# Executive Summary
# BR702 Occurrence Investigation

On March 25, 2012, at 1044 Taipei local time[1], a Boeing B747-400 airplane, registration number B-16411, operated by EVA Airways Corporation performing a scheduled passenger flight BR702 took off from Taoyuan International Airport (elevation 106 ft) for Shanghai Pudong Airport. During climb it encountered a left outflow valve malfunction and abnormal cabin altitude. At 1054, around 47 nautical miles north-east of Taoyuan Airport with altitude of 20,800 ft, the aircraft had the “CABIN ALTITUDE” aural warning. Pilots donned the oxygen masks, performed emergency descent and declared emergency (Mayday) to the ATC. The aircraft returned to Taoyuan International Airport at 1128 without further incidents. The aircraft had 2 pilots, 14 cabin crew members and 367 passengers, total 383 people on board without injuries. The aircraft had no damage.

The Flight Data Recorder (FDR) showed that during the takeoff roll both left and right outflow valves started to close from 0.9% and 0.8% positions respectively and at 1045:14 the left outflow valve closed to 64.9% with the altitude 698 ft. The FDR records the position of the outflow valve in percent, however each percent is equal to one degree, such that the nominal full open position of the outflow valve is 0 degrees (recorded as 0%) and the nominal full closed position is 102 degrees (recorded as 102%). Afterwards the left outflow valve remained at that position until the cabin altitude warning came up. At 1047:57 the right outflow valve closed to the position of 102.1% with altitude 4,603 ft, and remained at that position until the cabin altitude warning came up.

[1] Taipei local time is UTC time + 8 hours.

The Cockpit Voice Recorder (CVR) transcripts showed that at 1052:44 the ATC gave the clearance to climb up to Flight Level (FL) 370 and at 1053:59 the flight crew started conversation about “outflow valve”. They decided to level the altitude first and requested the ATC for FL200 at 1054:08. After the ATC’s approval and aircraft leveling, then the captain called out “outflow valve left checklist” at 1054:30. The cabin altitude aural warning sounded in the cockpit at 1054:41. The captain called out “emergency descent” at 1054:51, and declared emergency to the ATC requesting for descend to 10,000 ft at 1054:59. The ATC gave the clearance of descending to 8,000 ft at 1055:03.

The FDR data showed that the left outflow valve might start to close at the at 1054:40 with position of 64.9% and at 1054:54 valve reaching to position 102.1% and then remained unchanged until landing. The right outflow valve started opening from the position of 102.1% at 1054:47 and reached 82.5% at 1054:51.

The flight crew stated during the interview that when taking off on that day the first officer was the Pilot Flying (PF) and the captain was the Pilot Monitoring (PM). After takeoff there was no anomaly in cockpit. When the aircraft reached altitude about 20,000 ft, the cabin pressure data popped up on the UPPER EICAS with cabin altitude around 6,000 to 7,000 ft display in white and continuing going up. With checking the ECS Synoptic page on the LOWER EICAS, the right outflow valve was already fully closed while the left outflow valve stopped at 9 o’clock position. On the UPPER EICAS, the cabin altitude display soon turned into amber with the cabin altitude at 8,600 ft and rate about 1,200 fpm.

Soon afterwards the “OUTFLOW VLV L” message popped up on the UPPER EICAS without a caution or warning sound at that time. According to the manufacturer, the OUTFLOW VLV L advisory message is designed to pop up within a few seconds of the failure of the left outflow valve. The status message is designed to pop up approximately 10 seconds after the advisory message. The 747-400 EICAS system does not provide aural alerts for advisory or status messages. The recorded data indicates that the left outflow valve failure occurred at approximately 1045 when the cabin altitude was 698 ft. The flight crew statements and CVR data indicate the flight crew did not recognize cabin pressure control system abnormal and did not talk the message until the cabin altitude was at 8,600 ft. After recognizing the cabin altitude abnormal and the OUTFLOW VLV L message, captain decided leveling first and requested the ATC for leveling to 20,000 ft. After aircraft leveling, while the pilots performed the OUTFLOW VLV L procedure according to the Quick Reference Handbook (QRH), the cabin altitude continued rising over 10,000 ft and the cabin altitude warning sounded in cockpit. The captain immediately called out “emergency descent” and declared “Mayday” to request the ATC for immediate descent to 10,000 ft. Subsequently, the captain took over to act as PF, pilots donned oxygen masks, performed the emergency descent procedure and manually deployed passenger oxygen masks. Just before emergency descent, the first officer was doing the OUTFLOW VLV L procedure and already started to close the left outflow valve manually.

At 1101:06, the aircraft descended and leveled at 8,000 ft. After confirming the cabin altitude back to normal, the flight crew took off the oxygen masks. The flight crew decided and performed an air turn back after consulting with company. With radar vector by the ATC the aircraft

landed at Runway 05R at Taoyuan International Airport at 1127:40.

During troubleshooting the EVA Airways found the AC motor of left outflow valve failed. The aircraft was back to service after replacing the AC motor. The investigation team sent the AC motor to manufacturer for teardown and analysis. On the Failure Analysis Report provided by the manufacturer, the failure is rotor shaft/brake interface breakdown and brake release air gap growth. Manufacturer summarized that the defects seen on the unit are similar to other field returns. The manufacturer can only speculate on the causes as they appear to be from the motor brake not disengaging properly, possibly from an incorrect voltage at the AC motor. Root cause determination activities are on-going at Boeing and the system supplier. They will continue to work together towards a solution.

According to Article 6 of the ROC Aviation Occurrence Investigation Act, and the content of Annex 13 to the Convention on International Civil Aviation (Chicago Convention), which is administered by the International Civil Aviation Organization (ICAO), the Aviation Safety Council (ASC), an independent agency of the ROC government responsible for civil aviation occurrences investigation, immediately launched a team to conduct the investigation. The investigation team also included members from operator, EVA Airways, Civil Aeronautics Administration Taiwan and the state of manufacture, represented by USA NTSB.

After initial data collection, the Safety Council released a Preliminary Report on April 20, 2012. About 4 months of factual data collection, the

Safety Council finished and released the Factual Data Report. The analysis portion of the investigation was completed in early November, 2012. A Draft Final Report in Chinese was finished at the end of November, 2012 and sent to the EVA Airways, Civil Aeronautics Administration Taiwan and NTSB for their comments. The Safety Council also prepared a courtesy translation in English of draft Executive Summary to NTSB for better communications. After receiving and reviewing the comments, the Safety Council completed its investigation report, which was approved by the Safety Council Members on 26 February, 2013, at the 8th Council Meeting.

## Findings as the result of this investigation

The Safety Council presents the findings derived from the factual information gathered during the investigation and the analysis of the occurrence. The findings are presented in three categories: **findings related to the probable causes**, **findings related to risk**, and **other findings**.

**The findings related to the probable causes** identify elements that have been shown to have operated in the occurrence, or almost certainly operated in the occurrence. These findings are associated with unsafe acts, unsafe conditions, or safety deficiencies that are associated with safety significant events that played a major role in the circumstances leading to the occurrence.

**The findings related to risk** identify elements of risk that have the potential to degrade aviation safety. Some of the findings in this category identify unsafe acts, unsafe conditions, and safety deficiencies that made this occurrence more likely; however, they cannot be clearly

shown to have operated in the occurrence. They also identify risks that increase the possibility of property damage and personnel injury and death. Further, some of the findings in this category identify risks that are unrelated to the occurrence, but nonetheless were safety deficiencies that may warrant future safety actions.

**Other findings** identify elements that have the potential to enhance aviation safety, resolve an issue of controversy, or clarify an issue of unresolved ambiguity. Some of these findings are of general interest and are not necessarily analytical, but they are often included in ICAO format accident reports for informational, and safety awareness, education, and improvement purposes.

## Findings Related to Probable Causes

1. During initial climb, the Cabin Pressure Control System's left outflow valve failed such that the valve was stuck in the 64.9% position while under automatic control. The left outflow valve was found to have failures in the AC motor interface between the rotor shaft and the brake shaft, and to have growth of the air gap in the brake at a level that prevented the brake from releasing when commanded. The 64.9% position of the left outflow valve and full closed position of the right outflow valve resulted in cabin air leakage beyond expected climb and cruise levels. The position of the left outflow valve prevented the aircraft from pressurizing normally and resulted in the high cabin altitude conditions that occurred on this aircraft.
2. The data show that the flight crew might not notice the left outflow valve failure and EICAS fault message until the aircraft reached the altitude 20,000 ft, approximately 9 minutes after the valve failure.

This resulted that the flight crew were unable to start and complete the OUTFLOW VLV L checklist and manually close the left outflow valve in a timely manner. During climb, the continuously leaking of cabin pressure led to the cabin altitude reaching the point of cabin altitude warning.

3. When performing the QRH “OUTFLOW VLV L” procedure, the first officer closed the left outflow valve with manual mode, the cabin altitude warning came up almost at the same time. While the left outflow valve was gradually closing and the cabin altitude was recovering, the flight crew did not notice the cabin altitude being controllable. The captain decided to perform emergency descent for safety reasons, don the oxygen mask and release passenger emergency oxygen mask. Had the flight crew completed the checklist prior to initiating the emergency descent, they would have been aware that the cabin was controllable.

## Findings Related to Risk

1. The defects seen on the outflow valve AC motor are similar to other field returns. The manufacturer can only speculate on the causes as they appear to be from the motor brake not disengaging properly, possibly from an incorrect voltage at the AC motor. Root cause determination activities are on-going at Boeing and the system supplier.
2. Regarding the non-normal procedures for cabin altitude or rapid depressurization, there exists inconsistent QRH procedure between Boeing B747-400 cargo aircraft and passenger aircraft. For the item 3, in addition to the “Verify packs are on and outflow valve are closed”, the QRH of cargo aircraft contains “Check the cabin

altitude and rate", but it is not covered in the QRH of passenger aircraft. The Airplane Flight Manual (AFM) also suggests this non-normal procedure should include this item "Check the cabin altitude and rate". The QRH of passenger aircraft without this item is not consistent with the AFM suggestion and also not like the cargo QRH such coherent for pilots to perform the next step, to determine "If the cabin altitude is uncontrollable".

**Other Findings**

1. The certificates of flight crew were in accordance with Civil Aviation Regulations.
2. There was no evidence to show that the flight crew was affected by any alcohol or medication during that flight.
3. When the left outflow valve failed at 1045, after very a short delay the EICAS should show the "OUTFLOW VLV L" Advisory message and Status message, which were not affected by take-off inhibit. Until the pilot had call-out of "outflow valve left checklist" at 1054:30, the fault stayed active constantly after time 1045.
4. The flight crew statements on the timing and sequence of display the "OUTFLOW VLV L" message and cabin pressure data are not consistent with the design of the cabin pressurization system, design of the EICAS system or the, FDR data and on-board computer's maintenance records. Testing and simulation of the 747-400 has previously shown that the "OUTFLOW VLV L" message will show on EICAS display shortly after pushing the manual mode control switch "MAN L" or simulating the left outflow valve failure.
5. According to the analysis of layout in cockpit, the location of the relevant message display and the flight crew's operation and

interaction, the pilots were supposed to notice the “OUTFLOW VLV L” Advisory message when it showed on EICAS display during climb; however there was no other objective evidence to support the flight crew’s statement during the interview that “OUTFLOW VLV L” Advisory message did not come up until they found the cabin altitude abnormal at the altitude about 20,000 ft.

6. The noisy recording of CVR cockpit area microphone was caused by the bad grounding between the control panel and the cockpit area microphone.

7. After the occurrence EVA Airways has incorporated the proper section of aircraft maintenance manual to CVR annual inspection job card 2031FC for maintenance personnel’s reference when performing annual CVR test.

8. Regarding the aircraft declared emergency, the work load for pilots may become lighter when controllers provide radar vector instead of an instruction for the aircraft to a waypoint.

9. In this case with the left outflow valve failed at 64.9% in auto mode, at the time when the pilots found cabin altitude abnormal (just higher than 8,500 ft) the valve might be manually closed to full position in time before the cabin altitude reached 10,000 ft .

## Safety Recommendations

Safety recommendations derived as the result of this investigation are listed. Safety actions that have been accomplished, or are currently being planned by the stakeholders as the result of the investigation process are listed right after the recommendations. It should be noted that the Safety Council has not verified the safety actions.

**To EVA Airways**

Reinforce flight crew‘s awareness and understanding of cabin altitude anomaly and cabin pressure control, reinforce the training of relevant operation and procedures. (ASC-ASR-13-03-001)

**To Civil Aeronautics Administration, Ministry of Transportation and Communications**

Require EVA Airways to reinforce flight crew‘s awareness and understanding of cabin altitude anomaly and cabin pressure control, reinforce the training of relevant operation and procedures. (ASC-ASR-13-03-002)

## Safety Actions Taken or Being Planned

**According to the EVA Airways**

1. The safety actions to enhance the flight crew‘s awareness, knowledge and procedures for cabin pressure control and cabin depressurization have been posted on the “What can we learn” section on the website dedicated to EVA flight crew as of May 27th, 2012, as well as in the self-learning material about the cabin pressurization system. EVA’s regular annual proficiency training and proficiency check (PT2 and PC2) also include this occurrence as a case study in the EBT (Evidence Based Training). All relevant knowledge and procedures of cabin pressure control system become key points to related training and oral test.

2. Using EVA’s 744 flight crew for instance, 179 people out of 221 (81%) have completed the training and check mentioned above as of January 15th, 2013; and more than 80% of completion rate are observed in other fleet types. EVA expects to fully complete this

training and check by April, 2013.

**According to the Civil Aeronautics Administration, Ministry of Transportation and Communications**

1. Just after the occurrence, CAA sent inspectors to simulate this event with the Operator's 747-400 simulator. The simulation flights were operated by the Operator's 747-400 Chief Pilot. The result of simulation indicated that the emergency descent could be avoided if flight crew had applied QRH procedure correctly. To improve pilots' reaction to loss of cabin pressurization, CAA reviewed the Operator's training syllabus and found most training of the "EMERGENCY DESCENT" composed of the scenario "RAPID DECOMPRESSION". This would make common connection between the "DECOMPRESSION" and "EMERGENCY DESCENT". CAA required the Operator to review and adjust relevant training syllabus and scenario to enhance pilots' situation awareness and operation procedure of both "RAPID DECOMPRESSION" and "SLOW DECOMPRESSION".

2. Regarding the aircraft declared emergency, the work load for pilots may become lighter when controllers provide radar vector instead of an instruction for the aircraft to a waypoint.

On October 19, 2012, Air Navigation & Weather Services, CAA, issued a special notice to the Air Traffic Control units about the guidance to assist the flight crew who request for radar vector under the emergency situation. In the text it described that providing an instruction to a waypoint and radar vector would give different workloads to pilots, the ATC shall coordinate to provide radar vector as the greatest assistance instead of giving instruction to a waypoint. This notice of how to assist aircraft which encounter

emergency situation would be incorporated into the regular shift-handover notices and the advanced ATC simulator training course.

**According to the Boeing Commercial Airplane Company**

Regarding the non-normal procedures for cabin altitude or rapid depressurization, there exists inconsistent QRH procedure between Boeing B747-400 cargo aircraft and passenger aircraft. For the item 3, in addition to the “Verify packs are on and outflow valve are closed”, the QRH of cargo aircraft contains “Check the cabin altitude and rate”, but it is not covered in the QRH of passenger aircraft. The Airplane Flight Manual (AFM) also suggests this non-normal procedure should include this item “Check the cabin altitude and rate”. The QRH of passenger aircraft without this item is not consistent with the AFM suggestion and also not like the cargo QRH such coherent for pilots to perform the next step, to determine “If the cabin altitude is uncontrollable”. The Safety Council asked the Boeing Company about above issue via NTSB’s assistance. The Boeing Company responded it as follows,

The FCOM procedures for the 747-400 Passenger and 747-400 Freighter will be standardized by adding the Check cabin altitude rate step to the 747-400 passenger checklist. This change is planned to be published in the April 2013 revision. However, Boeing does not believe that this change would have affected the EVA 747-400 event.