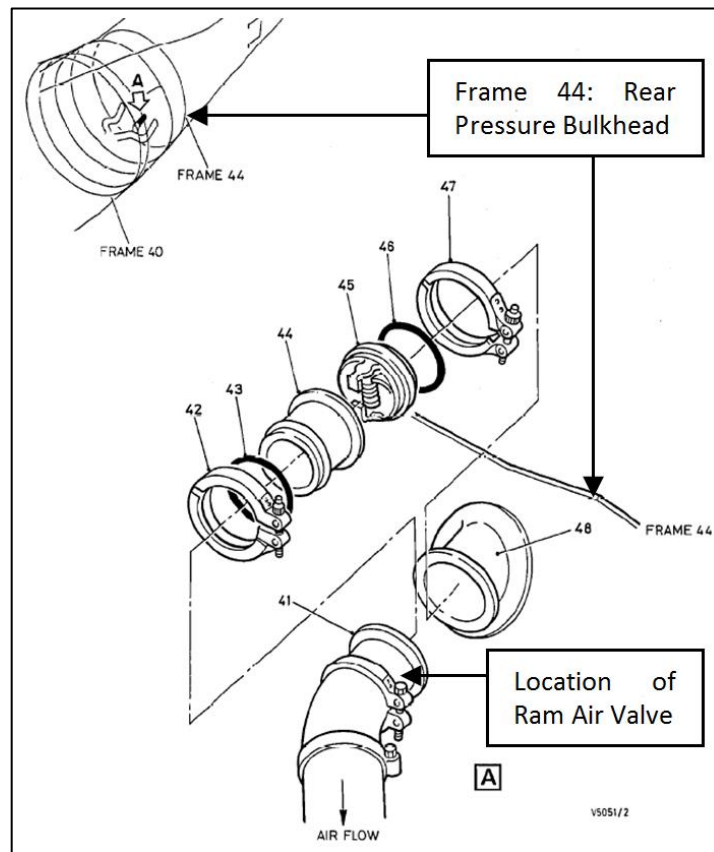


Figure No. 5: AMM 21-51-14 Fig.201
(Location of the ram air valve and rear pressure bulkhead added for clarity)

There are no design features that preclude an incorrect installation of the ram air NRV. The procedure states, *inter-alia*:

(2) Insert non-return valve (45) in duct (44), making certain spindle of valve is positioned vertically and valve flaps operate in direction of airflow.

Regarding post-installation testing, the AMM states that there is “No test required”. The Operator was originally of the view that the lack of a post-installation test contributed to the event and sent a ‘Technical Publications Query’ to the aircraft Manufacturer to request that a suitable post-installation test be developed. The aircraft Manufacturer replied to this request by stating that the addition of a test requirement was unnecessary as the installation instructions were “appropriate”.

In addition to the Operator’s request, the Investigation asked the aircraft Manufacturer to comment on why there was no test requirement following the installation of a ram air NRV, yet there was a test requirement for the identical valves fitted to the recirculation system. In response, the Manufacturer stated that the testing of the recirculating air NRVs required the provision of bleed air (from the engines or the APU), but did not require the aircraft to be pressurised, whereas the only way to test the correct function of the ram air NRV [on an in-service aircraft] was to pressurise the aircraft, which they said “given it does not serve a safety function, was [at the time of aircraft development and certification] evidently considered excessive and not warranting test”.

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1.9.2 Post-Manufacture Testing

The Investigation considered the possibility that the ram air NRV was installed incorrectly at aircraft manufacture and was then reinstalled in the same orientation during maintenance.

The aircraft Manufacturer provided the Investigation with a copy of the '*Fuselage Proof Pressure Test*', which they considered was the most likely means by which an incorrectly installed ram air NRV might have been identified post aircraft manufacture (prior to aircraft delivery). The test introduces compressed air into the fuselage at a pressure of 9.0 psi. The pressure supply is then shut off and the fuselage is tested to ensure that the leak rate is within specified limits. The Manufacturer advised that in order to test for correct installation of the ram air NRV, the test would have had to include an instruction to select the ram air valve to the OPEN position. This test does not include such an instruction.

1.10 Additional Action Taken by the Operator

The Operator carried out their own safety investigation following the event and promulgated details of the occurrence throughout its maintenance department by way of an article in its '*MSMS [Maintenance Safety Management System] Engineering Report Q3 [quarter 3] 2016*' and later, in a Safety Bulletin specific to the occurrence.

The Operator's investigation report (dated May 2017) contains a number of safety recommendations. One of these requested an internal review of communications when oxygen masks are in use, because the '*Emergency Descent*' announcement made by the Flight Crew was not readily understandable by those in the cabin. Also, as a result of the Cabin Crew's erroneous expectation that the oxygen masks would automatically drop during an emergency descent, the Operator's investigation report contained a recommendation requesting an internal review of the Operations Manual-B (Cabin Crew Operating Manual) "*to ensure that cabin crew decompression drills are explained in both contexts of slow and rapid decompression*". The Operator's investigation report also included a recommendation in relation to its reporting responsibilities due to the AAIU not being directly informed of this serious incident. At the time of writing, these recommendations remain open.

The Operator informed the Investigation that in addition to the fleet inspection performed following the occurrence, its AMP has been amended to include a specific inspection requirement for the ram air NRV, to be performed every 20,000 flight cycles. This requires an inspection during reinstallation by a second technician (independent inspection²⁰) to ensure that the NRV has been refitted correctly.

Task 215000-RAI-10030-1, which led to the generation of the work order for NRV S/N 922867-7, installed in the ram air position on EI-RJW, has not been performed on the ram air NRV on any RJ aircraft in the Operator's fleet since the post-occurrence fleet inspection was carried out.

²⁰ **Independent Inspection** (Ref. EASA Part 145 AMC4 145.A.48(b)): An independent inspection is an inspection performed by an '*independent qualified person*' of a task carried out by an '*authorised person*'.



1.11 Action taken by the Aircraft Manufacturer

Subsequent to the Operator's report of the incorrect installation of the ram air NRV, the aircraft Manufacturer issued an '*All Operator Message*' (AOM reference number 16-016V-1, dated 15 September 2016). The AOM contained de-identified details of the occurrence and stated that there were two contributing factors to the occurrence:

- The ram air switch was in the OPEN position.
- The NRV had been installed the wrong way round.

The AOM recommended that operators of RJ aircraft review their operational and maintenance procedures. The Manufacturer advised the Investigation that it received no feedback from other operators as a result of the AOM.

The aircraft Manufacturer advised that whilst the potential consequences of the ram air NRV being installed incorrectly were undesirable, its review of this condition, which took account of the applicable certification standards, did not identify "*as defined in EASA Part 21.A.3B(b)*²¹, a potential unsafe condition, because any loss of cabin pressure would not result in a rapid depressurisation of the cabin".

1.12 Action taken by Maintenance/Repair Organisation

The MRO, where the last heavy maintenance inspection was carried out, issued a '*Safety and Compliance Bulletin*' following the occurrence (issue date 18 August 2016) to highlight what had occurred. The bulletin stated that "*With the ram air NRV incorrectly installed, ram air was not available*" and that "*this report has been raised for information and awareness. Always confirm you are installing components in the correct location and orientation*". As further details emerged during the course of the AAIU Investigation, the bulletin was re-issued to emphasise the severity of the occurrence.

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2. ANALYSIS

2.1 General

An optional ram air system, which provides aircraft ventilation in unpressurised flight, was fitted to all Avro RJ aircraft in the Operator's fleet. The system can also assist with the clearing of smoke or fumes from within the aircraft. The normal position for the ram air switch is SHUT and it should only be selected to OPEN when instructed by an abnormal/emergency checklist such as the '*Emergency Descent after Pressurization Failure*' checklist or the '*Smoke, Fumes or Fire*' checklist (**Appendix A**).

²¹ **EASA Part 21:** Regulation (EU) 748/2012 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances as well as for the certification of design and production organisations. The Acceptable Means of Compliance (AMC) for 21.A.3B(b) defines the term "*unsafe condition*" (**Appendix C** contains further details).

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The NRV fitted to the ram air system ordinarily prevents a loss of pressurisation in the event of a failure of the ram air valve in the open position or its inadvertent opening. In the case of the subject aircraft, this protection was lost because the ram air NRV had been installed the wrong way round, and with the ram air switch inadvertently in the OPEN position on the occurrence flight, the aircraft did not pressurise correctly.

When the aircraft was passing FL160 during the climb out from LFPG, the Flight Crew noticed that the cabin rate of climb and cabin altitude had increased rapidly, and that a white PRESSN (pressurisation) advisory light was illuminated on the CWP. The (*Pressurization Controller Fault*) checklist associated with this fault did not contain a requirement to level off and the climb was continued. Then, when the aircraft was passing FL200, an amber PRESSN caution illuminated, indicating a failure of the pressurisation controller, while the cabin altitude continued to climb rapidly. Similar to the previous checklist, the '*Pressurization Controller Failure*' checklist now being followed did not contain a requirement to level off; however, the Flight Crew discontinued the climb and levelled off at approximately FL220.

As per the '*Pressurization Controller Failure*' checklist, the pressurisation panel/controller was selected to MAN at this stage, but control could not be regained. The subsequent CABIN HI ALT warning prompted an emergency descent. Following this manoeuvre, and when the remaining items of the '*Emergency Descent after Pressurization Failure*' checklist were being followed, one of which required the ram air switch to be selected to the OPEN position, it was realised that the switch was already in OPEN position. The Flight Crew likely thought that this was the cause of the pressurisation problem and moved the switch to the SHUT position. The pressurisation panel/controller was then re-selected to AUTO and control of the aircraft's pressurisation system was regained, and the flight was continued to EGNT.

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2.2 Ram Air Switch

The flight crew who operated the aircraft on the previous flight did not report any problems with the pressurisation system, indicating that the ram air switch was likely in the correct (SHUT) position while the aircraft was airborne during that particular flight leg. The Flight Crew who operated the aircraft on the occurrence flight did not recall touching the switch at any stage before the occurrence and could not explain how it was in the OPEN position. The aircraft's '*Normal Checklist*' does not contain an explicit requirement to check the position of the ram air switch before flight. However, it is contained in the expanded pre-flight checklist. The Investigation notes that the FCOM requires the flight crew to confirm the switch positions of the '*AS REQD*' items.

The positions of the switch and valve are not recorded on the FDR nor do they form part of the Operator's FDM data set. Consequently, the Investigation was unable to determine exactly when the ram air switch was selected to OPEN. The unguarded ram air switch is in close proximity to the switches for the air conditioning packs and is of the same shape and size as these switches, and may have been inadvertently disturbed when the post-flight checks were being completed after landing, or when pre-flight checks were being performed before the occurrence flight. It is also possible that the switch was inadvertently disturbed during access to, or egress from the cockpit when the flight crews changed over before the occurrence flight. The Operator advised that no maintenance was carried out during the turnaround in LFPG and that Ground Servicing personnel would normally not enter the cockpit at this time.



2.3 Installation of Ram Air Non-Return Valve

The aircraft Manufacturer's MPD and consequently the Operator's AMP did not contain a scheduled maintenance inspection of the ram air NRV. However, according to the Operator, its aircraft maintenance computer system automatically scheduled an inspection of this valve because its P/N was the same as two other identical four inch NRVs that were fitted to the air conditioning recirculating system and for which the aircraft's AMP did contain an inspection requirement. Consequently, three work orders were issued for the tasks for completion during the July-August 2011 heavy maintenance check. All three work orders referred to the AMM section to be used for the inspection:

AMM 21-50-64 (REMOVE, CLEAN, INSPECT AND CHECK OPERATION OF COOLING SYSTEM 4 INCH NON-RETURN VALVE RECIRCULATING AIR SUPPLY TO CAU OUTLET JET PUMP).

Correct locations ("RJW L/H" and "RJW R/H") were specified on the work orders relating to the NRVs actually fitted to the recirculating system. The other work order issued also referred to a recirculating system NRV, but with a location of "RJW AFT". There is no such NRV fitted to the recirculating system. However, the S/N that the work order referred to was the S/N of the NRV that was fitted to the ram air system (922867-7).

Work orders were also issued for inspections of the five inch NRVs fitted to the cabin and flight deck supply ducts. These NRVs are fitted in ducts emanating from the rear pressure bulkhead. The ram air duct, into which the ram air NRV (four inch) is fitted, also emanates from the rear pressure bulkhead. The flight deck supply duct (connected to the left hand five inch NRV) and the duct from the ram air NRV, are in close proximity to each other and are interconnected.

Maintenance records indicate that the same maintenance technician performed and certified the inspection on the left hand recirculating NRV and on the NRVs fitted to the cabin and flight deck supply ducts. The AMM sections referred to by the technician in the action taken section of the work orders were correct (21-50-64 and 21-50-54 respectively) and matched what was included on the task cards describing the work required. The same technician also certified the work order that was raised for NRV S/N 22867-7, which the work order stated, was located in the "AFT" position. However, the action taken section of the work order stated:

Aft NRV (cabin and flight deck supply ducts) removed, cleaned, inspected and refitted. Satis [satisfactory]. Ref AMM 21-50-54-201.

The AMM reference used was appropriate for an inspection of an NRV fitted to the cabin and flight deck supply ducts. This suggests that the technician, upon locating NRV S/N 22867-7, may have thought that due to the layout of the ducts at the rear pressure bulkhead, the NRV belonged to the normal cabin and flight deck supply. Section 21-50-54 of the AMM indicates the direction of airflow at the NRV installations in the cabin and flight deck supply ducts (**Section 1.7, Figure No. 4**); however, because this AMM section is not applicable to the ram air NRV, it does not indicate the direction of airflow at this valve. Notwithstanding this, the direction of airflow is embossed on the body of the ram air valve.

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Nevertheless, it is still possible that the technician misunderstood the direction of the airflow due to the layout of the ducts and intentionally refitted the NRV in the orientation consistent with this misunderstanding; component design is such that it does not preclude the incorrect installation of a ram air NRV.

No defects were recorded as a result of the maintenance inspection of the left hand recirculating NRV and the NRVs fitted to the cabin and flight deck supply ducts, indicating that the technician (who also installed the ram air NRV) correctly installed these valves. It is therefore equally possible that the technician correctly understood the direction of airflow at the ram air NRV, but unintentionally installed it the wrong way round.

It is essential that scheduled maintenance task requirements are clearly and accurately described to help ensure that the correct work is carried out. The Operator advised the Investigation that it has amended the aircraft's AMP to include a scheduled inspection of the ram air NRV, which will include a requirement for an inspection during reinstallation by a second technician to ensure the correct orientation of the NRV following its installation. Consequently, no Safety Recommendation is made regarding the incorrect maintenance task description.

The total aircraft cycles recorded when the NRV inspections were performed during the July-August 2011 heavy maintenance check was 18,715. The inspections are only scheduled every 20,000 flight cycles; therefore, it is probable that it was the first time the inspections had been performed since aircraft manufacture. There was no post-manufacture/pre-delivery test to verify correct installation of the ram air NRV. Consequently, the possibility of it being incorrectly installed at manufacture and the maintenance technician reinstalling the valve in the same orientation that he removed it, cannot be ruled out.

The only maintenance action recorded on the ram air system in the period from the July/August 2011 heavy maintenance inspection until the occurrence flight was on 3 December 2011, when FOD was removed due to a RAM AIR VALVE NIPS indication remaining on. The Operator advised that there was no record of the ram air NRV having been removed at this time. However, due to its close proximity to the ram air valve, the possibility of it being removed and then being incorrectly reinstalled at this time can also not be ruled out.

2.4 Ram Air Non-Return Valve Inspection

The incorrect installation of the ram air NRV was a latent error²² in that its adverse consequences lay dormant from at least December 2011 until the ram air switch was inadvertently moved to the OPEN position.

²² **Latent Error:** An error whose adverse consequences lie dormant for a period of time, only becoming evident when combined with other factors. Reason, J. (1990). *Human Error*. New York: Cambridge University Press.



As outlined earlier, it is considered likely that the technician was unaware that it was actually the ram air NRV that the work was being performed on. The AMM section referred to by the technician was applicable to the cabin and flight deck supply NRVs. This section contains an instruction on how to install these NRVs, with the *“valve flaps operating in direction of airflow”* and prescribes a post-installation test. The performance of this post-installation test would not have identified the incorrectly installed ram air NRV, because it was not applicable to that system.

The correct AMM section to be used during maintenance of the ram air NRV also contains an instruction to make certain that the *“valve flaps operate in direction of airflow”*. However, the procedure states that there is *“no test required”* following its installation. It's possible therefore that even if the technician had been aware of which NRV the inspection was being performed on and consequently was following the correct AMM, an installation error may still have occurred.

There is no scheduled maintenance requirement to remove and inspect the ram air NRV. Consequently, the issue of an associated installation error should not normally arise. However, it is possible that ram air NRVs on other aircraft in the worldwide RJ fleet have been removed or replaced for other reasons (e.g. defects or component access). Due to the lack of a post-installation test, it is possible therefore that there may be other aircraft with incorrectly installed ram air NRVs, which have the potential to be a factor in similar serious incidents. Furthermore, an incorrectly installed ram air NRV would prevent ram air from flowing when required and therefore could inhibit the clearance of smoke or fumes from the aircraft when the ram air valve is selected to OPEN as instructed by the checklists to be followed for such events.

The Investigation acknowledges that the Operator inspected the ram air NRV installation on 14 other RJ aircraft in its fleet, with no adverse findings, and also that the aircraft Manufacturer issued an AOM to highlight the occurrence to other operators. However, the Manufacturer advised of a previous similar occurrence and indicated that post aircraft manufacture/pre-delivery testing would not identify if a ram air NRV had been incorrectly installed at aircraft manufacture. Accordingly, the Investigation issues the following Safety Recommendation to the aircraft Manufacturer:

Safety Recommendation No. 1

BAE Systems should advise operators of 146-RJ aircraft equipped with ram air systems to verify that the ram air non-return valve is correctly installed (**IRLD2018004**).

2.5 Ram Air Non-Return Valve Installation Procedures

Regarding the lack of a post-installation test, the aircraft Manufacturer explained that this was because the ram air system was optional and did not *“serve a safety function”* and the only way to check the correct operation of the NRV on an in-service aircraft would be to pressurise the aircraft. The Manufacturer stated that this was *“evidently considered excessive”* at the time of aircraft development and certification. The Manufacturer advised that its review of the effect of an incorrectly installed ram air NRV did not identify *“as defined in EASA Part 21.A.3B(b), a potential unsafe condition, because any loss of cabin pressure would not result in a rapid depressurisation of the cabin”*.

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The aircraft's emergency checklists to be used as a result of warnings generated by the aircraft's master warning system and flight crew training should ensure that flight crews don oxygen masks when necessary. However, the Investigation is concerned that the failure of an aircraft to pressurise correctly after take-off, in addition to leading to events such as the subject serious incident, can also produce subtle and insidious effects which could impair flight crew performance and adversely affect their reaction to the warnings received. It is imperative therefore that the ram air NRV is correctly installed.

The Investigation acknowledges that pressurising an aircraft during maintenance could result in safety hazards for maintenance personnel and is therefore reluctant to issue a recommendation for such a test. However, due to the lack of a post-installation test, and because there are no design features to prevent incorrect installation, the correct installation of the ram air NRV relies solely upon the instruction in the AMM regarding the NRV flaps operating in the direction of the airflow. Therefore, this instruction should be clearly highlighted in the procedure. The Investigation considers that neither the text of AMM 21-51-14 nor the associated figure (**Appendix B**) sufficiently highlights the importance of the correct orientation of the NRV. Consequently, the following Safety Recommendation is issued to the aircraft Manufacturer:

Safety Recommendation No. 2

BAE Systems should review the ram air non-return valve installation procedures contained in AMM section 21-51-14 with a view to more clearly highlighting the importance of the correct orientation of the valve (**IRLD2018005**).

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2.6 Scheduled Maintenance Inspection

The aircraft Manufacturer's MPD does not contain a scheduled repetitive inspection/check requirement for the ram air NRV, yet such a check exists for the identical valves contained in the recirculating system (carried out every 20,000 flight cycles). The aircraft Manufacturer stated that this was because the purpose of the ram air system was to provide "*cabin ventilation at non-pressurised altitudes in the event of total failure of the air conditioning system*". However, the MPD/AMP does contain a requirement to perform an operational check of the ram air valve and indicating system, which is scheduled to be carried out every 10,000 flight cycles. This maintenance task would not identify an incorrectly installed or malfunctioning ram air NRV, nor is it designed to, yet correct system operation is predicated on the NRV functioning as intended.

The Investigation notes that the Operator has amended its AMP to include a specific inspection requirement for the ram air NRV, which requires a second (independent) inspection during reinstallation to ensure that this NRV has been refitted correctly. A regular, scheduled inspection of the ram air NRV, similar to that introduced by the Operator, coupled with the existing operational check of the ram air valve and indicating system, should ensure that the entire ram air system is operating correctly. Such an inspection may be of benefit to other operators and could identify a latent error or system defect before it manifests itself as a causal factor in a serious incident. Therefore, the following Safety Recommendation is issued to the aircraft Manufacturer:



Safety Recommendation No. 3

BAE Systems should consider developing a scheduled maintenance inspection requirement for the ram air system non-return valve, similar to that which is prescribed for the identical valves installed in the recirculating air supply system (IRLD2018006).

2.7 Operator's Internal Investigation

The Operator's internal investigation report contains a number of safety recommendations. Two of these are safety-related: One recommendation requested an internal review of communications when oxygen masks are in use, because the '*Emergency Descent*' announcement made by the Flight Crew was not readily understandable by those in the cabin. The other recommendation requested an internal review of the cabin crew operating manual "*to ensure that cabin crew decompression drills are explained in both contexts of slow and rapid decompression*", due to the Cabin Crew's erroneous expectation that the oxygen mask would automatically drop down during an emergency descent. At the time of writing, these recommendations remain open. Consequently, the following Safety Recommendation is issued to the Operator:

Safety Recommendation No. 4

CityJet should review its safety occurrence management processes to ensure that recommendations arising from its internal investigations are addressed in a timely manner (IRLD2018007).

3. CONCLUSIONS

3.1 Findings

1. The airworthiness certification for the aircraft was valid.
2. The ram air non-return valve was found installed the wrong way round on the aircraft.
3. There are no design features that preclude an incorrect installation of the ram air non-return valve.
4. The aircraft did not pressurise correctly on the occurrence flight due to a combination of an incorrect system configuration leading to an open ram air valve and the incorrectly installed ram air non-return valve.
5. The aircraft Manufacturer informed the Investigation that a similar event occurred in 2004.
6. The absence of reports of a malfunctioning pressurisation system suggests that the ram air switch was in the correct SHUT position for the airborne phase of the previous flight and was likely inadvertently moved to the OPEN position at some stage thereafter.

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7. The failure of the aircraft to pressurise during the climb-out on the occurrence flight eventually resulted in a CABIN HI ALT (cabin high altitude) warning on the Central Warning Panel in the cockpit.
8. When the CAB HI ALT warning was received, the Flight Crew declared a Mayday to ATC, donned their oxygen masks, and carried out an emergency descent.
9. One of the items in the '*Emergency Descent after Pressurization Failure*' checklist contained the requirement to select the ram air valve to OPEN when the cabin differential pressure was less than 1 psi. When the Flight Crew looked at the ram air switch, they discovered that it was already in the OPEN position.
10. When the Flight Crew moved the ram air switch to the SHUT position and re-selected the pressurisation to AUTO, normal operation of the pressurisation system was restored and the flight was continued to its destination.
11. Following the occurrence, the Cabin Crew informed the Flight Crew that the '*Emergency Descent*' announcement made by the Flight Crew while wearing their oxygen masks was not readily understandable by those in the cabin.
12. The aircraft Manufacturer's maintenance requirements did not require a periodic inspection/check of ram air non-return valve.
13. The aircraft Manufacturer's maintenance requirements included a periodic inspection/check of two non-return valves contained in the recirculating system, which had the same part number as the ram air non-return valve.
14. The Operator's maintenance computer system automatically scheduled an inspection of the ram air non-return valve because it had the same part number as the non-return valves installed in the recirculating system and which were subject to a scheduled inspection.
15. The description of the work required as contained on the work order and task card generated for the inspection of the non-return valve fitted to the ram air system, to be performed during the July-August 2011 heavy maintenance inspection, was not applicable to the ram air non-return valve.
16. The technician who performed the inspection of the ram air non-return valve during the July-August 2011 heavy maintenance check may have been of the understanding that the valve formed part of the normal cabin and flight deck supply system due to the incorrect work required description and the layout of the ducting.
17. The Aircraft Maintenance Manual procedure for the installation of the ram air non-return valve (AMM 21-51-14) does not require a post-installation test.
18. There was no post aircraft manufacture/pre-delivery test to verify correct installation of the ram air non-return valve.



19. The possibility of the ram air NRV being installed incorrectly at aircraft manufacture or during defect rectification in December 2011 could not be ruled out.
20. An inspection of the ram air non-return valves on the Operator's 14 other RJ aircraft identified no anomalies.
21. The Operator's internal investigation report contains a number of safety recommendations. Two safety-related recommendations remain open at the time of writing.

3.2 Probable Cause

Failure of the aircraft to correctly pressurise after take-off due the inadvertent selection of the ram air switch to OPEN, combined with an incorrectly fitted ram air non-return valve.

3.3 Contributory Cause(s)

There are no design features that preclude an incorrect installation of the ram air non-return valve.

4. SAFETY RECOMMENDATIONS

It is Recommended that:		Recommendation Ref.
1.	BAE Systems should advise operators of 146-RJ aircraft equipped with ram air systems to verify that the ram air non-return valve is correctly installed.	IRLD2018004
2.	BAE Systems should review the ram air non-return valve installation procedures contained in AMM section 21-51-14 with a view to more clearly highlighting the importance of the correct orientation of the valve.	IRLD2018005
3.	BAE Systems should consider developing a scheduled maintenance inspection requirement for the ram air system non-return valve, similar to that which is prescribed for the identical valves installed in the recirculating air supply system.	IRLD2018006
4.	CityJet should review its safety occurrence management processes to ensure that recommendations arising from its internal investigations are addressed in a timely manner.	IRLD2018007
View Safety Recommendations for Report 2018-005		

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Appendix A: RJ-85 Checklists

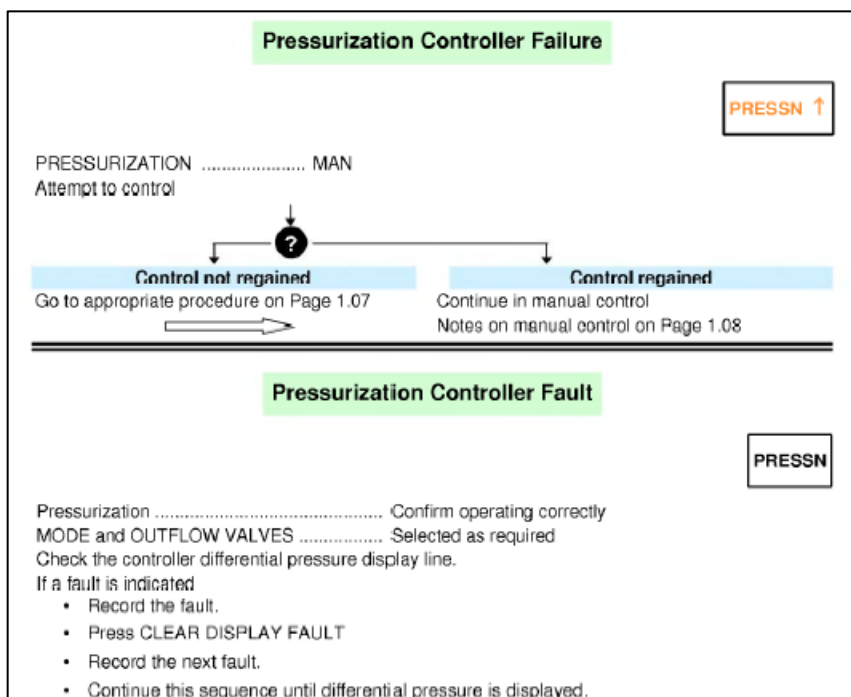


Figure No. A1: Abnormal and Emergency checklists for a pressurisation fault/failure

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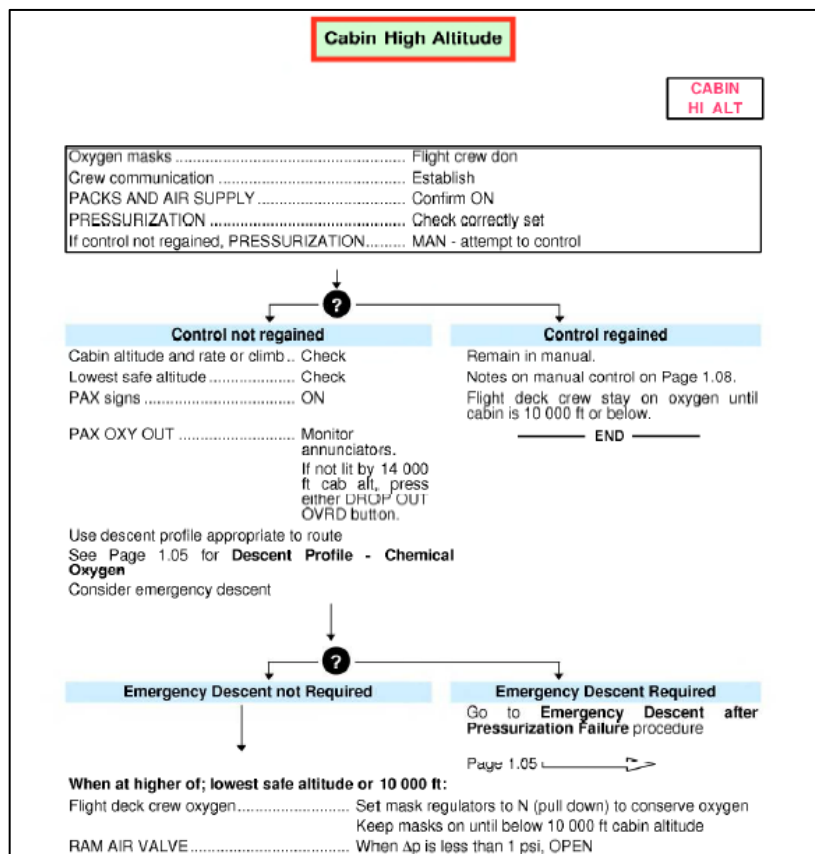


Figure No. A2: Abnormal and Emergency checklist for a CAB HI ALT (high altitude) warning



Appendix A: Aircraft Checklists (continued)

Emergency Descent after Pressurization Failure

Emergency descent	Announce
Thrust Levers	Flight idle
Target speed	Announce - M_{MO}/V_{MO} or 0.6 M/240 kt
	If structural integrity in doubt, do not exceed 0.6 M/240 kt and limit "g".
Airbrake	OUT
Oxygen masks	Confirm donned and crew communications established.
Establish flight at 10 000 ft or the lowest safe altitude if higher	

CONT IGN A and B ON
 Transponder As required

When at higher of; 10 000 ft or lowest safe altitude:

Flight deck crew oxygen Set mask regulators to N (pull down) to conserve oxygen
 Keep masks on until at or below 10 000 ft cabin altitude
 RAM AIR VALVE When Δp is less than 1 psi, OPEN
 CONT IGN As required

Figure No. A3: Abnormal and Emergency checklist for Emergency Descent

Smoke, Fumes or Fire
on the Flight Deck, in the Cabin or in the Electrical Equipment Bay

ELECT SMOKE

 May be lit

Oxygen masks and goggles	Flight crew don, check 100%
	Select EMERGENCY if necessary to keep fumes out of mask
Crew communications	Establish
If condition occurs on changeover between ENG AIR and APU AIR, revert to original air source.	

Land as soon as possible

Do not assume the fire is extinguished if smoke disappears or the ELECT SMOKE caption goes out

Instrument lights	Full bright
PANEL FLOOD lights	CTORM
EFIS	Full BRT
FLT DECK EMERG LTS	ON
GALLEY switch	SHED
CABIN EMERG lights	ON
NO SMKG	ON
FASTEN BELTS	ON
Cabin attendant's panel	Unnecessary lights off Pull all CBs
Flight deck door (if fitted)	Close
CABIN AIR	FRESH

Aircraft at or above 8 000 ft.
 PRESSURIZATION MAN MODE
 Then set MAN RATE to max UP until CAB ALT 8 000 ft; then set zero rate

Only if time permits:

- If air conditioning is the source of smoke or fumes, switch OFF one PACK at a time to establish and isolate the source.
- If the source is electrical and can be identified, electrically isolate relevant equipment.

When aircraft below 8 000 ft.

PACKS	OFF
RAM AIR	OPEN
OUTFLOW VALVES	DUMP

Figure No. A4: Abnormal and Emergency checklist for Smoke Fumes or Fire

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Appendix B: Extract from AMM 21-51-14

C. Install non-return valve

- (1) Remove blanks from ram air valve (41), rear duct (48) and duct (44).
- (2) Insert non-return valve (45) in duct (44), making certain spindle of valve is positioned vertically and valve flaps operate in direction of airflow.
- (3) Position duct (44), complete with non-return valve (45) and two new O-ring seals (43) and (46), between rear duct (48) and ram air valve (41). Secure duct (44) to rear duct (48) using clamp (47). Torque tighten clamp to 70 lbf.in. (0.79 mdm).
- (4) Secure duct (44) to ram air valve (41) using clamp (42). Torque tighten clamp to 70 lbf.in. (0.79 mdm).
- (5) If removed for access, install flight data recorder (Ref.AMM 31-31-27, page block 201) and/or cockpit voice recorder (Ref.AMM 23-71-24, page block 201).
- (6) Remove safety clips and tags and close circuit breakers --

PANEL	LABEL/SERVICE	GRID REF/IDENT
131-11-00	RAM AIR CTRL	M11
211-50-30	PACK 1 VALVE	E29
211-50-30	PACK 2 VALVE	E30

- (7) Remove warning notice from flight deck.

D. Test

- (1) No test required.

E. Close up

- (1) In rear cargo compartment, install access panels 181HL and 182HR (Ref.AMM 25-50-21, page block 201).

WARNING : MAKE CERTAIN THE WEIGHT OF THE CARGO COMPARTMENT DOOR(S) IS SUPPORTED WHEN THE RELEASE PLUNGER IS PRESSED AND UNLATCHED TO CLOSE.

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(2) Close and secure rear cargo compartment door (81B).

(3) Make certain work area is clean, and clear of tools and miscellaneous equipment.

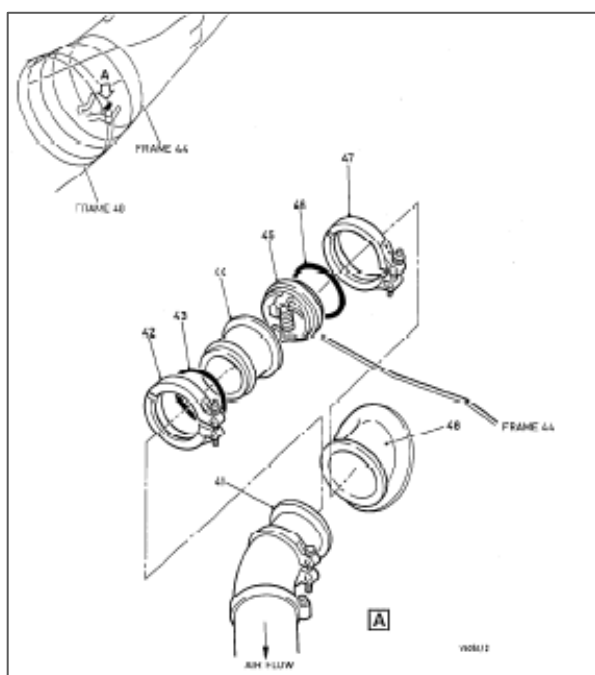


Figure No. B1: Extract from AMM 21-51-14 Ram Air NRV Installation Procedure



Appendix C: Acceptable Means of Compliance (AMC) as contained in Annex 1 to ED Decision 2012/020/R (Issue 2, 30 October 2012)

AMC 21.A.3B(b) Unsafe condition

An unsafe condition exists if there is factual evidence (from service experience, analysis or tests) that:

- (a) An event may occur that would result in fatalities, usually with the loss of the aircraft, or reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be:
 - (i) A large reduction in safety margins or functional capabilities, or*
 - (ii) Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely, or*
 - (iii) Serious or fatal injury to one or more occupants**

unless it is shown that the probability of such an event is within the limit defined by the applicable certification specifications, or

- (b) There is an unacceptable risk of serious or fatal injury to persons other than occupants, or*
- (c) Design features intended to minimise the effects of survivable accidents are not performing their intended function.*

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Note 1: Non-compliance with applicable certification specifications is generally considered as an unsafe condition, unless it is shown that possible events resulting from this non-compliance do not constitute an unsafe condition as defined under paragraphs (a), (b) and (c).

Note 2: An unsafe condition may exist even though applicable airworthiness requirements are complied with.

Note 3: The above definition covers the majority of cases where the Agency considers there is an unsafe condition. There may be other cases where overriding safety considerations may lead the Agency to issue an airworthiness directive.

Note 4: There may be cases where events can be considered as an unsafe condition if they occur too frequently (significantly beyond the applicable safety objectives) and could eventually lead to consequences listed in paragraph (a) in specific operating environments. Although having less severe immediate consequences than those listed in paragraph (a), the referenced events may reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew workload, or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries.

- END -

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

Produced by the Air Accident Investigation Unit

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