Republic of the Philippines
CIVIL AVIATION AUTHORITY OF THE PHILIPPINES

AIRCRAFT ACCIDENT INVESTIGATION AND INQUIRY BOARD

FINAL REPORT

HL7525
AIRBUS A330-322

OPERATOR: KOREAN AIR LINES CO., LTD.

TYPE OF OPERATION: SCHEDULED COMMERCIAL OPERATION

DATE OF OCCURRENCE: OCTOBER 23, 2022

PLACE OF OCCURRENCE: MACTAN-CEBU INTERNATIONAL AIRPORT, LAPU-LAPU CITY, CEBU, PHILIPPINES

AAIIB-2025-046

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FOREWORD

This report was produced by the Aircraft Accident Investigation and Inquiry Board (AAIIB), Civil Aviation Authority of the Philippines, MIA Road, Pasay City, Philippines.

The report is based upon the investigation carried out by the AAIIB in accordance with Annex 13 to the Convention on International Civil Aviation, Republic Act 9497 Section 42, and Philippine Civil Aviation Regulation Part 13.

Readers are advised that the AAIIB investigates for the sole purpose of enhancing aviation safety. Consequently, AAIIB reports are confined to matters of safety significance and may be misleading if used for any other purpose. It should be noted that the information in AAIIB reports and recommendations is provided to promote aviation safety, and in no case is it intended to imply blame or liability.

Furthermore, no part of the AAIIB report or reports relating to any accident or investigation shall be admitted as evidence or used in any suit or action for damages arising out of any matter mentioned in such report or reports.

FINAL REPORT

TITLE: Accident involving an Airbus 330-322 type of aircraft with Registry Number HL7525 that experienced runway overrun during landing roll at Runway (RWY) 22 of Mactan-Cebu International Airport (RPVM), Lapu-lapu City, Cebu, Philippines on October 23, 2022, 2310H local time (1510 UTC).

Notification of Occurrence to National Authority

The Notification of accident to AAIIB CAAP was relayed to the OIC, AAIIB through the Operation Center-CAAP at 2345H on October 23, 2022.

Identification of the Investigation Authority

The Aircraft Accident Investigation and Inquiry Board (AAIIB), the mandated accident investigation organization within the Civil Aviation Authority of the Philippines (CAAP) as the state of Occurrence is conducting the investigation.

Organization of the Investigation

In accordance with provisions of ICAO Annex 13, AAIIB-CAAP had conducted a full investigation of the accident and appointed the Investigator-in-Charge being the state of occurrence. Moreover, the following states had appointed accredited representatives: Bureau d'Enquêtes et d' Analyses (BEA), France, being the state of aircraft manufacturer, Aviation and Railway Accident Investigation Board (ARAIB), Republic of Korea, being the State of Aircraft Operator and State of Registry. In addition, the Air Accidents Investigation Branch (AAIB), United Kingdom; Swiss Transportation Safety Investigation Board (STSB), Switzerland; and National Transportation Safety Board (NTSB), United States of America, had also appointed representatives because they were involved in some aircraft parts examinations.

Authority Releasing the Report

The Final investigation report was released by Aircraft Accident Investigation and Inquiry Board (AAIIB) and published at the CAAP website on ____________________.

Synopsis:

On or about 2310H local time (1510 UTC), October 23, 2022, an Airbus A330-322 type of aircraft with Registry Number HL7525, operated by Korean Air, experienced a runway overrun during the landing roll at Runway (RWY) 22 of Mactan-Cebu International Airport (RPVM), Lapu-lapu City, Cebu, Philippines. One (1) flight crew member, four (4) cabin crew members, and fifteen (15) passengers sustained minor injuries. Instrument Meteorological Conditions (IMC) prevailed at the time of the accident. The flight took off from Incheon International Airport (RKSI), Incheon, Korea. The Aircraft Accident Investigation and Inquiry Board determined that the cause factors of this accident were attributed to the increase of VSI attributed to the forward pitch control from the captain that resulted in the ground contact before the runway, the increase in vertical wind factor during the aircraft's descent on the second approach, and the right-hand MLG hitting a 15-centimeter step of the cemented edge of RWY 22, resulting in multiple damage/faults to the said landing gear and consequently the loss of most of the deceleration means, specifically aircraft braking failure resulting in runway overrun.

LIST OF ACRONYMS AND ABBREVIATIONS

A/C - Aircraft
ACARS - ARINC Communication Addressing and Reporting System
ARAIB - Aviation and Railway Accident Investigation Board of Korea
ATIS - Automatic Terminal Information Service
AMM - Aircraft Maintenance Manual
ASV - Automatic selector valve
BEA - Bureau d’Enquêtes et d’Analyses
BDDV - Brake Dual Distribution Valve
BSCU - Braking & Steering Control Unit
CAAP - Civil Aviation Authority of the Philippines
CAS - Calibrated Air Speed
CB - Cumulonimbus
CL - Centerline Lights
CMC - Central Maintenance Computer
CVR - Cockpit Voice Recorder
DAR - Digital Access Recorder
(D)FDR - (Digital) Flight Data Recorder
ECAM - Electronic Centralized Aircraft Monitoring
EDP - Engine Driven Pump
EEC - Electronic Engine Control
EIVMU - Engine Interface and Vibration Monitoring Unit
FCDC - Flight Control Data Concentrator
FCPC - Flight Control Primary Computer
FCOM - Flight Crew Operating Manual
FCTM - Flight Crew Techniques Manual
FBS - Full Back Stick
FDR - Flight Data Recorder
FIN - Functional Item Number
G/A - Go Around
GS - Ground Speed
HQ - Handling Quality
HSMU - Hydraulic System Monitoring Unit
ILS - Instrument Landing System
IMC - Instrument Meteorological Condition
KAL - Korean Air Lines
LAL - Lower Articulation Link
LGCIU - Landing Gear Control Interface Unit
LH - Left Hand
LOC - Instrument landing system Localizer
LP - Low Pressure
MCC - Maintenance Control Center
MCT - Max Continuous Thrust
MLG/ L/G - Main Landing Gear/ Landing Gear
MPD - Maintenance Planning Document
NLG - Nose Landing Gear
NRV - Non-Return Valve
NTSB - National Transport Safety Board
NVM - Non-Volatile Memory
OCC - Operational Control Center
OEM - Originated Equipment Manufacturer
OLD - Operating Landing Distance
PAPI - Precision Approach Path Indicator
PCAR - Philippine Civil Aviation Regulation
PM / PF - Pilot Monitoring / Pilot Flying
P/N - Part Number
PBOV - Park Brake Operated Valve
PBSEL V - Park Brake Selector Valve
PRV - Pressure Release Valve
PSIA - Pounds per square inch Absolute
PT - Pitch Trimmer
QRH - Quick Reference Handbook
RA - Radio Altitude
REF - Reference
REIL - Runway End Identifier Lights
RH - Right Hand
RL - Runway (edge) Lights
RPVM - ICAO Designation for Mactan-Cebu International Airport
RWY - Runway
S/N - Serial Number
SALS - Short Approach Light System
SLS - Safran Landing Systems
SFCC - Slats/Flaps Control Computer
SOP - Standard Operating Procedures
T/D - Touchdown
TPIS - Tire Pressure Indicating System
T/R - Thrust Reverser (s)
TRK /FPA - Track / Flight Path Angle
TSD - Troubleshooting Data
UTC - Universal Time Coordinated
WOW - Weight on Wheel

1. FACTUAL INFORMATION

Aircraft Registration No.	:	HL7525
Aircraft Type/Model	:	Airbus A330-322
Operator	:	Korean Air Lines Co., Ltd.
Address of Operator	:	260, Haneul-Gil, Gangseo-Gu, Seoul, Korea
Place of Occurrence	:	Mactan-Cebu International Airport, Lapu-Lapu City, Cebu, Philippines
Date/Time of Occurrence	:	October 23, 2022 at about 2310H/1510UTC
Type of Operation	:	Scheduled Commercial Operation
Phase of Flight	:	Landing
Type of Occurrence	:	Aircraft Overrun due to Loss of Braking

1.1 History of Flight

On or about 2310H local time (1510 UTC), October 23, 2022, an Airbus 330-322 type of aircraft with registry number HL7525 experienced a runway overrun during landing roll at Runway (RWY) 22 of Mactan-Cebu International Airport (RPVM), Lapu-lapu City, Cebu, Philippines.

The aircraft is being operated by Korean Air. One (1) flight crew member, four (4) cabin crew members, and fifteen (15) passengers sustained minor injuries. The aircraft sustained damage and was subsequently destroyed.

Instrument Meteorological Conditions (IMC) prevailed at the time of the accident. The flight took off from Incheon International Airport (RKSI), Incheon, Korea.

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The captain was the pilot flying (PF) when the accident happened. There was a change of runway in use from RWY 04 to RWY 22 as the variable winds shifted direction favorable to RWY 22 during the first approach for landing. While on approach for landing, after descending below the minima, during the interview, the crew encountered heavy rain and elected to go around as they lost runway visibility.

A second (2nd) approach was flown, and a second (2nd) go-around at 14:26:23 UTC was performed due to a sudden increase of vertical speed followed by an aural warning "Sink rate." While initiating the go-around, the aircraft landing gears contacted the ground. An Electronic Centralized Aircraft Monitor (ECAM) message was noted by the crew indicating a landing gear control interface unit (LGCIU) 1 and 2 fault. After reporting the go-around to the air traffic controller (ATC), the crew requested to hold over reporting point ALMAR and performed ECAM actions. While performing ECAM action on the LGCIU 1 and 2 fault, an ECAM message of BRAKES ANTI SKID FAULT was noticed. These two (2) messages were displayed to the flight crew only at 1,500 ft RA (as inhibited below), i.e., 32 seconds after the touchdown, and a third (3rd) approach for landing was decided.

While initiating the third (3rd) approach for landing, the crew performed a normal landing gear down procedure in accordance with ECAM actions for LGCIU 1 and 2 faults at 14:44.29 UTC. However, the right main landing gear down-lock indicator was not illuminating on the L/G indicator panel. The crew requested from ATC to cancel the approach clearance and requested again hold over reporting point ALMAR at 14:45.30 UTC to resolve the technical issue. After the crew carried out the QRH procedure for landing with abnormal landing gear, an indication of the HYD B RSVR LO LVL message was displayed. The crew then performed another ECAM action. The flight then continued its approach to RPVM.
During landing on the fourth (4th) approach, the aircraft failed to stop and overran the end of the runway. After colliding with the localizer antenna and runway approach lighting system, the aircraft came to a complete stop at the grassy portion about 235 meters from the end of runway 22 at coordinates 10°17'41.8" N 123°57'59.9" E with a final heading of 245° (Figure 1).

The passengers evacuated utilizing the L2 and R2 cabin door slide rafts. The crew and passengers were ferried to the airport terminal by shuttle buses. Mactan Cebu International Airport Authority (MCIAA) Rescue and Firefighting Services immediately responded to help secure the aircraft. There was no fire ensued after the accident.

Figure 1 - The aircraft at its final resting point.

1.2 Injuries to Person (s)

Injuries	Crew	Passengers	Others	TOTAL
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	5	15	0	20

1.3 Damage to Aircraft

The aircraft sustained damage and was subsequently destroyed.

1.4 Other Damages

1.4.1 Four (4) sets of Runway Approach Lights (Figure 2).
1.4.2 One (1) ILS Localizer Antenna (Figure 3).

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Figure 2 - RPVM RWY 04 Approach lights.

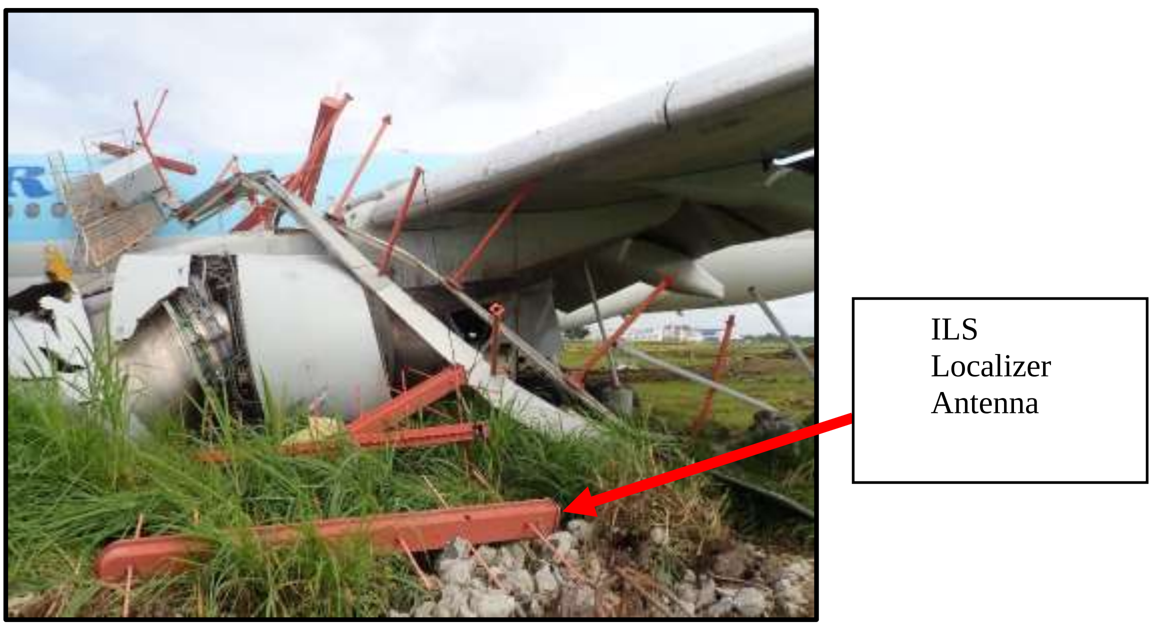

Figure 3 - RPVM RWY 22 Localizer antenna.

1.5 Personnel Information

1.5.1 Captain

Gender	:	Male
Date of Birth	:	10 October 1970
Nationality	:	Republic of Korea
License	:	ATP-11-003311

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Valid up to	:	Issued on 16 January 2008 (No Expiration Date)
Type rating	:	Airbus A330
Medical Certificate	:	301-02818 Issued on 09 November 2021 (Valid up to 30 November 2022)
Time on Aircraft	:	9,285 Hours
Grand Total time	:	13,043 Hours

Other Information:

Latest Recurrent Training: July 01, 2022
Latest SIM Training: July 04-05, 2022
Rest before last flight: 69 hours
Latest flight duty prior to the accident: October 20, 2022
Total flight time on the day of the accident: 5+05 hours
Total flight time in a week prior to the accident: 14+15 hours
Total flight time in a month prior to the accident: 37+57 hours
Total flight time in the past 3 months prior to the accident: 177+45 hours

1.5.2 First Officer (FO)

Gender	:	Male
Date of Birth	:	16 November 1984
Nationality	:	Republic of Korea
License	:	CP-12-009107
Valid up to	:	Issued on 17 December 2013 (No Expiry Date)
Type rating	:	Airbus A330
Medical Certificate	:	271-06930 Issued on 07 February 2022 (Valid up to 28 February 2023)
Time on Aircraft	:	1,035 Hours
Grand Total time	:	1,603 Hours

Other Information:

Latest Recurrent Training: August 17, 2022
Latest SIM Training: August 17-18, 2022
Rest before last flight: 48 hours
Latest flight duty prior to the accident: October 21, 2022
Total time on the day of accident: 5+05 hours
Total flight time in a week prior to the accident: 6+28 hours
Total flight time in a month prior to the accident: 25+52 hours
Total flight time in the past 3 months prior to the accident: 106+17 hours

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1.6 Aircraft Information

The Airbus A330 is a twin engine widebody aircraft developed and produced by Airbus Industry. The A330-322 registered HL7525 performed its maiden flight on 12 May 1998 in Toulouse, France and was delivered to Korean Air Co. Ltd., on 06 June 1998.

1.6.1 Aircraft Data

Registration Mark	:	HL7525
Manufacturer	:	Airbus
Country of Manufacturer	:	France
Type/Model	:	Airbus/ A330-322
Operator	:	Korean Airlines Co., Ltd.
Serial No.	:	MSN 219
Date of Manufacture	:	June 26, 1998
Certificate of Airworthiness Valid up to	:	AS05051issued on September 21, 2012 (Pursuant to Article 21 of Enforcement Regulation of Aviation Act. This certificate shall remain in effect until suspended, curtailed or restricted)
Certificate of Registration Valid up to	:	2013-013 issued on June 26, 1998 (No expiry date)
Category	:	Commercial Air Transport
Number of Air Crew	:	2
Time Since New	:	78,197 Flight Hours

1.6.2 Engine Data

Manufacturer	:	Pratt & Whitney	
Type	:	Turbine	
Model	:	PW4168	
Serial No.	:	P733539CN (1) / P733500CN (2)	
Date Last Installed	:	19 August 2021 (1) 07 May 2022 (2)	
Time Since New	:	63,863 (1)	67,905 (2)
Cycle Since New	:	23,413 (1)	21,535 (2)
Time Since Overhaul	:	13,562 (1)	1,061 (2)

1.7 Meteorological Information

The satellite image of the weather by PAGASA (Figure 4) and the weather report at the time of occurrence that was provided by Mactan tower were as follows:

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October 23, 2022 1300Z
Information N13:00
Direction of wind 320 degrees; Velocity of wind 3 knots; Prevailing visibility 8 kilometers; Clouds F018 CB B100; Temperature 27°C; Dew point 26°C; Altimeter setting (QNH) 1011 Millibars 29.85 inches Hg; Rem CB E, S, NW with OL.

October 23, 2022 1400Z
Information O14:00
Direction of wind 320 degrees; Velocity of wind 3 knots; Prevailing visibility 8 kilometers; Clouds F018 CB B100; Temperature 27°C; Dew point 26°C; Altimeter setting (QNH) 1012 Millibars 29.88 inches Hg; Rem CB W, SE-S with OL.

October 23, 2022 1500Z
Information P15:00
Direction of wind 320 degrees; Velocity of wind 3 knots; Prevailing visibility 7 kilometers; Clouds S018 CB 0010; Temperature 27°C; Dew point 25°C; Altimeter setting (QNH) 1021 Millibars 30.15 inches Hg; Rem CB CC, QCRA.

Additionally, meteorological satellite provided by Japan meteorological Agency (JMA), indicates that there was a severe weather distribution developing near RWY 22 around 14:26Z to 14:30Z on October 23, 2022. At 15:08Z of the final landing time, the weather condition improved.

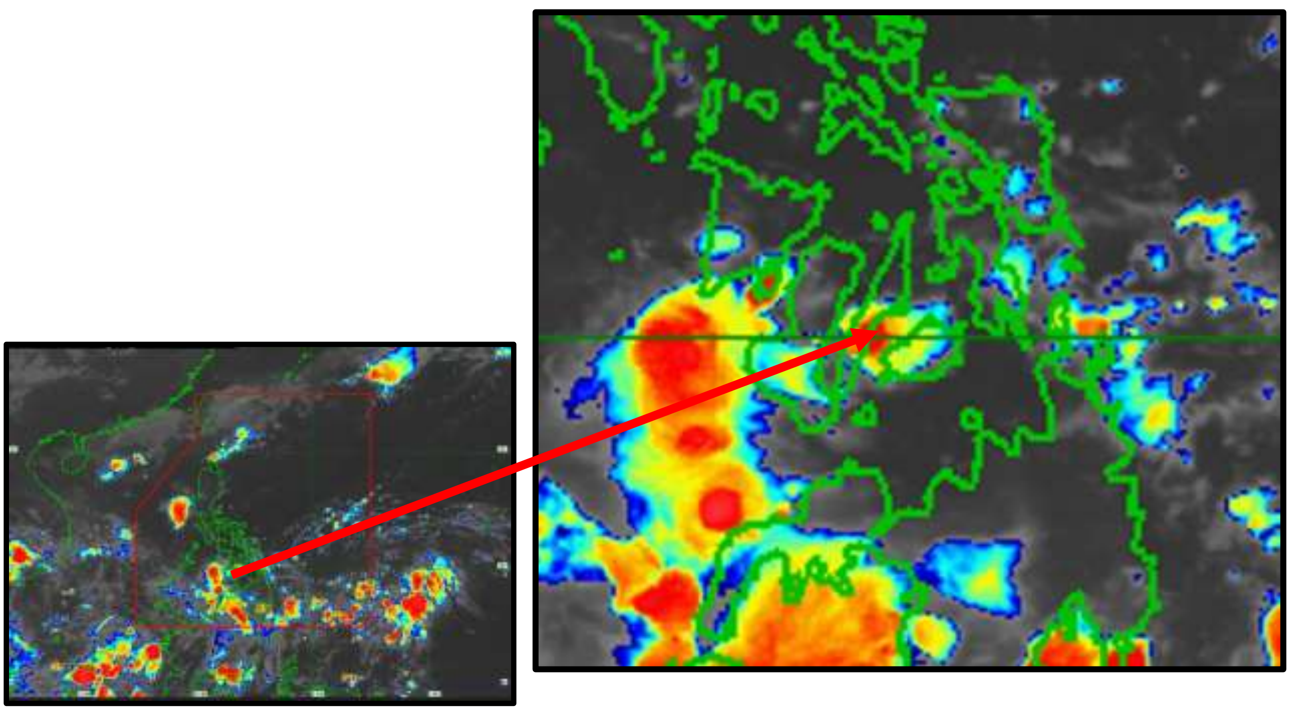

Figure 4 - PAGASA provided satellite image at RPVM.

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1.8 Aids to Navigation

At the time of the accident, the navigational aids—Doppler VHF Omni-Range/Distance Measuring Equipment (DVOR/DME)—were operational, albeit with an expired Flight Inspection Report Certificate (FIRC). A regular monthly ground check was performed, and enhanced daily monitoring of the equipment was conducted while awaiting the conduct of flight inspection.

On November 9, 2022, a flight inspection was conducted by the Flight Inspection Calibration Group (FICG) at Mactan DVOR/DME, and consequently, a FIRC was issued with operational status Usable (Unrestricted) valid until November 9, 2023. Mactan Cebu Instrument Landing System (ILS) was unserviceable with an active NOTAM prior to the accident. The Precision Approach Path Indicator (PAPI) and Aeronautical Ground Lighting (AGL) are operational.

1.9 Communications

Mactan Tower VHF communication radios were all functional. The communications between Air Traffic Services (ATS) and the crew were normal as recorded on ground-based automatic voice recording equipment and Cockpit Voice Recorder (CVR) for the duration of the flight. The quality of the recorded transmissions was good.

1.10 Aerodrome Information

1.10.1 General Information

Mactan-Cebu International Airport (IATA: CEB, ICAO: RPVM), is located in the City of Lapu-Lapu, a part of Metro Cebu and serves the Central Visayas region. The airport is managed by the Mactan–Cebu International Airport Authority (MCIAA). The airport features two terminals. Terminal 1, which was built in 1990, serves as the airport's domestic terminal. Terminal 2, which was constructed in 2018 and serves as the airport's international terminal.

Aerodrome Name	:	Mactan-Cebu International Airport – RPVM
ARP coordinates and site at AD	:	101827N; 1235845.9830E
Aerodrome Operator address, telephone, telefax,	:	Mactan-Cebu International Airport Authority Mactan-Cebu, International Airport, Lapu-lapu City 6016 +63 032 340-0226 Fax: +63 032 340-0228 SITA: NOPAPX
Types of traffic permitted	:	IFR-VFR

AD category for fire fighting Rescue Equipment	:	CAT IX. Has Trauma Van, Ambulance, 3 Fire Trucks, Individual Aluminized Protective Clothing, Fire Extinguishers, Self-Contained Breathing Apparatus, Power Saw, Stretchers, Fire Axe, Crow Bar, Bolt Cutter, 119 trained personnel.
Helicopter Landing Area Coordinates	:	Nil
ATS Communication Facilities	:	H24
Operational Frequencies	:	Tower 118.10Mhz Ground Control 121.80Mhz Approach Control 1: 124.70Mhz Approach Control 2: 121.20Mhz Domestic Ramp: 123.25Mhz Sub-ACC Control: 132.20Mhz ATIS: 126.60Mhz Clearance Delivery: 125.10Mhz FSS Radio: 5205Khz FOBS: 118.5Mhz
Airspace classification	:	A; ATZ-B; CTR-D; TMA and Sub TMA-D
Runway Direction	:	04/22
Runway Length	:	04/22 3310 Meters
Runway Width	:	04/22 45Meters
Surface	:	04/22 PCN 70 F/B/W/T CONC+ASPH

1.11 Flight Recorders

1.11.1 General

Both Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR) were removed from the aircraft by the CAAP-AAIIB. The recorders were brought to Bureau d'Enquêtes et d' Analyses (BEA), Paris, France for read-out and analysis.

1.11.2 Cockpit Voice Recorder (CVR)

Cockpit Voice Recorder (CVR)
Manufacturer: Honeywell
Part Number: S200-0012-00
Serial Number: 00455

The exterior of the CVR showed no evidence of structural damage. A direct download was performed using the official manufacturer DAPU box (Digital Audio Playback Unit). The readout was performed as a two-step process, as described in manufacturer procedure.

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First, the four (4) High Quality (HQ) channels were digitized while being replayed in real time using the official manufacturer lightweight equipment L3-Com DAPU. A second similar readout was performed with the DAPU to retrieve the audio data from two (2) Standard Quality (SQ) channels. The data obtained was derived from the read-out and analysis at BEA flight recorder laboratory.

The following CVR files were obtained:

- BEA2022-0513_HL7525_A200S_01_M24.wav (Captain, 30 minutes channel)
- BEA2022-0513_HL7525_A200S_02_M24.wav (First Officer, 30 minutes channel)
- BEA2022-0513_HL7525_A200S_03_M24.wav (3rd crew and passenger address, 30 minutes channel)
- BEA2022-0513_HL7525_A200S_04_M24.wav (Cockpit area microphone, 30 minutes channel)
- BEA2022-0513_HL7525_A200S_05_M24.wav (Mixed band, 2 hours channel)
- BEA2022-0513_HL7525_A200S_06_M24.wav (Cockpit area microphone, 2 hours channel)

A transcript was prepared starting from the time a system call out of “100” at 14:26:20 UTC up to the time it stopped recording.

At 14:26:21UTC, a call out of “sink rate” from the FO was heard. It was followed by “sink rate” from Ground Proximity Warning System (GPWS). At 14:26:23 UTC, a call out of “Go-Around” from the FO was also heard then a system call out of “40”. followed by a “sink rate” from GPWS. At 14:26:24 UTC, a response of “Go-Around” was heard from the captain. At 14:26:25 UTC, a system call out of “10” was heard followed by “Flaps One Step” from the FO.

At 14:26:26 UTC, Noise from the shocks of the Main Landing Gear (MLG) with the ground followed by “positive climb” from the FO was heard.

At 14:26:31UTC, “MAN TOGA SRS Go-Around Track and Gear Up” from the captain followed by a “Gear-Up” from the FO was heard. “Korean Air Six Three One Going Around from the FO was also heard at 14:26:39 UTC.

At 14:26:47 UTC, a transmission of “Six Three One, maintain four thousand, contact one two one decimal two” from ATC which was acknowledged by the FO.

At 14:28:24 UTC, the ATC asked the Pilot reason for going around, the captain said “un-stabilized”, which was repeated by the FO, which was acknowledged by the ATC.

At 14:29:37 UTC, while talking with the Operation Control Center, the captain was heard saying “Yes, we made a first Go-Around, because of un-stabilized, the second trial was rejected due to heavy rains and then during rejected landing, we hit the runway surface”.

At 14:30:59 UTC, the Captain said “ECAM Action” followed by the FO saying, “ECAM Action, Landing Gear LGCIU 1 and 2” a second later was heard.

At 14:31:11 UTC, the FO said “For landing gear extension, normal extension try, if unsuccessful landing gear gravity extension only for landing gear up”.

At 14:31:24 UTC, the captain was heard saying “I am worried about the brakes”.

At 14:31:38 UTC, a callout of “maximum brakes 1,000 PSI” by the FO was heard.

At 14:31:59 UTC to 14:32:01 UTC, the captain was heard giving instruction to the Purser to make a passenger announcement that they made a go- around.

At 14:32:15 UTC, “GPWS Terrain Detection Fault followed by GPWS Terrain Off” from the FO was heard.

At 14:32:24 UTC, the FO said “Status, then Maximum Brake Pressure, 1,000 PSI”

At 14:35:06 UTC, the captain while talking with the Maintenance Control Center (MCC) was heard saying “Yes we had Landing LGCIU 1 and 2 fault and NORMAL BRAKE Fault, ANTI-SKID Fault, and REVERSER Fault” at 14:35:15 UTC.

14:36:21 UTC, the captain while talking with the Operation Control Center (OCC) was heard saying “Yes we had Landing LGCIU 1 and 2 fault and normal brake anti-skid is not working neither reverser”.

At 14:40:55 UTC, the captain was heard saying “Did we hit inside the runway? Did we? In front? The FO replied “Yes maybe probably at the end area” at 14:41:00 UTC.

At 14:41:03 UTC, “It was not outside, was it?”, was heard from the captain. The FO replied “Yes”. Then the captain said “If it was so, it is okey”.

At 14:43:15 UTC, the ATC said “Korean Air Six Three One, turn left direct Victor Mike Two Two Alpha, descend Two Thousand Four Hundred Feet, you are cleared RWY 22.

At 14:43:44 UTC, the captain was heard saying “Gear Down”. It was followed by the FO saying “Gear Down”.

At 14:43:51 UTC, the captain said “It is not coming down” then the FO responded “Yes”.

At 14:44:49 UTC, the captain said “Where is the Landing Gear?” Followed by “Why is it not coming down”, five seconds later.

At 14:45:00 UTC, the captain said “Gear Down” and the FO responded “Gear Down”. It was followed by a comment from the captain “One side is not coming on”.

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At 14:45:25 UTC, the captain said “Request hold at Almar, then the FO acknowledge.

At 14:45:36 UTC, ATC was heard saying “Confirm you will hold over Almar”. Three seconds later, the FO said “Affirm mechanical problem Korean Air Six Three One”.

At 14:45:43 UTC, ATC was heard saying “Climb and hold ALMAR at four thousand”.

At 14:45:49 UTC, the captain said “Direct Almar”.

At 14:46:34 UTC, while the captain was talking with MCC, he was heard saying “We just made a landing gear gravity extension followed by Right Landing Gear indicated unsafe, there is no green light “, second later.

At 14:47:08 UTC, the captain said “It is not indicating down and lock”.

At 14:47:16 UTC, still talking with MCC, the captain said “Yes we made landing gear gravity extension but right-side main landing gear extension does not indicate triangle”.

At 14:53:46 UTC, the FO was heard reciting the landing with abnormal landing procedure.

At 14:54:49 UTC to 14:55:22 UTC, the captain was heard informing the Purser about the problem. As a coordination, a brace command by the captain will be given one-minute prior touchdown.

At 14:56:56 UTC, while talking with OCC, the captain was heard saying “We are going to make an emergency landing, right main landing gear is indicating unsafe”. It was acknowledged by OCC a second later.

At 14:57:18 UTC, the captain was heard saying “Tower, Korean Air Six Three One, Mayday (3x), landing gear unsafe, we are going to make an emergency landing approach, please prepare”.

At 14:58:05 UTC, ATC was heard saying “Korean Air six three one, if able you are cleared for RNAV Approach Runway two-two and wait to standby for weather at Mactan”.

At 15:00:07 UTC, “Hydraulic Bravo Reservoir Low Level, Blue Engine One Pump OFF” said the FO and the captain responded “Pump Off”.

At 15:00:23 UTC, the FO said “Anti-Skid Off”, and the captain responded “Anti-Skid Off”. Two seconds later, the FO said “Clear Hydraulic”, and the captain said “Clear Hydraulic”.

At 15:00:31 UTC, the FO said “Blue Engine One Pump Low Pressure, Clear Hydraulic”, and “Clear Hydraulic” was the response of the captain.

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At 15:03:19 UTC, the captain said “Ok take a look, after landing if the situation is not going well, take everything off”, and the FO replied “Ok”.

At 15:03:28 UTC, the FO was heard saying “At touchdown, all engine master switches off in sequence”.

At 15:04:28 UTC, the captain instructed the FO “Stop on the runway request”, and the FO was heard saying “Stop on the runway, request emergency equipment Korean Air six three one”.

At 15:05:02 UTC, ATC was heard saying “Korean Air six three one, Confirm declaring emergency”, and the FO replied “Affirm, Korean Air six three one”.

At 15:05:10 UTC, ATC said “request nature of emergency sir”, and the FO replied “landing gear unsafe, Korean Air six three one”.

At 15:05:39 UTC, the FO said “Blue Reservoir level Low”.

At 15:06:58 UTC, the captain said “After touchdown when the aircraft start to drift, shut the engines down” and the FO replied “Yes, Yes, Captain”.

At 15:07:39 UTC, sound similar to landing gear touchdown was heard.

At 15:07:59 UTC, the captain was heard saying “Is nosewheel steering working”, The FO replied “No, it is not”, two seconds later.

At 15:08:02 UTC, the captain said “It is not working stop on the runway”, the FO replied “Yes”.

At 15:08:05 UTC, the FO said “I will shut it down in sequence”, “Number One Off”, the PIC said “No do not shut it down (2x) “, at 15:08:10 UTC.

At 15:08:11 UTC, the captain said “Do not shut it” (5x).

At 15:08:23 UTC, the captain said “Speed is not reducing”.

At 15:08:37 UTC, Noise similar to runway excursion was heard.

At 15:08:44 UTC, the CVR transcript ended.

Note*: Conversation of the pilots were translated from Korean to English language after the read out of the CVR.*

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1.11.3 Flight Data Recorder (FDR)

Flight Data Recorder (FDR)
Manufacturer: Honeywell
Part Number: 980-4700-042
Serial Number: SSFDR-0760

The FDR was in good condition. The seal on the side was intact, and the seal under the recorder was cut at the level of the screw. A direct download was performed using the official Honeywell Manufacturer tool (Playback 32 software on the PATS II computer). The .dlu file was synchronized in the BEA analysis software. The synchronization level was good. The FDR contained 195,228 seconds of synchronized flight data (corresponding to approximately 54 hours), recorded at the rate of 128 wps, in RBS format (Teledyne synchronization). The data obtained was derived from the read-out and analysis at BEA flight recorder laboratory.

1.12 Wreckage and Impact Information

1.12.1 The aircraft exited RWY 22 to its final resting point.

The aircraft failed to stop and overran the end of the runway. The aircraft exited RWY 22 with traces of all the landing gears. The NLG collapsed after hitting the concrete base slab of the approach light, after which its RH NLG wheel was detached upon hitting another concrete stud. The aircraft collided with the ILS localizer antenna and another runway approach lighting system before the aircraft came to a complete stop at the grassy portion about 235 meters from the end of RWY 22 at coordinates 10°17’41.8” N 123°57’59.9” E with a final heading of 245° (Figure 5).

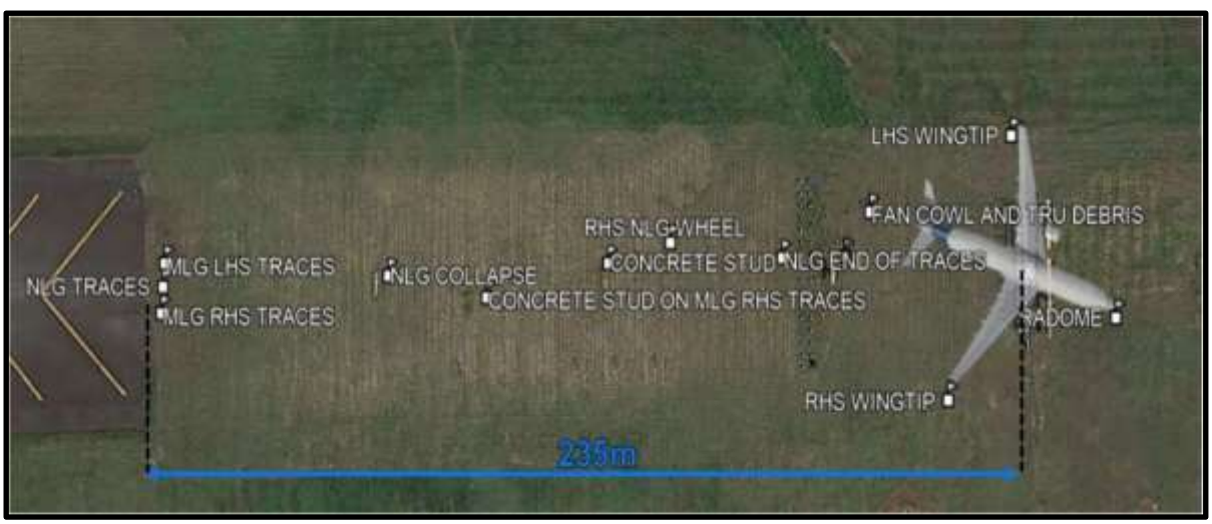


Figure 5 - The aircraft path exiting RWY 22.

As mentioned above, the aircraft Nose Landing Gear collapsed and the lower part of the forward fuselage was heavily damaged (Figure 6).

Figure 6 - The aircraft rested on its no the lower part of the forward fuselage heavily damaged

The area where the aircraft exited RWY 22 have visible tire marks on the ground leading to the aircraft. (Figure 7).

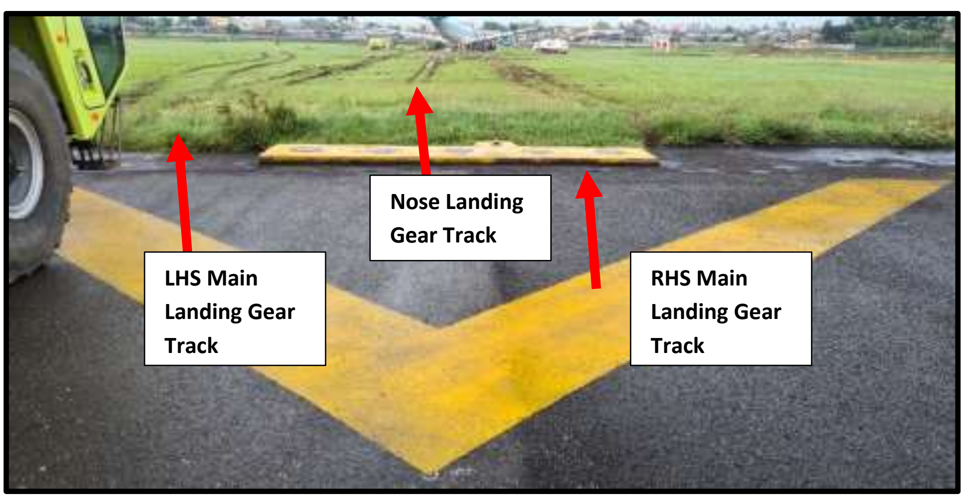


Figure 7 - The aircraft tire marks exiting RWY 22.

The ILS localizer antenna coiled to the aircraft wings and fuselage. The electrical power box was also damaged. The approach lights with concrete stands were also affected by the collision (Figure 8). Presence of the detached NLG wheel was observed within the path of the aircraft (Figure 9).

Figure 8 - The aircraft left wing colliding with the Electrical Power box and Approach lights.

Figure 9 - Presence of the detached NLG wheel was observed within the path of the aircraft.

1.12.2 The aircraft MLG had ground contact before threshold of RWY 22

During the second (2nd) approach at RWY22, the pilots configured the aircraft for landing, and the landing gear extended. With the autopilot 1 (AP1) disengaged and the master warning active, the FO mentioned "sink rate." Then the GPWS announced, "Sink rate." The captain initiated a go-around after the GPWS indicated the sink rate. The crew heard a noise similar to the landing gear touching the ground. It revealed that the aircraft contacted the ground before the beginning of the paved portion of runway 22 (Figure 10). There were LH MLG tire marks on the edge portion of RWY 22 (Figure 11-left). The RH MLG also hit the other edge portion (Figure 12-right).

Figure 10 - The edge of the paved portion before the threshold of RWY 22.

Figure 11 and 12 - The aircraft main landing gear tire marks before the paved potion of RWY 22.

1.12.3 On-Site Investigation

An ICAO Annex 13 investigation was launched by the Aircraft Accident Investigation and Inquiry Board-Civil Aviation Authority of the Philippines (AAIIB-CAAP) with the Bureau d'Enquêtes et d' Analyses (BEA), Paris, France, and the Aviation and Railway Accident Investigation Board (ARAIB) of Korea as accredited representatives. BEA nominated Airbus as a technical advisor. Both the ARAIB team of Korea and the

Airbus team arrived on October 25, 2022. The BEA team arrived at the site on the evening of October 26, 2022.

The AAIIB-CAAP team arrived on the site immediately after the occurrence and performed a preliminary site investigation. The ARAIB and Airbus team at their arrival also performed a preliminary investigation after access was granted to the aircraft wreckage site. On October 27, 2022, the site investigation of the aircraft wreckage continued. Several component parts of the aircraft, as advised by the Airbus team, were removed and turned over to the AAIIB team for quarantine in order to support possible future investigation work.

The last inspection of the accident site, in particular at the threshold of RWY 22, was done on October 30, 2022. During the inspection, wheel marks were seen on the unpaved portion before RWY 22. The distance measurement of the wheel marks shows similarity to the design characteristics of the A330 aircraft. Main landing gear (MLG) components were also found in this location. It further revealed that the right-hand (RH) MLG then hit a 15 cm step at the edge of the paved portion before the threshold of RWY 22.

1.12.4 Accident Site Examination Result

The main conclusion of the accident site examination was summarized below:

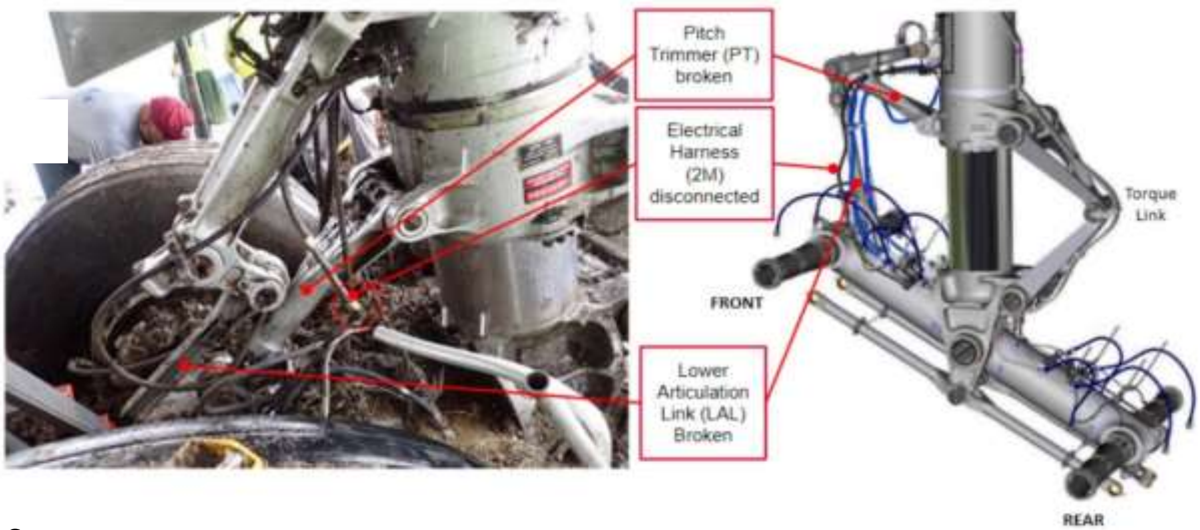
- **a.** After a high energy longitudinal runway excursion, the aircraft hit the localizer and approach lights installations.
- **b.** The nose landing gear collapsed during the runway excursion.
- **c.** Both main landing gears were found in the down locked position.
- **d.** No trace of an eventual tire burst during touchdown was found on site.
- **e.** The right main landing gear Lower Articulation Link (LAL) was found broken.
- **f.** The right main landing gear pitch trimmer was found broken.
- **g.** Electrical harnesses from the front and aft parts of the right main landing gear were found damaged.
- **h.** Green and blue braking system hydraulic hoses from the right main landing gear were found broken, leading to leakages.

Note: *The pictures below illustrate the RH MLG damage, it was at down locked position and all its tires deflated (Figure 13 a, b, c, d, e, f).*

13-a.

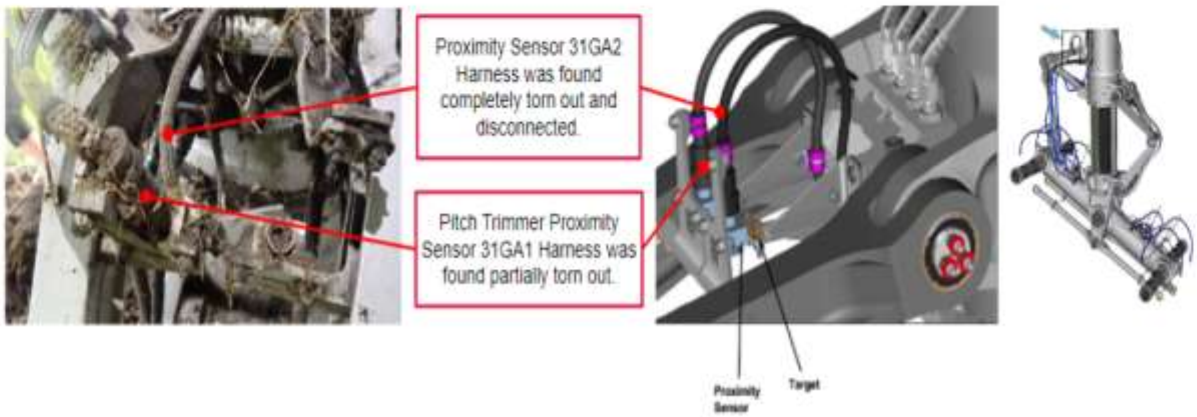
13-b.

- **Front side:**



13-c.

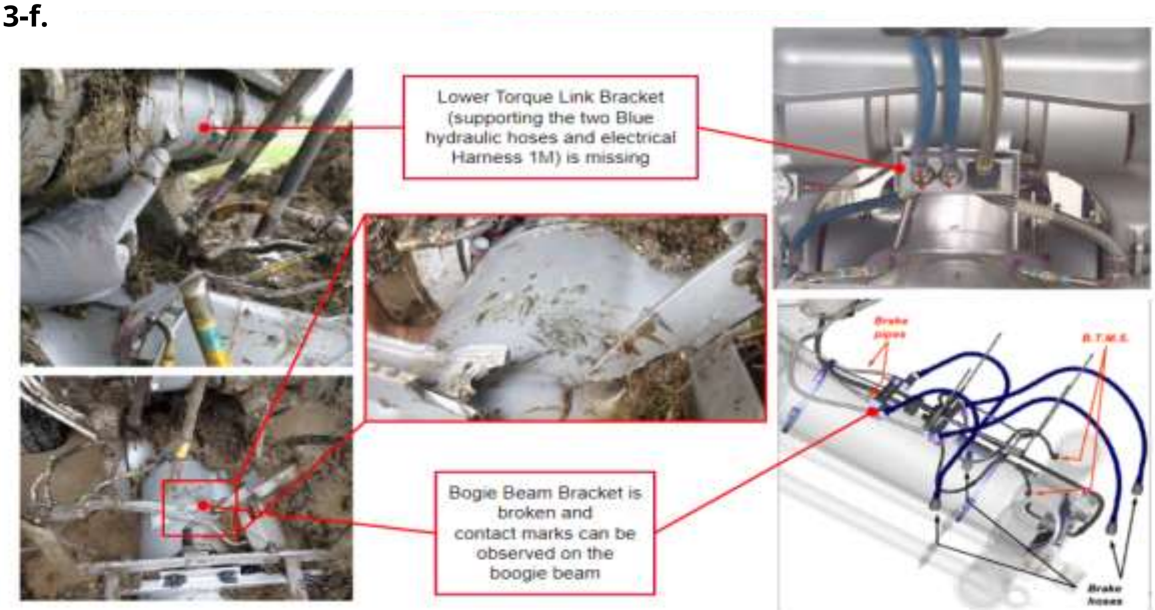
13-d.



13-e.

- **Rear side:**

13-f.



1.13 Medical and Pathological Information

Both Pilots had undergone post-accident physical examination on October 25, 2022. They were found to be physically fit to perform flying duties. There was no medical impediment on the pilots that could had a bearing on this occurrence.

1.14 Fire

No fire was reported by MCIAA crash fire rescue duty personnel.

1.15 Search and Survival Aspects

1.15.1 Notification of Emergency Situation

The captain informed the cabin purser about the emergency landing before it took place. The captain will issue a brace command one minute before touchdown as part of the coordination. This coordination prepares the passengers to brace properly and reduces the risk of injury. The captain also informed the ATC of the landing gear problem and requested emergency equipment. ATC immediately directed the MCIAA Aircraft Rescue and Fire Fighting (ARFF) to respond and arrived shortly after the aircraft stopped at the end of RWY 22. The MCIAA Airport Police also arrived at the area to secure the crash site while the medical team assisted the flight crew and passengers. Shuttle buses were deployed to transfer passengers to the designated reception area at the airport terminal for medical evaluation.

1.15.2 Evacuation Events

According to the written statements of the cabin crew, they were sitting in their respective jump seats during landing. Through the intercom, the purser briefed the other cabin crew members about the emergency landing. Since passenger briefing for emergency landing is not possible, the flight crew instructed the passengers to execute the anti-impact posture command in case of an emergency landing.

The purser also explained the anti-impact posture to the passengers in Korean and English through the public address (PA). Moreover, the passengers were instructed to follow according to the instructions of the cabin crew. The cabin crew further informed the passengers about the location of the emergency evacuation door (Figure 14).

Prior to touchdown, the captain announced through the PA, "Brace." The cabin crew then continued shouting "Brace" until the aircraft came to a complete stop.

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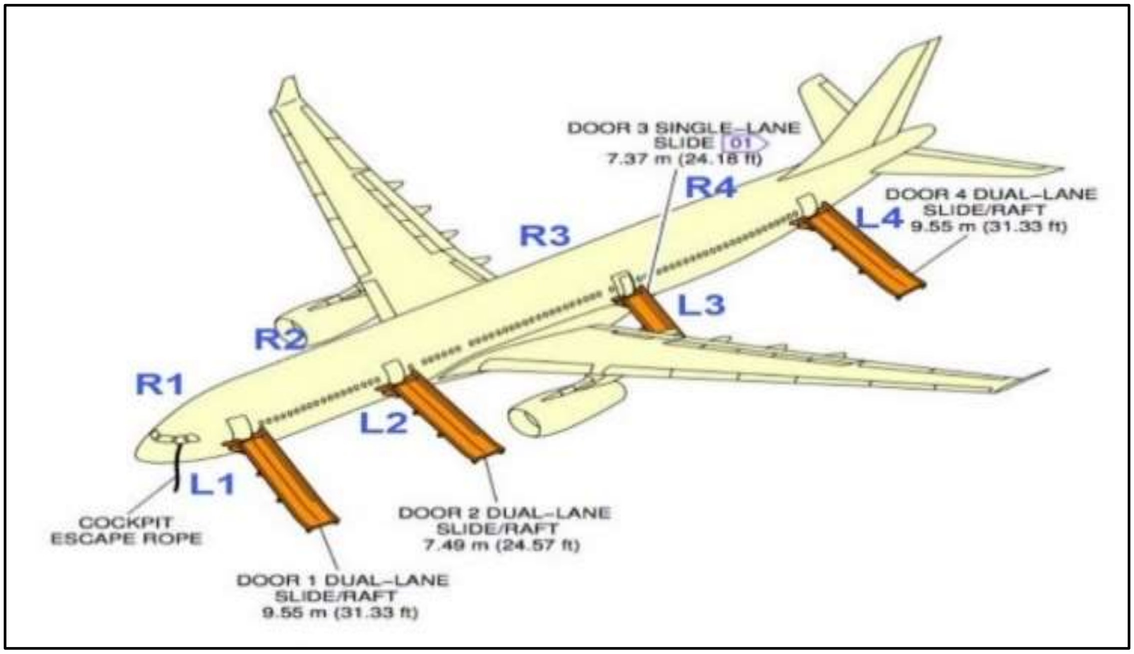

Figure 14 - A330 location of emergency evacuation doors.

The emergency aisle and exit lights in the cabin automatically activated after the aircraft stopped and continued to function properly during the evacuation procedures. The purser made an announcement using the megaphone, commanding, "Remain seated and keep calm." The purser, after seeing that the ceiling of the galley near the R1 door had collapsed and the cockpit door was broken, informed the captain through the broken cockpit door about the cabin condition. The purser also directed other cabin crew to check the condition if there was smoke or fire inside and outside the aircraft**.** Meanwhile, the captain, after the aircraft stopped, went out of the cabin and instructed the cabin crew to open the L2 and R2 emergency doors and use the escape slide for passenger evacuations (Figures 15 and 16).

Figure 15 - A330 L2 emergency evacuation door.

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Figure 16 - A330 R2 emergency evacuation door.

During site investigation, it was noted that L1 door was closed. It can be opened for slide removal but is difficult to close, which is consistent with the structural deformation at the door structure or fuselage door surrounding it. The R1 door was also closed. It can be moved but was not possible to be fully opened by the door handle, which is consistent with the structural deformation at the door structure or fuselage door surrounding structure. Moreover, the cabin floor panel between L1 and R1 was found bent upward. The cabin floor panel between the cockpit and forward galley was also found bent upward. However, no perforation of panels was observed. The L3 and R3 were not used due to the final position of the aircraft being considered unsafe. L4 and R4 were too high to use the slides for the emergency evacuation.

After getting the instructions from the captain, the purser announced in English and Korean through the megaphone to evacuate using the L2 and R2 evacuation slides. The purser sent two (2) cabin crew out of the aircraft to check the conditions of the grounds. The evacuation was done by rows. The use of R2 was discontinued in the process of evacuation because it was punctured by a protruding steel bar from the damaged approach light concrete post. The purser then immediately blocked the door and led the remaining passengers who had disembarked through the L2 door. Most of the passengers were calm during the evacuation. One cabin crew member was stationed at each door, and one was stationed at the bottom of the slides to assist the passengers. The evacuation flow was adjusted for the elderly and passengers with mobility difficulties. Wheelchaired passengers who were hesitant to evacuate were assisted by a cabin crew seating behind them as they slid together. The airport rescue team arrived in the middle of the evacuation and assisted the cabin crew in helping the passengers.

After all passengers had disembarked from the aircraft, the cabin crew checked the entire cabin four (4) times to ensure that no one was left behind. After confirming that the cabin was empty, the cabin crew gathered the emergency and medical equipment, including the first aid kit, megaphone, and flashlights. On the other hand, after receiving the report from the purser about the completion of the passenger evacuation, the pilots returned to the cockpit. They brought out along with them the flight log, several documents, and iPads. The captain and purser also conducted a final cabin check to ensure that there were no passengers left inside the aircraft. Both were the last to disembark from the aircraft. Other cabin crew used the flashlights to guide passengers to a secured and safe area away from the aircraft. While waiting for the shuttle buses, the purser accounted for the passengers and ensured that no one was injured. Two ambulances transported the elderly and wheelchair-bound passengers. The cabin crew were later distributed to the three buses that transported other passengers to the terminal building.

1.16 Test and Research

The following aircraft main landing gear and its related parts, braking system and its related parts and the computers and recorders were removed from the aircraft and quarantined for further examinations to support the investigation:

1.16.1 Computers

These computers were sent to BEA for non-volatile material (NVM) analysis/examination and to its manufacturer.

DESIGNATION	PART NUMBER	SERIAL NUMBER
EEC eng1	822830-14-034	4171-0892
EEC eng2	822830-14-034	UNK
LGCIU 1	007LG03	007LG02543
LGCIU 2	005LG00 AMDT 1	1282
CMC 2	LA2G00700	2G0000937
BSCU	C202933	1760
FCPC 2	LA2K2B100	2K2009908
FCPC 3	LA2K2B100	2K2008364
FCDC 1	87292337V04L15	530
HSMU	735-632-5 AMDT A	493
EIVMU 1	271-200-025	908
EIVMU 2	271-200-025	842

1.16.2 Main Landing Gear Parts

1.16.2.1 RH Main Landing Gear

The following parts were sent to the BEA in order to determine the root cause and sequence of the damages observed on RH MLG. These parts were further

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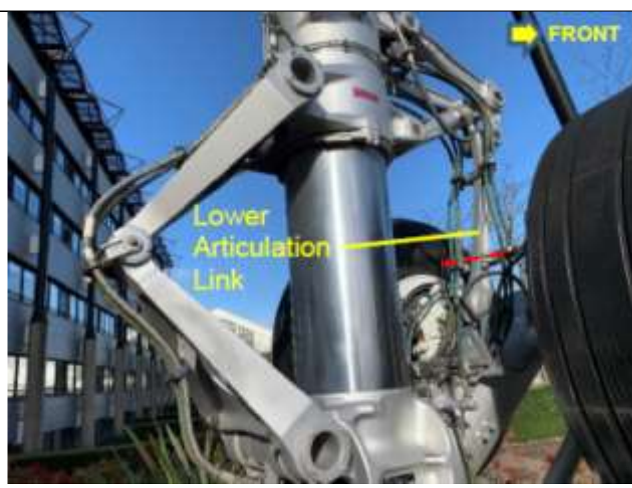
sent for examination to the manufacturer Safran Landing System in Gloucester, UK.

IMAGE No.	DESCRIPTION	LOCATION	P/N
1	R/H MLG Lower Articulation Link (2 parts)	Front side of the bogie	201589208
2	R/H MLG Pitch Trimmer (2 parts)	Front side of the bogie	114258004-070
3	2M electrical harness	Front side of the bogie	201655084
4	R/H MLG NORMAL BRAKING bogie beam bracket/manifold (2 parts: a, b) + GREEN hydraulic hose (rigid): c + part of lower torque link bracket: d + BLUE hydraulic hose (flexible): e + BLUE hydraulic hose (rigid): f	Aft side of the bogie	201274608
5	Two (2) ALTERNATE BRAKING hydraulic hoses + Upper part of 1M electrical harness	Aft side of the bogie	Hose 1 (middle): 201042298 Hose 2: 201042299 Harness: 701114502
6	Lower part of 1M Electrical Harness	Aft side of the bogie	201042731

IMAGE No.	PART LOCATION	IMAGE OF REMOVED PART
1		

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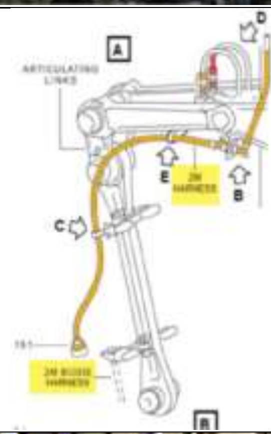
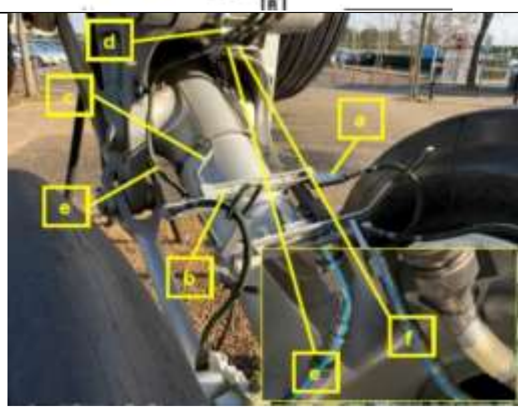
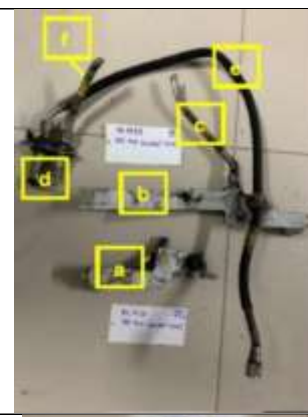
2		
3		
4		
5		

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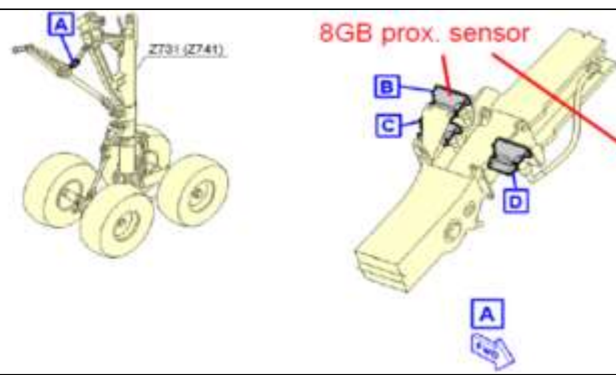
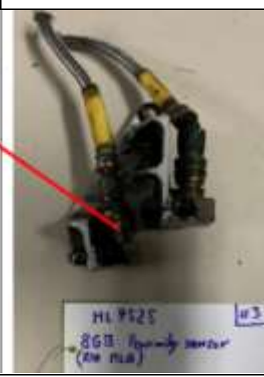
6		

Additionally, 8GB sensor was sent to the BEA to give details of the fault transmitted through ACARS. This part was sent to Safran Landing System in Gloucester, UK, then to the manufacturer Crane Aerospace in Lynnwood, USA, and finally back to Gloucester.

IMAGE No.	DESCRIPTION	LOCATION	P/N
7	Proximity Sensor 8GB (downlock) with its connector and 15cm of harness	R/H MLG lock link (side stay assembly)	C13502-08

IMAGE No.	PART LOCATION	IMAGE OF REMOVED PART
7		

1.16.2.2 LH Main Landing Gear

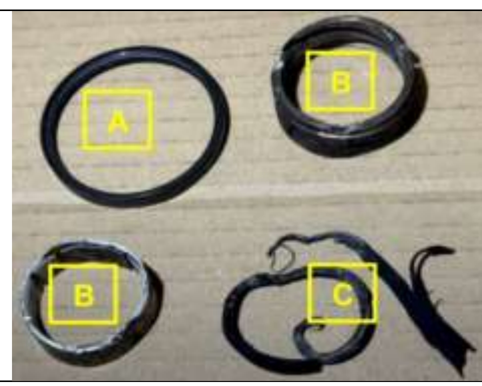
The L/H MLG Lower Articulation Link was removed from the aircraft and sent to the BEA to determine whether it had undergone any permanent deformation. This part was sent for examination to the manufacturer Safran Landing System in Gloucester, UK.

IMAGE No.	DESCRIPTION	LOCATION	P/N
8	L/H MLG Lower Articulation Link	Front side of the bogie	201589208

	PART LOCATION	IMAGE OF REMOVED PART
		

1.16.2.3 Parts found on RWY22 threshold

During on-site observation of RWY22 threshold, some parts were found on the ground. They were collected and sent to the BEA for identification. These parts were sent to Safran Landing System in Gloucester, UK.

IMAGE No.	DESCRIPTION	IMAGE OF PART
9	• 1 seal - A • 2 pieces of electrical connectors - B • 2 pieces of rubber - C	

1.16.2.4 Alternate Braking System Parts

The leak of blue hydraulic system during flight after the second approach to RWY22 was considered not be the sole consequences of the two severed blue hydraulic hoses on the R/H MLG, because brakes were not applied during flight. An internal leak in the alternate braking system (that could be present prior to the event) could explain the depletion of the blue reservoir. That is why the following major components of the alternate braking system were removed from the aircraft and sent to the BEA. They were then sent to Safran Landing System (Molsheim facilities) for examination.

Note: Each component is identified by a number in Figure 17. Some components have several designations, described on the column listed in the table below.

IMAGE No.	DESIGNATION	SERIAL No.	P/N	NOMENCLATURE
1	Accumulators (x 2)	088256-04644	1566	5426GG/5427GG
2	Alternate brake park manifold assembly - Park hydraulic manifold	C24819000-3	H0242	5439GG / 5401GG
3	Pressure transducer 4GK	CZ9DM6A	B CLS	4GK
4	Shut-Off Valve 9GZ	C24984000	H0020	9GZ
5	Automatic selector valve (ASV)	A25461020-2	Y00192	5202GG
6	Dual Valve - Brake Dual Distribution Valve (BDDV)	A25434021-2/A	H0443	5403GG
7	Parking Brake Control Valve - Park brake selector valve (PBSELV)	C24703002-2	H1261	4GZ
8	Park Brake Operated Valve (PBOV)	-	-	5801GG
9	Dual shuttle Valve	A25316020	H2557	5404GG
10	ALT Pressure transducers manifold 3GK1 & 3GK2	-	-	5405GG
11	RH Alternate Brake Servo Valve Manifold	Manifold: • P/N : C24880020 ; S/N: H0247 Brake servo valves : • P/N: C20374000-2; S/N: J837 C20374 • P/N: C20374000-2; S/N D437 C20374 Return Accumulator: • P/N: C20288000-2; S/N: 00553 Safety Valves: • P/N: 024757020 S/N: H1351	5491GG 1GY2 2GY2 5410GG 5411GG	

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		• P/N: 024757020 S/N: H1294		
12	LP Blue Manifold Check valve	F291-10862-000-00	5499425	6005JM 5402GG

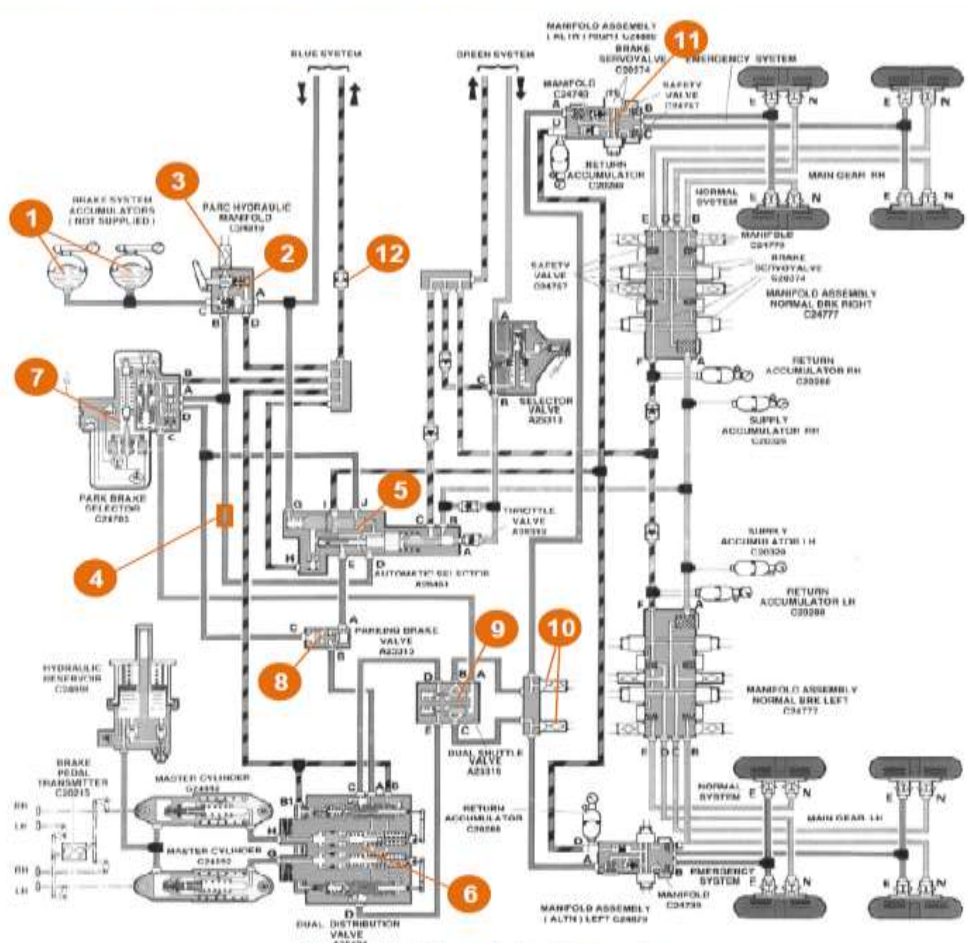

Figure 17 - Alternate braking system.

1.17 Organization and Management Information

1.17.1 Operator

Korean Air Co., Ltd., operating as Korean Air , was the flag carrier of South Korea. Korean Air was established on March 1, 1969, after the Hanjin Group acquired government-owned Korean Air Lines, which had operated since June 1962. Korean Air is a founding member of the airline alliance SkyTeam and SkyTeam Cargo. It is one of the ten (10) airlines ranked 5-star airline, and the top airlines in the world in terms of passengers carried and is also one of the top-ranked international cargo airlines. The aircraft HL7525, is form part on the company's list of aircrafts.

1.17.2 Operator Aircraft Maintenance

The maintenance functions of HL7525 are being undertaken by Korean Air Maintenance & Engineering Division with official address at Powerplant Maintenance Center. Korean Air, 10 Seckcheon-ro, 468 Beon-gil Oh Jeong-Gu Ojeong-gu, Buchgeon-si, Gyeonggi-do, Korea 14446 with a Maintenance Repair Organization (MRO) Certificate ratings on Airframe, Powerplant, Components and Specialized Services.

2. ANALYSIS

2.1 Operations

2.1.1 Initial Approach RWY 04/First Approach RWY 22

The captain was the pilot flying (PF), while the first officer (FO) was the pilot monitoring (PM) during the event. During the initial approach at RWY 04, after receiving clearance from ATC for an RNAV RWY 04 approach, the runway was changed to RWY 22 as per ATC instructions before passing the Initial Approach Fix (TONYO) as the variable winds shifted direction favorable to RWY 22. The descent and approach at RWY 22 were uneventful apart from the intermittent moderate to heavy rains encountered during the course of the descent for the approach.

The aircraft was fully configured for landing and in a position to execute a safe landing. After descending below minima, the captain lost visual cues due to a sudden downpour of rain. At about 1412 UTC, the captain aborted the landing and carried out a standard missed approach procedure as published. The flight crew decided to make a second attempt to land.

2.1.2 Second Approach RWY 22

At 14:20:16 UTC, when the aircraft was at 4,088 ft. pressure altitude (PA), the aircraft airspeed was recorded at 205 kts, Open Desc was active, and A/THR reduced thrust to idle. At 14:20:51 UTC, when the aircraft was passing 3,440 ft. PA, the airspeed was 198 kts, and the pilots configured the aircraft for landing and extended the landing gear. At 14:25:23 UTC, the autopilot was disengaged. At 14:26:20 UTC, the aircraft system annunciated 100 ft RA. At 14:26:21 UTC, a call out of “sink rate” from the FO was heard. It was followed by a “sink rate” from the Ground Proximity Warning System (GPWS) at 14:26:23 UTC. A callout of “Go-Around” from the FO was also heard, then a system callout of “40,” followed by a “sink rate” from GPWS. At 14:26:24 UTC, a response of “Go-Around” was heard from the captain. At 14:26:25 UTC, a system call out of “10” was heard, followed by “Flaps One Step” from the FO.

2.1.3 Go-Around and Ground Contact before RWY 22

At 14:26:25 UTC, RA was one foot, both N1 engines increased, and Mode SRS, GA TRACK, and A/THR MAN TOGA were all active. At 14:26:26 UTC, at an RA of -4 ft, there was a vertical acceleration reading on the main landing gear of 1.67G, where it decreased to 1.27G and increased again to 1.70G.

A noise similar to the landing gear having a ground contact was heard. At 1,500 ft RA (i.e., 32 sec after the touchdown), an Electronic Centralized Aircraft Monitor (ECAM) message was noted by the crew indicating LGCIU 1 and 2 fault. Meanwhile, other messages dedicated to maintenance also appeared at the Aircraft Communication Addressing and Reporting System (ACARS), such as:

- PROX SNSR (8GB) / LGCIU 1 (05GA1)
- PROX SNSR (29GA2) / LGCIU 2 (05GA2)
- TPIC (2GV)
- TACHOMETER WHEEL SPEED (13GG2) / BSCU (3GG)
- TIRE PRESS SNSR (10GV2)

During the on-site examination, tire marks indicated that the aircraft made ground contact before reaching the paved portion of RWY 22. It was also observed that the right-hand main landing gear (RH MLG) struck the uneven concrete edge adjacent to the unpaved area of RWY 22, with a step approximately 15 cm in height (Figure 18). This uneven surface is located in the transition zone between the paved portion of the runway strip and the graded part of the undeclared RESA.

Such existing surface was not in accordance with the published AANSO-CAAP Manual of Standards, 2nd Edition, dated February 2017, chapter 6.4.1.13, ICAO Annex 14 Volume 1, chapter 3.5.8, and ICAO Doc 9157 Aerodrome Design Manual Part 1, which states that "a RESA must be prepared or constructed so as to reduce the risk of damage to an aeroplane undershooting or overrunning the runway. The aerodrome operator has to consider improving the conditions of the threshold end of Runway 04/22 to meet the CAAP and ICAO requirements.

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Figure 18 - The 15 centimeters step at of the cemented edge of RWY 22.

The site investigation further shows that the RH MLG lower articulation link was broken. Moreover, as a consequential event of the step impact, the rupture of the RH MLG led to tearing off the 2M electrical harness. All the sensors (L/G position, brake temp, tire pressure, etc.) and tachometers (wheelspeeds) of the MLG are powered through two electrical routes: 1M and 2M. For LGCIUs, 1M supplies sensors are dedicated to LGCIU1, and 2M supplies sensors are dedicated to LGCIU2. The loss of the 2M electrical route resulted in losing half of the proximity sensors of the RH MLG (i.e., tachometers, bogie trail proximity sensors, pitch-trimmer proximity sensors, and tire pressure indication system (TPIS) sensors).

After the rear wheels of the RH MLG hit the step, the bogie beam had a sharp derotation that resulted in the LAL being ruptured. This subsequently allowed the bogie beam to continue its derotation freely and made contact with the lower torque link (front wheels not being stopped by the ground due to the aircraft trajectory). The sequence of events was shown in figure 19.

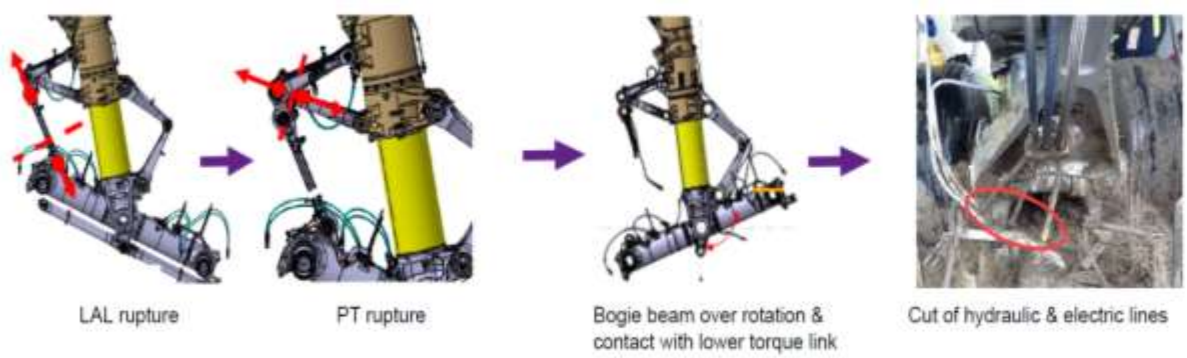

Figure 19 - The Derotation.

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Several parts were removed from the RH MLGs and other collected from the site of suspected touchdown were returned to the manufacturer in order to assess the load sustained by the RH LAL during the first ground contact for analysis. A significant amount of work by the manufacturer has been performed to support the investigation into the performance of the MLG during the events preceding and during the runway excursion that were summarized as follows:

A. Lower Articulating Link Fracture

The laboratory investigation found significant evidence that the RH LAL was fractured in a manner consistent with ductile overload, with no specific crack initiation site or other fracture morphologies observed. This suggests that there was no prior defect present in the part and the fracture was purely a result of a tensile overload.

On the other hand, there was no fracture of the LH MLG LAL. Physical measurements of key dimensions were performed and found to be within drawing tolerance. A 3D scan was also performed, with the resulting model compared with a nominal model. This showed that the two models concurred with each other, demonstrating that no permanent deformation had occurred.

Manufacturing records further showed that the LALs from LH and RH MLGs were manufactured together in the same batch, supplier cast number, and heat treatment cycle. They also shared the same post-heat treatment test coupon and so were as close to matching as it is possible to be. Therefore, it was deemed of interest to understand why the LAL from the LH MLG remained intact, while the opposite hand LAL fractured into two.

As such, a dynamic model analysis was performed in order to compare the LAL loads expected for each MLG based on the runway step conditions reported. The analysis showed that a very high LAL load can be generated by the MLG aft wheels after hitting a step as in this case.

The model predicted RH LAL loads that exceeded the expected fracture load for the LAL. The model provided a load 38.4% greater than the certified load and 18.3% greater than the expected fracture load. In this case the LAL loads predicted provides good evidence that the aft MLG wheels after contacting the step caused the LAL fracture.

In the case of the LH LAL, which remained intact, the loads generated by the model were less than that for the RH. For the LH LAL, the loads were 13.2% less than the certified fracture load and 25.8 % less than the expected fracture load. This supports the fact that only the RH LAL was found fractured on the aircraft.

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B. Bogie Pitch Trimmer Damage

The dynamic analysis showed that immediately following the scenario of a RH LAL rupture, there was an increase of internal pressure as the pitch trimmer responds to the release to the elastic strain energy by being pulled off its stops to extend rapidly. The model showed that the internal pressure increased to 1059 bar, which is 74 % greater than the design burst pressure. Based on this, it is likely that, following the fracture of the RH LAL, the pitch trimmer rupture could be a probable result.

Moreover, the laboratory investigation found that the threads on the pitch trimmer piston rod were observed to have sheared in the direction away from the pitch trimmer cylinder. This matches with a pressure exceedance modelled and the seal component that was found at the start of RWY 22. The laboratory investigation found that the threaded end of the pitch trimmer piston rod had also sustained secondary damage which was constant with the proposed interfaces following its rupture.

The associated threads on the nut were found in good condition, this was expected, based on the material property differences between the rod and nut. In addition, only one side of the threads is required to deform for the interface between the components to be lost.

C. Brake Manifold

The laboratory investigation confirmed that the RH MLG manifold had fractured into two pieces and the associated rigid pipes had been cut/pinched. The damage correlation work performed showed that once the articulation mechanism is disconnected, the bogie beam is free to swing rearwards provided the forward wheels do not contact the ground, coming to a stop against a number of components, including the manifold. The work showed that bosses on the sleeve bracket and torque link lugs could potentially cut hydraulic rigid pipes attached to the bogie beam in a manner that is consistent with the damage confirm in the laboratory.

D. Hoses and Harnesses

A number of hoses and harnesses were returned with damaged. These were retrieved from areas that the MLG gear which operated outside their usual ranges of motion that result to damage. The damage of these parts may result in the loss of functions and error messages recorded during the event.

E. Parts Found at RWY 22 Threshold

The laboratory investigation concluded that the seal found at the beginning of RWY 22 was most likely to have originated from the pitch trimmer. This coincides with the time and location that the pitch trimmer was initially damaged following the RH LAL fracture. The harness connector piece found at this location was linked to the 2M Bogie

Harness through a number of different approaches. This provides a high degree of confidence that this was the origin of the part found.

The non-metallic section found was concluded to likely be tire debris. This potentially originated from the aircraft during the event; however, it may be the case that tire debris at the end of a runway is not so unusual.

The findings of the pitch trimmer seal and harness connector are strong evidence that the RH MLG was significantly damaged at the location they were found, namely the step at the beginning of RWY 22. The fact that the harness connector was suspected to originate from a connection on the LAL, which fractured, it was not unexpected that this may have become detached when the aircraft was at this location. Following this, the pitch trimmer was believed to have been damaged, possibly resulting in the loss of the subject seal at this location.

F. Bogie Pitch Trimmer Proximity Sensor Bracket (31GA1 & 31GA2)

With the RH MLG Bogie Pitch Trimer Rod End disconnected due to the lower articulation link fracture, it was possible for contact to occur between the BPT cylinder and the pitch trimmer proximity sensor brackets as the release of energy swung it upwards. This matched damage was seen on the RH MLG proximity sensor 31GA2 harness that was completely torn out and disconnected. The proximity sensor 31GA1 harness was also partially torn out.

At 14:26:29 UTC, with an RA of 23 ft and an airspeed of 134 knots, an autobrake fault and an anti-skid fault were recorded in the DFDR. This fault stayed until the end of the FDR reading. The landing gear selector up and down parameters also started to be non-computed data (NCD). As extracted from AMM 32-00-00, the Landing Gear Control and Interface Units (LGCIU) controls the sequence of extending or retracting operations of the gears as well as opening and closing the doors. The LGCIU uses the position data from the proximity sensors to control the sequence of operations. Only one LGCIU controls the operations (Figure 20). Control changes from one LGCIU to the other after each retraction/extension cycle when the landing gear control lever is retracted from the extended position.

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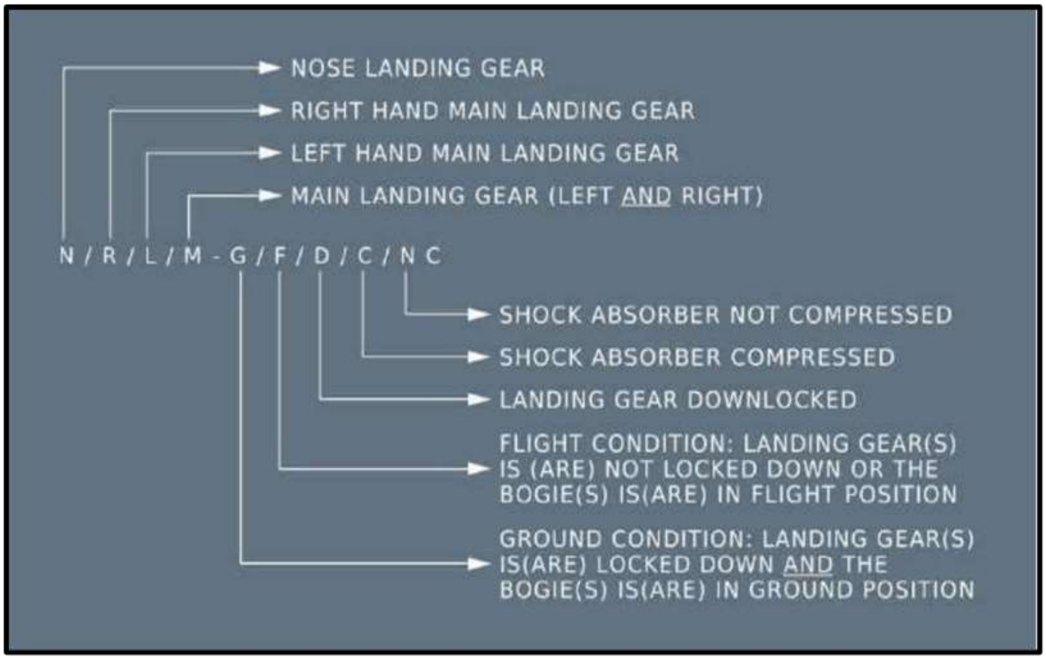

Figure 20 - Discrete logic signals provided by LGCIU to aircraft systems.

The brakes anti-skid fault is triggered when the anti-skid failed. According to the Flight Crew Operating Manual (FCOM) DSC 32-30, the anti-skid system compares the speed of each MLG wheel given by the tachometer with the aircraft speed called reference speed. Brake anti-skid fault and change from normal braking to alternate braking without anti-skid were due to the loss of more than two (2) tachometers (on the RHS MLG).

During the interview, the captain stated that while on their second approach at RWY 22, the aircraft experienced a steep descent due to downdraft. The FO said that when he saw the vertical speed indicator (VSI) suddenly increase, he called out, “Sink rate, go-around.” The statements by the crew were confirmed by the CVR during the approach; at 14:26:20 UTC, a system callout of “100” was heard, followed by a callout of “sink rate” from the FO seconds later. It was followed by “sink rate” from GPWS at 14:26:23 UTC. At 14:26:24 UTC A callout of “Go-Around” from the captain was heard, then a system callout of “40” moments later. At 14:26:25 UTC, a system call out of “10” was heard, followed by “Flaps One Step” from the FO.

At 14:26:26 UTC, noise from the shocks of the MLG with the ground, followed by “positive climb” from the FO, was heard. At 14:28:24 UTC, ATC was heard saying, “Korean Air six three one, reason of missed approach.” At 14:28:29 UTC, the captain replied, “unstabilized.”.
At 14:29:37 UTC, the PIC, while talking with the OCC, was heard saying, “Yes, we made a first go-around because of unstabilized; the second go-around was initiated due to heavy rain.”

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Further, at 14:40:55 UTC, the PIC was heard saying, “Did we hit inside the runway, in front?” and the FO replied, “Yes, maybe probably at the end area,” three seconds later.

According to the Operator, Airbus 330/340 Flight Crew Technique Manual (FCTM) PR-NP-SOP-250 P 1-2/16, a stabilized approach is essential for achieving successful landings. When the aircraft is close to the ground, a high sink rate should be avoided, even in an attempt to maintain a close tracking of the glideslope. Priority should be given to attitude and sink rate. If a normal touchdown is not possible, a go-around should be performed. If the aircraft has reached the flare height at VAPP with a stabilized flight path angle, the normal SOP landing technique will lead to the right touchdown attitude and airspeed. We have reinforced specific PM callouts for excessive pitch attitude during landing.

In this event, a high-pitch sidestick activity was recorded between 11 degrees nose down (ND) and 16 degrees nose up (NU), with a max deflection of 16 degrees. The pitch angle decreased from +5.5 degrees to an average of +3 degrees, and Vz increased from -400 ft/min to -1100 ft/min.

There was also a high roll sidestick activity between 17 degrees left hand (LH) and 18.3 degrees right hand (RH) (max deflection 20 degrees); the roll angle moved between 8.5 degrees LH and 4 degrees RH. The increase in VSI can be attributed to the combination of several downdrafts associated with the pilot nose-down inputs below 200 ft RA. It resulted in ground contact before the runway (Figure 21).

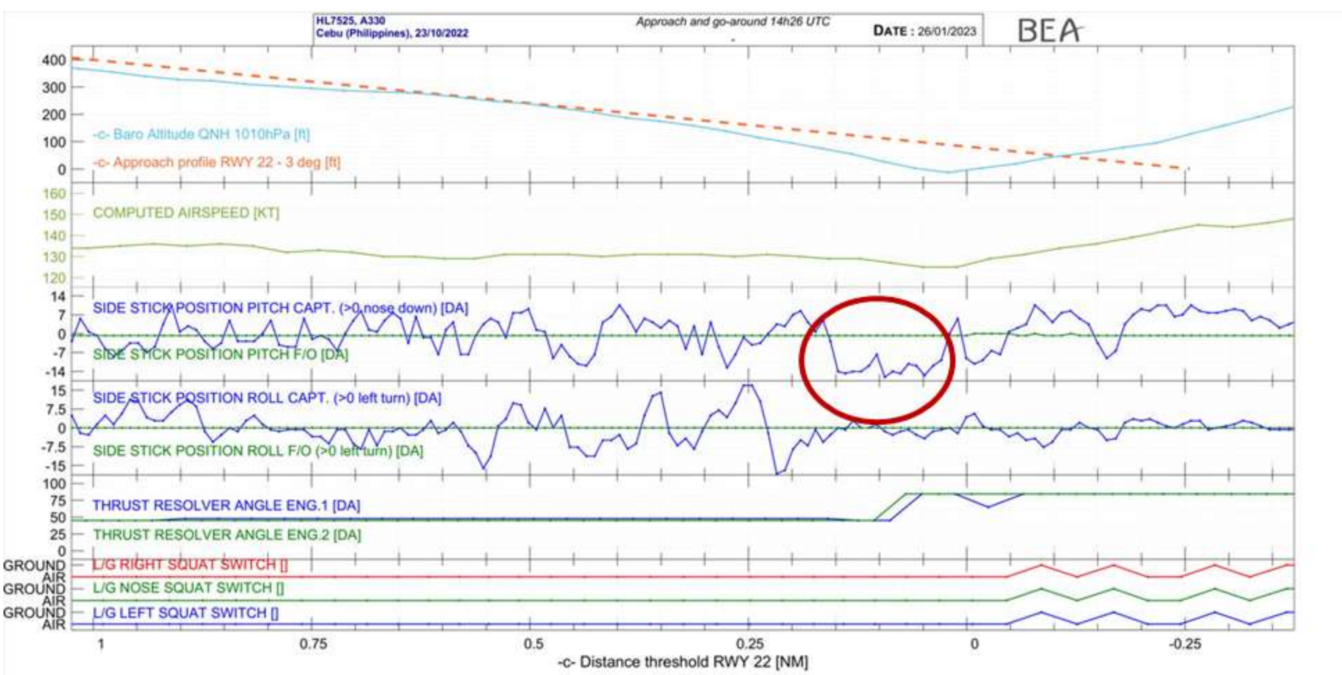

Figure 21 - The forward pitch control input initiated by PF related to go-around.

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Further, when the aircraft transitions from IMC to VMC, the flight crew should continue to include the PFD in the scan so they can initially maintain pitch, heading, and a stabilized flight path down to flare. Prior to flare, avoid destabilization of the approach and steepening the slope at low height in attempts to target a shorter touchdown.

The Go Around procedure, which was provided in the associated chapter of the FCOM, indicates rotation and TOGA thrust selection should be done simultaneously. Further, the FCTM provides this consideration about the flap's retraction in case of a go-around near the ground: "Only when the aircraft is safely established in the go-around, the flight crew retracts flaps one step and the landing gear.".

In this event, the flaps were retracted one step when the aircraft was already on the ground. An early flaps retraction when performing a go-around near the ground will reduce the lift before the aircraft gets a positive climb trajectory and therefore increase the chance of touching the ground during the maneuver.

Further based on FDR analysis, the contributing factor to the aircraft's descent during the second approach was identified as an increase in vertical wind factor (Figure 22).

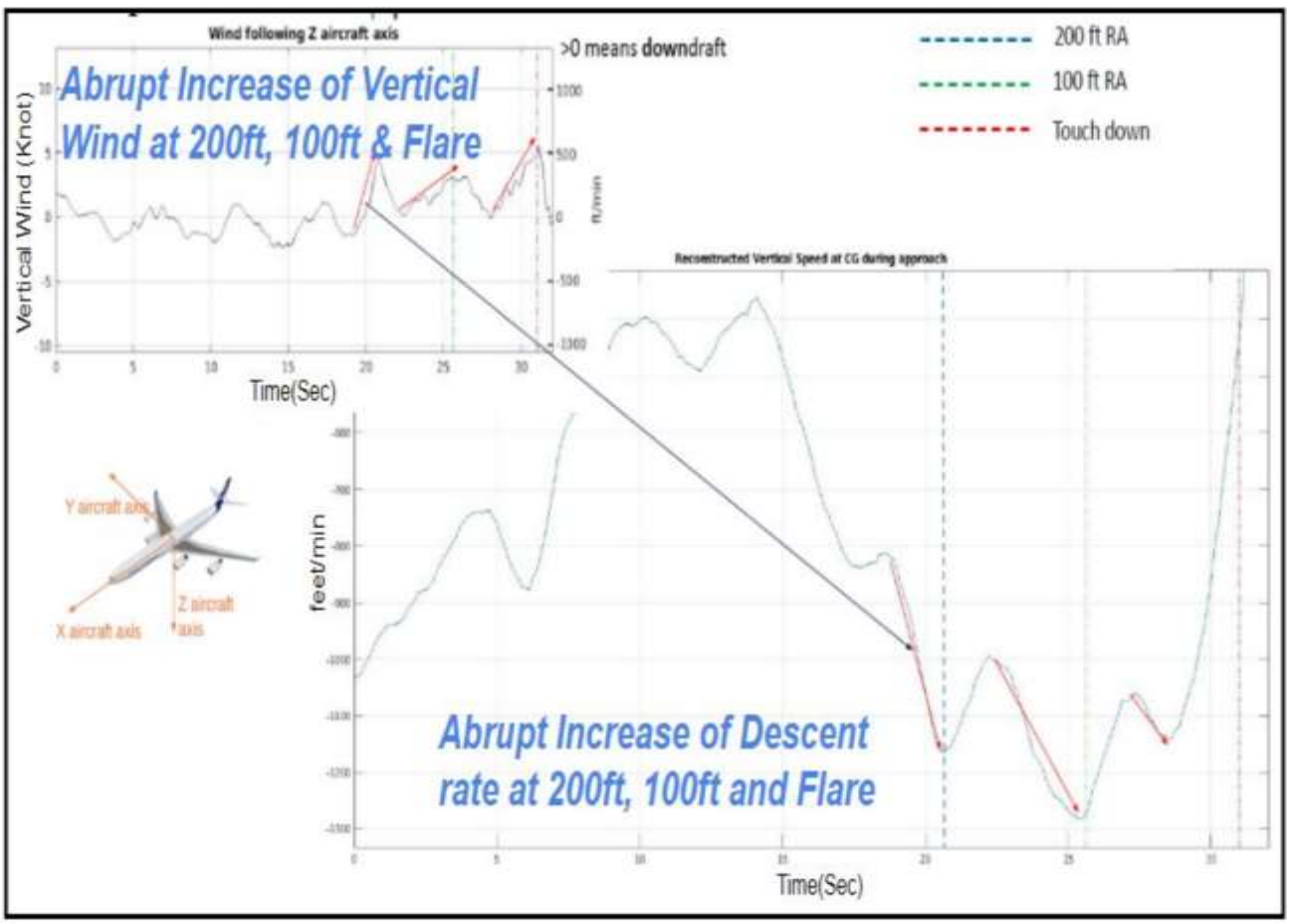
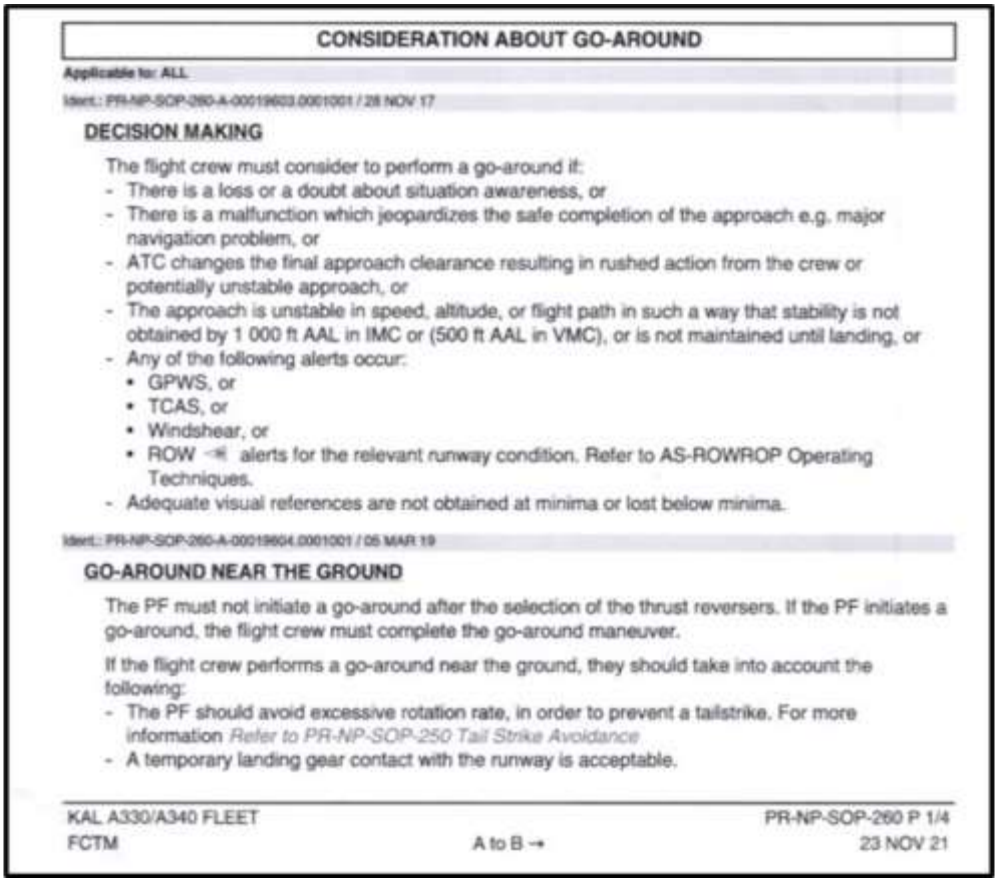


Figure 22 - The increase in vertical wind factor.

According to the company A330 FCTM, (PR-NP-SOP-260A.... Go-Around) If the decision to continue has been made at minima and the visual references become insufficient, a go-around must be initiated (Figure 23).



CONSIDERATION ABOUT GO-AROUND

Applicable to: ALL

Ident.: PR-NP-SOP-260-A-00019603.0001001 / 28 NOV 17

DECISION MAKING

The flight crew must consider to perform a go-around if:
- There is a loss or a doubt about situation awareness, or
- There is a malfunction which jeopardizes the safe completion of the approach e.g. major navigation problem, or
- ATC changes the final approach clearance resulting in rushed action from the crew or potentially unstable approach, or
- The approach is unstable in speed, altitude, or flight path in such a way that stability is not obtained by 1 000 ft AAL in IMC or (500 ft AAL in VMC), or is not maintained until landing, or
- Any of the following alerts occur:
  - GPWS, or
  - TCAS, or
  - Windshear, or
  - ROW alerts for the relevant runway condition. Refer to AS-ROWROP Operating Techniques.
- Adequate visual references are not obtained at minima or lost below minima.

Ident.: PR-NP-SOP-260-A-00019604.0001001 / 05 MAR 19

GO-AROUND NEAR THE GROUND

The PF must not initiate a go-around after the selection of the thrust reversers. If the PF initiates a go-around, the flight crew must complete the go-around maneuver.

If the flight crew performs a go-around near the ground, they should take into account the following:
- The PF should avoid excessive rotation rate, in order to prevent a tailstrike. For more information *Refer to PR-NP-SOP-250 Tail Strike Avoidance*
- A temporary landing gear contact with the runway is acceptable.

KAL A330/A340 FLEET FCTM | A to B → | PR-NP-SOP-260 P 1/4 23 NOV 21

Figure 23 - KAL A330 FCTM go-around reference.

A late go-around may result in ground contact (Figure 24). The flight crew must consider to perform a go-around if adequate visual references are not obtained at minima or lost below minima, there is a loss and/or a doubt about situation awareness.

Figure 24 - The MLG visible tracks were seen before the pavement of RWY 22.

2.1.4 First Holding at ALMAR

After the ground contact and go-around, upon reaching reporting point ALMAR at 14:33:36 UTC, the crew started to compute the landing distance. At 14:34:43 UTC, the crew was heard in the CVR informing the Maintenance Control Center (MCC) about the LGCIU 1 and 2 fault. They also discussed whether to land at Cebu or divert to Davao. Moreover, heard in the CVR, MCC was asking the crew if the landing gear was extended, to which the crew said that the landing gear was retracted. At 14:41:14 UTC, heard in the CVR, the crew also contacted the Operation Control Center (OCC) about the LGCIU 1 and 2 fault and asked if they could continue with another approach or divert.

During the interview, the crew said they retracted the landing gear; however, based on the FDR analysis, the landing gear parameters are invalid after 1426H UTC. It was not possible to determine the position of the landing gear since there was a fault in LGCIU 1. To determine if the landing gears remained extended or were retracted after the ground contact was shown in the table below (Figure 25). Wherein the time periods chosen were for all the flaps at 0°, the packs were ON, HPV 1 was closed, and HPV 2 was not fully closed. These conditions were set similarly while the aircraft was holding at 4,000 feet to allow comparison of fuel consumptions with landing gear at a retracted position. Fuel consumption calculation from FDR data (CAS, N1, and fuel flow) confirmed that the landing gears remained extended, although there was a retraction procedure after the go-around callout by the crew. This was further confirmed by the CVR recording, where the aerodynamic noise does not change upon landing gear selection by the crew. In addition, this was also consistent with the analysis of the various failures versus the logic of the system.

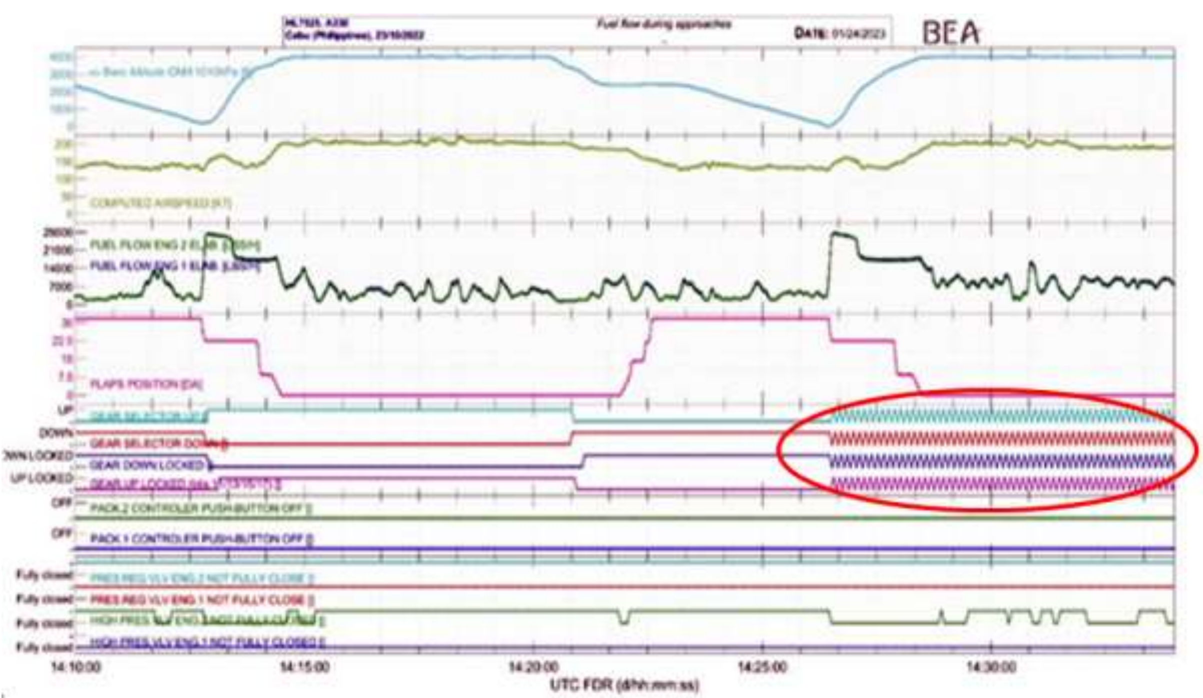


Figure 25 - Landing gears undetermined position.

Likewise, based on the Fuel Penalty Factors/ECAM Alert Table of A330 QRH Operational Data, it indicates that the fuel consumption increases by 180% with the landing gear extended. This further confirms that the landing gears were in extended position after the ground contact and go-around (Figures 26, and 27).

Average value	UTC Time period	CAS	ENG 1 N1 ENG 2 N1	ENG 1 Fuel flow ENG 2 Fuel flow	Average fuel consumption L/h
Landing gear retracted	14:15:22 – 14:20:02	205 kt	48.8 % 46.6%	4855 LBS/h 4525 LBS/h	4690 LBS/h
Landing gear unknown	14:28:41 – 14:30:16	202 kt	67.2 % 65.7 %	8996 LBS/h 8476 LBS/h	8736 LBS/h
Landing gear unknown	14:28:41 – 14:31:42	203 kt	63.2% 61.8%	8202 LBS/h 7782 LBS/h	7992 LBS/h

Figure 26 - Fuel consumption when landing gear was extended (A330 QRH extract section FUEL PENALTY FACTORS/ECAM ALERT TABLE)

L/G	RETRACTION FAULT L(R) LENGTHENING FAULT GEAR NOT UPLOCKED GEAR UPLOCK FAULT	L/G RETRACT	All landing gears are extended	180 %
	DOORS NOT CLOSED	L/G DOOR	All landing gears doors are extended	15 %

Figure 27 - Extended landing gear increases fuel consumption. (A330 QRH extract section LANDING GEAR)

Furthermore, the analysis of the Non-Volatile Memory (NVM) of the two LGCIUs sent to the manufacturer revealed that from 14:26:36 UTC**,** the L/G lever was actually in the UP position. At that time, the two LGCIUs were already lost, that was indicated by the loss of the L/G SQUAT parameters at 14:26:28 UTC and the parameters related to the L/G lever and lock position at 14:26:31 UTC. These parameters are provided by the LGCIUs to the FDR. Therefore, the L/G lever although was selected UP but the L/G remained extended as no more LGCIUs were capable of operating the L/G.

2.1.5 Third Approach to RWY 22

During the third approach at 14:43:45 UTC, at RWY 22, the crew was heard in the CVR call out “gear down.” At 14:43:52 UTC, the crew was heard in the CVR that the landing gear is not coming down. At 14:44:05 UTC, the crew was heard in the CVR reading the landing gear gravity extension procedure. At 14:45:00 UTC, the crew was heard in the CVR saying landing gear down, but they noticed that one side of the landing gear did not come down a few seconds later. At 14:45:30 UTC, the crew was heard in the CVR requesting ATC to return holding at ALMAR.

At the moment of the ground contact before the runway, an ACARS message was triggered “Prox Snsr (8GB)/LGCIU 1 (05GA1). Three proximity sensors, 7GB, 8GB, and 9GB, show the down locks of the Nose L/G (NLG) and Main L/G (MLG) are locked. These are independently connected to the NLG and MLG down lock indicator lights in the cockpit through the LGCIU 1. The “not down locked” indication on the RH MLG on the L/G indicator panel remained after the application of the L/G gravity extension procedure because the failure of the down lock indication proximity sensor 8GB was still present.

To determine why the RH MLG was not indicating a green light during the landing gear gravity extension, the sensor for RH MLG (8GB) was removed from the aircraft and was sent to the manufacturer for examination and analysis. A visual examination was conducted on the proximity sensor 8GB, wherein it presented a damaged sensing surface and crack propagation indicative of target contact.

The returned proximity sensor was determined to have physical damage to its sensing face, as a noncontact sensor, this is considered an unusual finding. The physical damage to the Ryton face appears to be new damage; this is in line with it occurring during the event. An energy-dispersive x-ray spectroscopy (EDS) was conducted on the sensing surface, and metallic material surface (i.e., traces of Cr, Fe, Ni, and Zn) was found in the two witness marks (Figure 28)

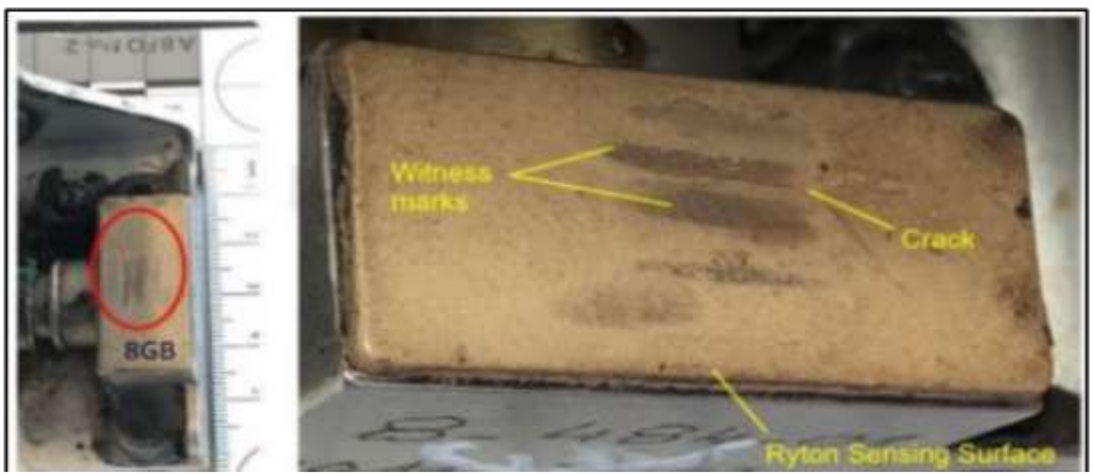


Figure 28 - The witness marks found in the RH MLG (8GB) sensor.

The investigation concluded that the sensor failed an electrical performance test that was carried out in line with the Approved Maintenance Manual (AMM), wherein it was only able to produce a target FAR result. This is consistent with a sensor that would be unable to confirm MLG downlock.

A 2D X-ray of the damaged sensor also showed that the internal pole pieces had become separated from the magnetic core, which confirms an internal physical damage. Based on these findings, the manufacturer suggests that the likely scenario

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during the event was that the target made contact with the proximity sensor. This resulted in the damage seen, thereby rendering the downlock indication defective.

Inspection of the 8GB proximity sensor bracket shows that there was permanent deformation in the area where the 8GB sensor is mounted. It has been shown that the direction of deformation found reduced the distance between the sensor and target. A non-destructive inspection using x-rays of the proximity sensor 8GB identified that both pole pieces were separated from the U-shaped magnetic core. The separation of the pole pieces was the result of the U-shaped magnetic core being pushed down by 1.289 mm (0.0507 inch). There was also a failed functional test and electrical characterization on sensor 8GB on both far and near target inductance measurements.

Based on these findings, damage to the 8GB proximity sensor was believed to have occurred during the step impact during the second go-around. Supporting evidence for this was the fact that a fault message was recorded at 14:26 for this proximity sensor, and at the same time stamp, seven other faults and warning messages were recorded. This would be expected for a significant impact, causing damage to a number of components. Following damage to the sensor, the downlock of the RH MLG could not be confirmed. This resulted in the third approach being stopped and the aircraft put in a holding pattern again.

2.1.6 Second Holding at ALMAR

At 14:46:34 UTC, the crew was heard in the CVR informing the Maintenance Control Center (MCC) that they performed a landing gear gravity extension, but the right landing gear was not indicating a green light. At 14:48:35 UTC, based on the FDR, the aircraft passed ALMAR and entered the holding pattern. At 14:53:46 UTC, the crew was heard in the CVR reading the abnormal landing gear procedure. At 14:54:25 UTC, after the L/G Gravity Extension, when the R/H MLG still did not indicate downlock, the flight crew followed the procedure and applied the 'LDG WITH ABNORMAL L/G PROC’. At 14:54:41 UTC, the crew was heard in the CVR performing the first item of landing with an abnormal landing gear procedure. At 14:54:49 UTC, the crew was heard in the CVR informing the cabin personnel of the emergency landing. At 14:55:04 the captain said to the cabin personnel, “Emergency landing brace for impact.” At 14:56:05 UTC, the crew was heard in the CVR informing OCC that they will perform an emergency landing. Meanwhile, at 14:59:00 UTC, multiple fault codes also appeared at the ACARS, such as Hyd Blue Reservoir Low Level, Hyd Blue Eng 1 Pump Low Press, and Hyd Blue Sys Low Press (Figure 29). This fault was triggered when the fluid quantity in the blue hydraulic reservoir goes below 5 liters (1.32 US Gals).

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330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1508	ROLLOUT	71-00-095	ENG 1 SHUT DOWN						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1508	ROLLOUT	28-24-005	FUEL ENG1 LP VALVE FAULT						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1507	APPROACH	22-10-020	AUTO FLT AP OFF						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1507	ROLLOUT	78-30-080	ENG 1 REV FAULT						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1507	ROLLOUT	78-30-085	ENG 2 REV FAULT						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1502	CRUISE			1502	29-31-16	SLT2 B HYD PRESS OFF	H	1	SFCC-S2
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1500	CRUISE	29-12-030	HYD B SYS LO PR	1459	29-11-51	B ENG1 PMP (E1-4000JG2)/B HYD RSVR	H	1	HSMU
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1500	CRUISE	29-12-020	HYD B ENG 1 PUMP LO PR	1459	29-11-51	B ENG1 PMP (E1-4000JG2)/B HYD RSVR	H	1	HSMU
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1459	CRUISE	29-12-015	HYD B RSVR LO LVL	1459	29-11-51	B ENG1 PMP (E1-4000JG2)/B HYD RSVR	H	1	HSMU
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1453	CRUISE			1453	29-11-34	HSMU (1JG) DISCRETE INPUT S206	H	1	HSMU
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1442	CRUISE	24-00-010	ELEC C/B TRIPPED						
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1432	CRUISE	34-48-150	NAV GPWS TERR DET FAULT	1432	34-48-34	GPWC (1WZ)/FWC1/2X(1WW1/2)/WXR1/2 (1SQ1/2)	H	1	GPWC
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1428	CRUISE			1428	32-31-71	LGCIU2(5GA2)	H	1	FWS
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-31-080	L/G LGCIU 1X2 FAULT	1426	32-49-16	TIRE PRESS SNSR(10GV2)	I	1	TPIC
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-31-080	L/G LGCIU 1X2 FAULT	1426	32-61-13	PROX SNSR (8GB)/ LGCIU 1 (05GA1)	H	1	LGCIU1
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-31-080	L/G LGCIU 1X2 FAULT	1427	32-49-34	TPIC(2GV)	H	1	FWS
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-40-030	BRAKES ANTI SKID FAULT	1426	32-31-73	PROX SNSR (29GA2)/ LGCIU 2 (05GA2)	I	1	LGCIU2
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-40-030	BRAKES ANTI SKID FAULT	1426	32-42-57	TACHOMETER-WHEEL SPEED (13GG2) / BSCU(3GG)	H	1	BSCU-C1
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-40-030	BRAKES ANTI SKID FAULT	1426	32-49-16	TIRE PRESS SNSR(10GV2)	I	1	TPIC
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-40-030	BRAKES ANTI SKID FAULT	1426	32-61-13	PROX SNSR (8GB)/ LGCIU 1 (05GA1)	H	1	LGCIU1
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-40-030	BRAKES ANTI SKID FAULT	1427	32-49-34	TPIC(2GV)	H	1	FWS
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-31-080	L/G LGCIU 1X2 FAULT	1426	32-42-57	TACHOMETER-WHEEL SPEED (13GG2) / BSCU(3GG)	H	1	BSCU-C1
330_AC	P	HL7525	KE0631	ICN	CEB	20221023	1426	CLIMB	32-31-080	L/G LGCIU 1X2 FAULT	1426	32-31-73	PROX SNSR (29GA2)/ LGCIU 2 (05GA2)	I	1	LGCIU2

Figure 29 - ACARS downlink messages.

2.1.7 Fourth Approach/ Landing and Runway Excursion at RWY 22

On the fourth (4th) approach at RWY 22, at 14:57:18 UTC, the captain then declared "MAYDAY" (3X) and informed the ATC of the landing gear problem. At 14:59:07 UTC, the PIC also requested ATC for emergency equipment. As the aircraft was descending for landing, at 15:00:07 UTC, "Hydraulic Blue Reservoir Low Level, Blue Engine One Pump OFF," said the FO, and the PIC responded, "Pump Off." This alert was triggered as a result of the application of the HYD B RSVR LO LVL procedure (i.e., the BLUE ENG1 pump switched OFF). This alert triggers when the engine pump pressure is ≤ 1,450 PSI.

The A330 braking system utilizes only two hydraulic systems, Green and Blue, out of the three available hydraulic systems, as sources. Normal braking uses the green hydraulic system as its brake source, while alternate braking and parking braking use the blue system as their source. Accumulator braking, which is used for parking and in emergency situations, is exclusively provided by the Blue hydraulic system. The green hydraulic system does not serve as a source for accumulator braking. Once the brake system is switched from Normal Brake to Alternate Brake based on specific conditions, the green hydraulic system could not be utilized as a braking source anymore. In the A330 hydraulic system, there is no separate function to reserve fluid other than the accumulator in case of hydraulic fluid loss.

As mentioned above, the hydraulic blue reservoir low-level alert is triggered when the fluid quantity is below 5 liters (1.32 US gallons) in the reservoir. It is inhibited from 80 kts airspeed from takeoff to an altitude of 1500 ft. and from 800 ft and at 80 kts upon landing. However, this alert does not consider the hydraulic quantity of the accumulators. The blue engine 1 pump low-pressure alert is triggered when the engine pump pressure is below 1,450 PSI. It is inhibited from 80 kts airspeed from takeoff to an altitude of 1500 ft. and from 800 ft and at 80 kts upon landing.

Aside from the conditions mentioned above for switching the brake system from normal brake to alternate brake, during site investigation, as a result of the second go-round after the ground contact, the RH MLG sustained heavy damages, in particular: the lower articulation link and pitch trimmer rod were fractured, brackets on the lower torque link were found missing, and the bogie pitch trimmer proximity sensor was found damaged. Moreover, 1M and 2M electrical harnesses were found ruptured/disconnected, which resulted in the loss of all four (4) RH MLG wheel tachometers. The two (2) blue hydraulic hoses were found with cuts or broken, which contributed to the blue hydraulic reservoir leak during the flight after the ground contact. This led to a change from normal braking to alternate braking without anti-skid (blue system).

At 15:07:03 UTC, the PIC called out, “Manual.” At 15:07:38 UTC, both thrust resolver angles reduce from 45 degrees to zero. Normal acceleration increases to 1.13G, then to a maximum of 1.23G. One second later, normal acceleration was reduced. At 15:07:39 UTC, noise on the CVR similar to main landing gear touchdown was heard.

At 15:07:40 UTC, there was a reduction from 0 degrees to -9 degrees and -12 degrees on both thrust resolver angles. At 15:07:41 UTC, there was an increase in fluctuation in the normal acceleration and both brake pedal positions. At 15:07:43 UTC, at a ground speed of 123 knots, left and right alternate pressure increases from 23 psi to 544 psi and 224 psi, respectively. At 15:07:53 UTC, at a ground speed of 107 knots, left alternate pressure reached a maximum of 672 psi and right alternate pressure to 352 psi. Meanwhile, the longitudinal acceleration decreases as the alternate pressure started to decrease and became equal at 32 psi, three seconds later. At 15:08:02 UTC, at a ground speed of 99 knots, both brake pedals have reached and stayed at a maximum of 68 degrees until the end of the FDR recording.

In the CVR, at 15:08:05 UTC, the FO was heard saying, “I will shut it down in sequence,” followed by ”Number 1 Off”, three seconds later. However, at 15:08:10 UTC, the PIC was heard saying, “Do not shut it” (7x). At 15:08:23 UTC, the PIC was heard saying, “Speed is not reducing”, At 15:08:37 UTC, a sound similar to a runway excursion was

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recorded in the CVR. The ground speed recorded at the time of the runway excursion was 83 kts.

Based on the Airbus QRH with abnormal landing gear, if one main landing gear is abnormal at touchdown, all engine masters are off (in sequence). After main gear touchdown, shut down the engine on the failure side first, then the other engine before nacelle touchdown. In this event, engine 1 was temporarily shut down instead of engine 2 by one of the crew.

2.2 Braking Actions Upon Landing Before Runway Excursion.

Braking actions upon landing braking parameters were plotted during the final landing around 15:07UTC. Both engine thrust levers were moved backwards at 15:07:38, when radio altitude was four (4) feet as shown in the plot below (Figure 30).

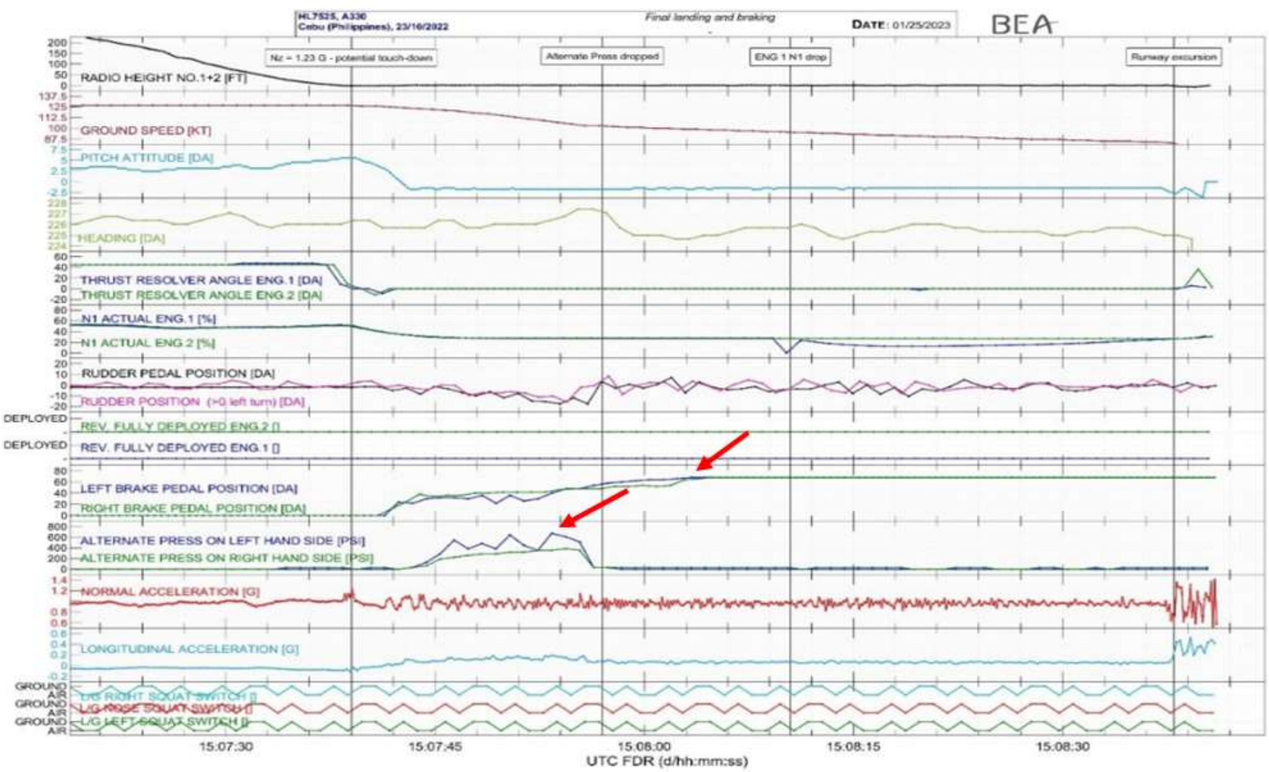

Figure 30 - Braking parameters at moment of final landing, and runway excursion.

When autobrake status had been at fault since 14:26 UTC, the landing gear squat parameters became invalid. The alternate brake pressure increases to a maximum of around 700 psi. As the longitudinal acceleration decrease, this indicates an increase of the braking.

The alternate brake pressure dropped to 0 psi at 15:07:56 UTC. Both thrust levers stayed at 0° (IDLE). From 15:08:03 UTC and up to the end of the flight, both brake pedal position was at 70°, corresponding to the max deflection and ground speed was 99 kts. Based on FDR analysis, after touchdown, the alternate braking pressure was applied more on the left side, even though the crew used the right brake pedal more than the left (Figure 31). This was explained by the rupture of hydraulic hoses at the RH MLG brake level.

LH MLG **RH MLG**

Figure 31 - Tire condition after the accident as per Airbus wheel numbering convention.

Moreover, after the occurrence the two Parking-Brake Accumulator pressure gauges (5432CG & 5432GG) indicated around 1,200 PSI. The aircraft brake pressure accumulator gauges were also inspected and observed the following (Figure 32):

1. Parking Brake Accumulator Pressure-Guage (5432GG) – The pressure was about 1,200 PSI.
2. Yellow Power Accumulator Pressure-Guage (5433GG) – The Pressure was around 1,200 PSI.

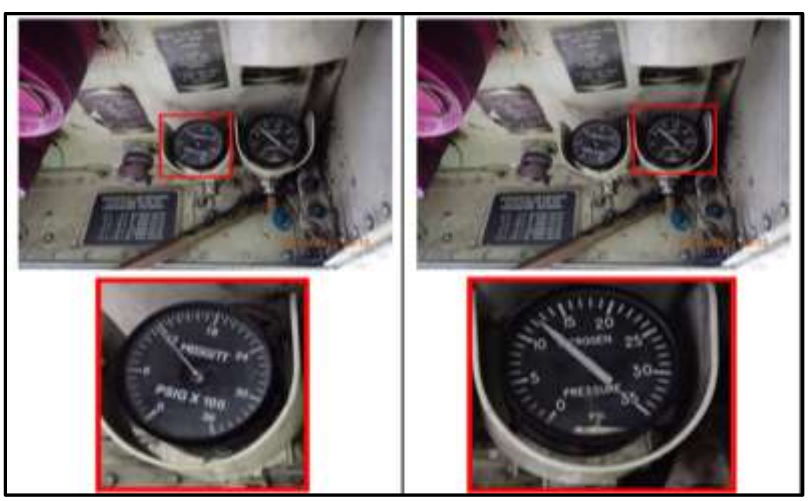

Figure 32 - The aircraft brake pressure accumulator gauges during inspection.

2.3 Loss of Alternate Braking

As mentioned above, just before the final approach was initiated, a blue hydraulic system low level ECAM alert (HYD B RSVR LO LVL) was triggered at 14:59:36 UTC. The Alternate Braking System is hydraulically powered by the Blue hydraulic system or by dedicated braking accumulators in case of the blue hydraulic system failure. The damages on the braking/hydraulic system were only observed during the site investigation of RH MLG bogie beam (i.e. severed hydraulic pipes at the aft of the RH MLG).

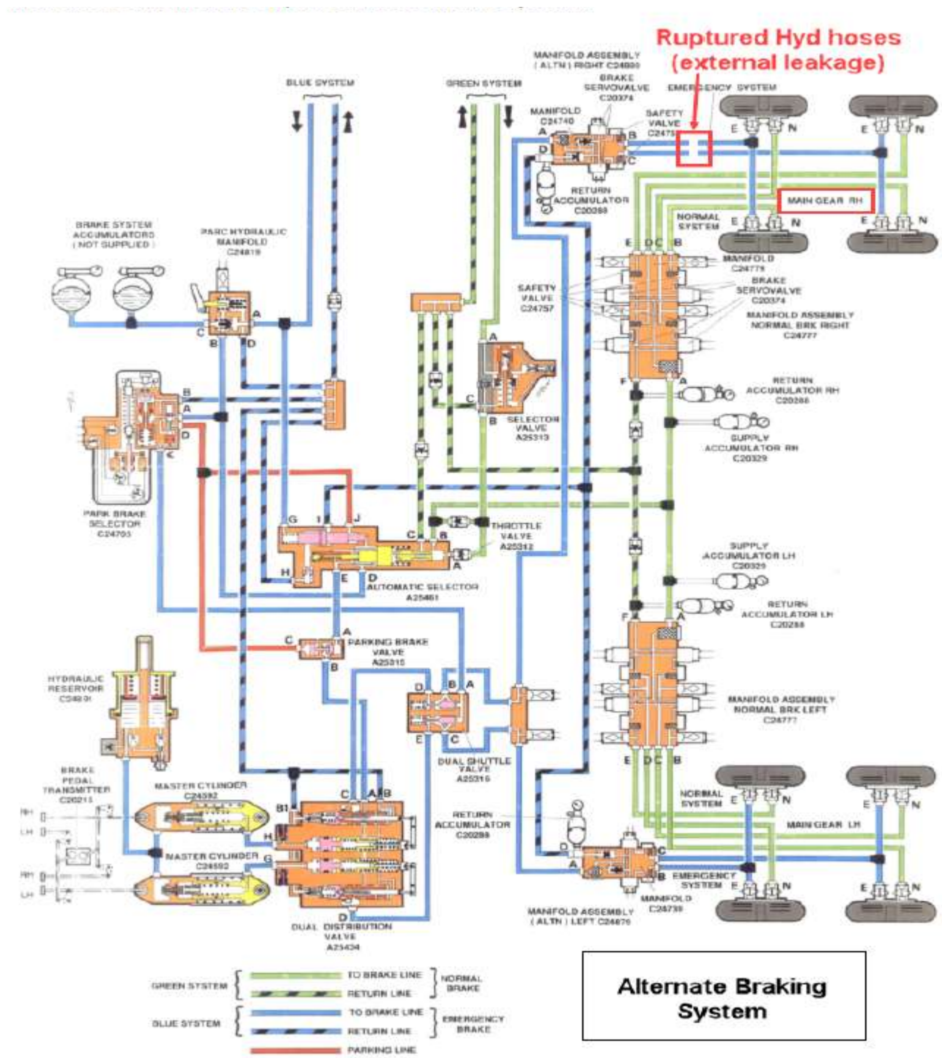

Figure 33 - The aircraft alternate brake system diagram.

By design of the brake lines (Figure 33), the Brake Dual Distribution Valve (BDDV) and the brakes are only pressurized during active braking. This means that during the event flight, the blue hydraulic fluid should not have reached the leak point at the RH brake level as it is normally blocked by the BDDV. Therefore, by design, the alternate braking system with only two severed hoses at brake level could not be the single cause for the loss of the blue hydraulic system during the final approach. Apparently, there is an additional failure in the Alternate Braking System to explain this loss.

As per specifications, the maximum internal leakage of the BDDV should be limited to 30cc/min. However, the leak rate of the blue hydraulic system during the event has been estimated at 500cc/min considering the following information:

- The leakage started when the two hydraulic hoses were ruptured (i.e. at the time of touchdown off runway 14:26:26 UTC),
- The HYD B RSVR LO LVL ECAM alert, that indicates that the fluid level in the blue reservoir reached 5L, triggered at 14:59:36 UTC,
- The nominal servicing level of the blue hydraulic reservoir is 22L.

Based on those figures, it can be assessed that 17L were lost in 33min (i.e. leak rate of ~0.5L/min).
This leak rate is far below the threshold to trigger the safety valves of the alternate brake system (calibrated at ~12L/min).

Two possible leakage paths are possible:

- Through the Brake/Supply lines (i.e. blue lines in the schematic) due to an internal leakage at BDDV level ⇨ BDDV (5403GG) has been removed and sent to OEM for examinations (SAFRAN).
- Through the Return lines (i.e. dashed lines in blue & back in the schematic).

The following components of the Alternate Braking System were removed and sent to OEM for examinations (SAFRAN):

- Park Hydraulic Manifold (5439GG)
- Automatic Selector (5202GG)
- Park Brake Selector (4GZ)
- RH Alternate Brake Servo Valve Manifold (5491GG)
- Safety Valves (“fuses”) (5410GG & 5411GG)
- Check Valve (5402GG)

All these components were tested as per CMM and all were found No Fault Found (NFF) except the Park Hydraulic Manifold, where an internal leakage was found on the Pressure Release Valve (PRV) as shown in figure 34 A and B.

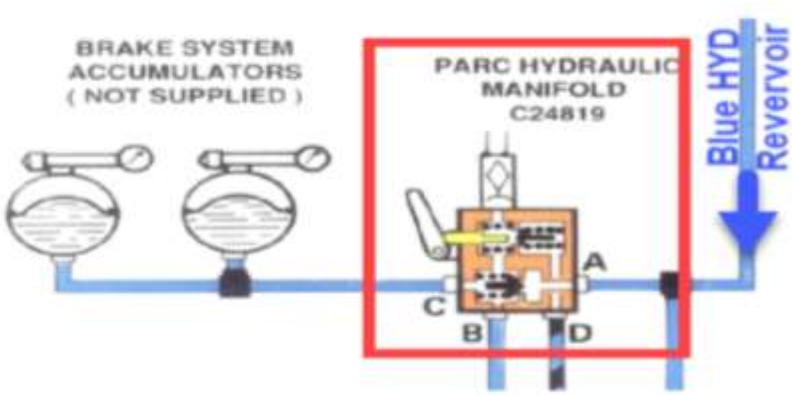

Figure 34 A - The Park Hydraulic Manifold Schematic

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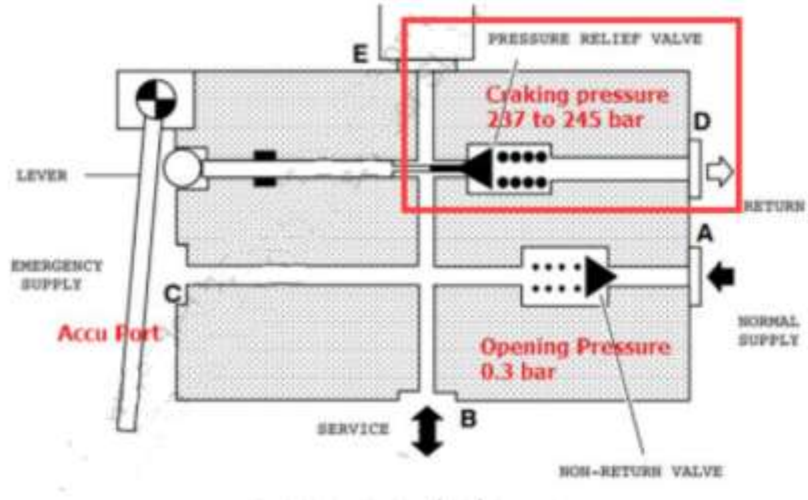

Figure 34 B. The Park Hydraulic Manifold Schematic.

During the examination, as indicated in the above schematics, the normal cracking pressure of the PRV (i.e., the pressure at which the valve is supposed to open) is between 237 and 245 bar. However, the following behavior of the PRV was observed during the examinations: By increasing the service pressure (port B), a leakage (continuous flow) was observed at port D. When the pressure was increased above 207 bar, a leak rate of 500 cc/min was reached at around 210 bar. The leakage stopped (i.e., dripping at 5 cc/min) when the pressure was decreased down to around 140 bars, wherein it fully stopped below 59 bars.

Therefore, the cracking pressure of the PRV was well below the nominal one (defined by the specifications) and was close to the operational supply pressure of the blue hydraulic system (i.e., 206 +3/-0 bars at zero outlet flow). On the other hand, as the hydraulic lines were cut at the brake level, all the return lines (including port D of the Park Hydraulic Manifold) were at atmospheric pressure, i.e., 1 bar, instead of the 5-bar nominal pressure in the return lines. This resulted in increasing the delta pressure between the two ports of the PRV and eased its opening at operating supply pressure.

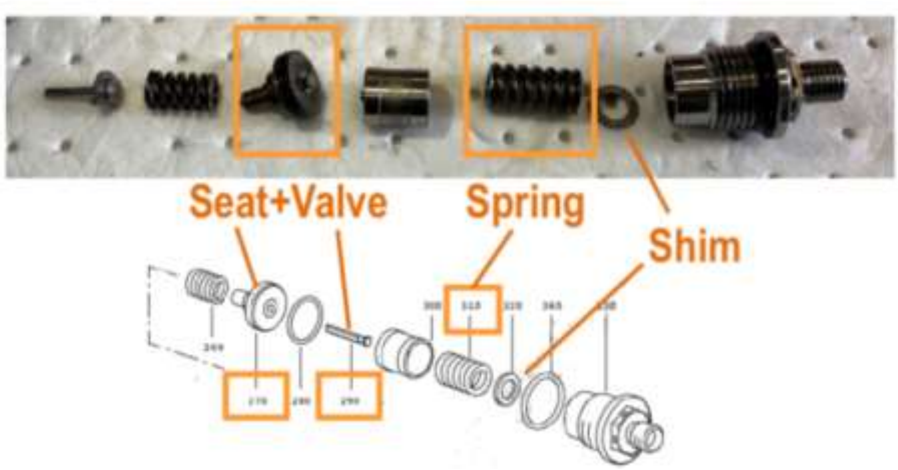

Figure 35 - The disassembled PRV for examinations.

The PRV was then disassembled for examinations (Figure 35). The cracking pressure is ensured by the spring and adjusted at the correct value thanks to the shim. The results of the spring and shim examinations were the following:

- **a.** Stiffness of the spring at the min of the CMM requirement (56 N/mm for 57 N/mm mini).
- **b.** A reduced free length of the spring was measured (23.5mm instead of 23.8mm
- **c.** The shim thickness was 1.18 mm.

Further examinations of the seat and valve also revealed the following damage (Figure 36):

- **a.** A circular mark on the valve on the interface area with its seat,
- **b.** A radius edge on the seat instead of an expected sharp edge.

Figure 36 - Damage in the seat and valve

These damages explain the abnormal cracking pressure observed during the test of the PRV. At this stage of the investigation, the root cause of these damages is still not known and the analysis is still on-going.

The PRV function is to protect the system from any overpressure in the Alternate Braking System and is normally closed during operation. According to the manufacturer, this valve is not supposed to be regularly operated, the cracking pressure is normally reached only after an over-pressure on the blue Hydraulic circuit and during manual decompression operations for maintenance. In qualification, 1000 operations of the valve are required and completed. The consequences of a sole internal leakage of the PRV are a pressure decrease in the Accumulators after a long aircraft parking (without any hydraulic power). This can be detected by the flight crew who, as per A330/A340 flight crew operating manual Standard Operating Procedures (SOPs), will check the accumulator pressure during the Preliminary Cockpit Preparation: (Figure 37)

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KOREAN AIR

A330/A340
FLIGHT CREW
OPERATING MANUAL

PROCEDURES
NORMAL PROCEDURES
STANDARD OPERATING PROCEDURES
- PRELIMINARY COCKPIT PREPARATION

Ident.: PRO-NOR-SOP-04-D-00010910.0001001 / 06 MAY 22

PARKING BRAKE

	* ACCU PRESS indicator.......... CHECK		PM
L2	*The ACCU PRESS indication must be in the green band. If required use the electric pump on blue hydraulic system to recharge the brake accumulator.*		
L1	* PARK BRK handle.......... ON		PM
L2	*When one brake temperature is above 500 °C (or above 350 °C with the brake fans ON), avoid applying the parking brake, unless operationally necessary.*		
L1	* BRAKES PRESS indicator.......... CHECK		PM
L2	*Check for normal indications.*		

Figure 37 - Preliminary Cockpit Preparation.

In the SOP, the flight crew is requested at each first flight of the day to recharge the accumulators using the blue electrical pump in case of low pressure (i.e. outside the green band) and no A/C logbook entry is required (as standard procedure). On the other hand, there is currently no maintenance task in the A330 MPD that would detect such a failure. Therefore, such a PRV failure remains undetected (i.e."dormant"). It has to be noted that this PRV failure has no consequence on the braking system if there is no external leakage (as the hydraulic circuit is a closed circuit).

Coming back to the event, the leak path was the following diagram shown below (cf. blue line, figure 37-a):

1. From the blue hydraulic reservoir through the PRV (internal leak) of the Park Hydraulic Manifold (D port) and the return lines, then;

2. Through the BDDV (without any pedal deflection port B is opened to ports C and D), then;

3. Through the Dual Shuttle Valve (fully opened since parking brake was not operated during flight) and then;

4. Through the RH Alternate Brake Servo Valve Manifold (which is opened when in Alternate Braking mode);

5. To the severed hydraulic hoses at brake level (external leak).

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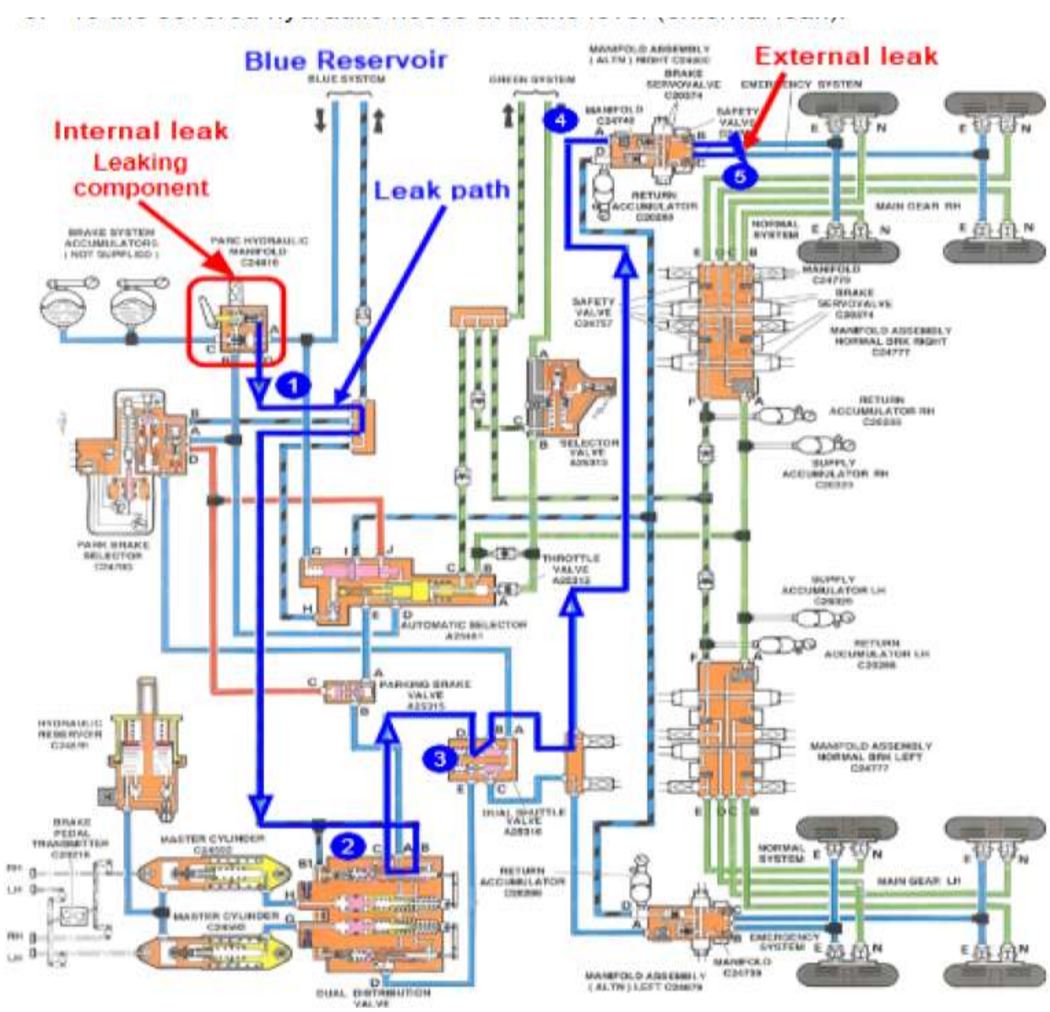


Figure 37 A - Hydraulic “Blue Line”.

Further, as per HYD B RSVR LO LVL ECAM procedure, all blue pumps were switched OFF. This resulted in a reduction of the supply pressure into the alternate braking system which closed the Non-Return Valve (NRV) of the Park Hydraulic Manifold (i.e. port A close), and isolating the blue hydraulic reservoir from the internal leak (i.e. port D). The NRV was tested and found working properly (see figure 34A).

As a result, the fluid level in the blue reservoir didn't decrease further after the blue hydraulic system was shut OFF (LO PR 15:20 UTC), which was very short after the triggering of the HYD B RSVR LO LVL ECAM alert (at 14:59:36 UTC). Therefore, the fluid level strapped in the blue hydraulic reservoir was close to the low-level limit (5L) of the HYD B RSVR LO LVL ECAM alert and was most likely sloshing around this threshold giving the explanation of the 21 Master Cautions (MCs) that triggered from 15:00:19 UTC to 15:05:53 UTC. These ECAM alerts did not appear in the ACARS messages as only the first occurrence was recorded.

The blue hydraulic reservoir was isolated from the leak (by the NRV) as soon as the blue hydraulic system was shut OFF, but not the Accumulator (port C still opened). Therefore, from the time the blue hydraulic system was shut OFF (LO PR 15:00:20 UTC), the Accumulators started to empty through the same leak path.

This loss of hydraulic fluid in the accumulators decreased the pressure of the accumulators. Therefore, at the brake pedal application during landing (15:07:42 UTC), the pressure of the accumulators was below the nominal pressure (i.e. 3000 PSI) which explained why the safety valves did not activate (not enough flow rate). The safety valves were actually tested and found working properly (i.e. as per CMM). This is highlighted by the simultaneous and abrupt drop of the RH and LH alternate brake pressures at 15:07:56 UTC (once the accumulators were fully emptied). As a reminder, the purpose of safety valves is to isolate a possible downstream braking line leakage during brake operations in order to preserve system from a global loss of hydraulic fluid. There is one safety valve per braking line (Figure 37-b).

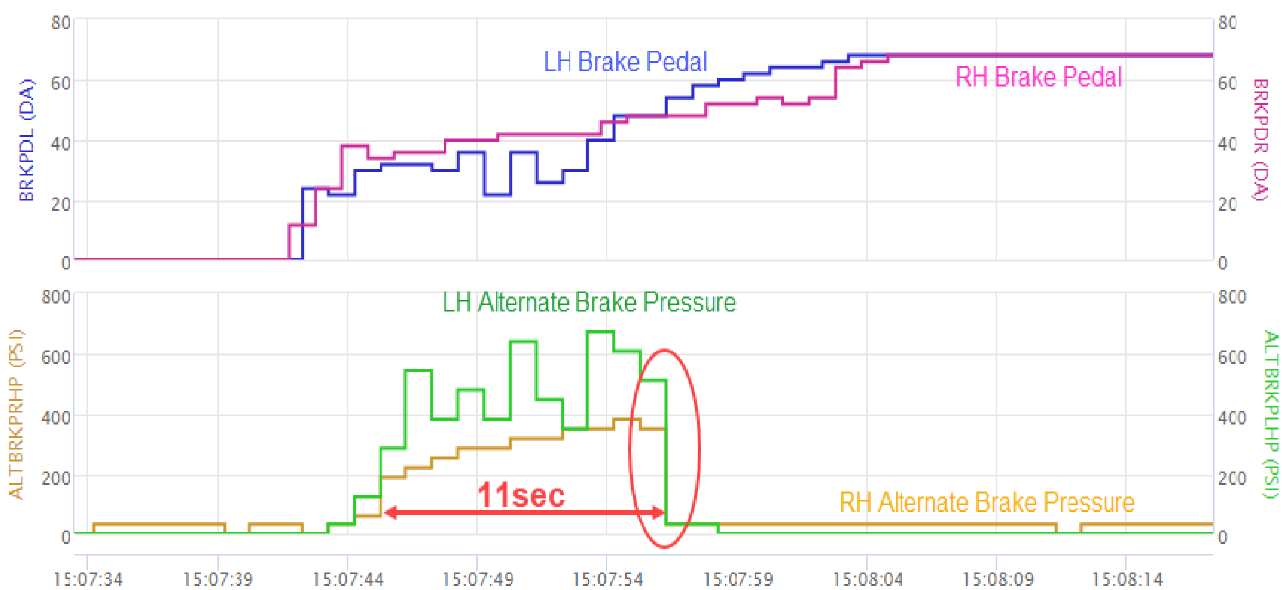


Figure 37 B - RH and LH alternate brake pressures.

Following this event, Airbus has launched a study to enhance the A330 reverser logic in order to keep thrust reversers (most important benefit in terms of landing performance) in the conditions of this event. With regard to the “dormant” failure on the alternate braking system, Airbus is investigating improvements of the maintenance documentation in order to better detect such an internal leakage (Reference: Airbus Contribution Report dated February 16, 2024).

2.4 Estimation of Blue Hydraulic Leak

During the final approach, an ECAM alert indicating a low level on the blue hydraulic system triggered. The flight crew performed the associated ECAM actions, and the blue hydraulic system was lost, leaving the braking on the accumulators as the only means of deceleration. Assuming that total blue hydraulic quantity at the beginning of the approach was equal to the maximum reservoir quantity (22.6L). However, the actual quantity in the blue hydraulic reservoir was likely less than this after the ground contact. Air pressure in the Blue reservoir was found to be nominal at about three (3) bars.

Based on the FDR, at 14:26 UTC, there was the start of a leak when the fault codes appeared in FDR and ACARS of L/G LGCIU 1 and 2 faults and brakes anti-skid faults. This is the result of the cut of electrical harnesses 1M and 2M and blue hydraulic hoses that bring hydraulic power to the brakes, which is part of the RH MLG damages caused by the impact with the pavement step on RWY 22 threshold.

At 14:59 UTC, fault code of HYD B RSVR LO LVL appeared, indicating that the fluid quantity is < 5 L (1.32 US Gal) in reservoir. The estimation of the hydraulic leak was done only considering the fluid quantity in the blue hydraulic reservoir, and without considering the accumulators volume. Therefore, if the blue reservoir had a maximum of 22.6 L before 1426 UTC, the blue hydraulic fluid leak could have been around 0.5 L/min or loss of approx. 17 L in 33 minutes, from 14:26UTC to 14:59UTC.

The Green reservoir was found empty. It is assumed that the Green hydraulic fluid leak happened due to the damages to the NLG supply green hydraulic system pipes after the NLG collapsed. Air Pressure in the Green reservoir was found at zero (0). The Yellow reservoir was found closed to normal level. Air Pressure in the Yellow reservoir was found nominal about three (3) bars. The A330 hydraulic reservoir and respective gauges are shown (Figure 38).

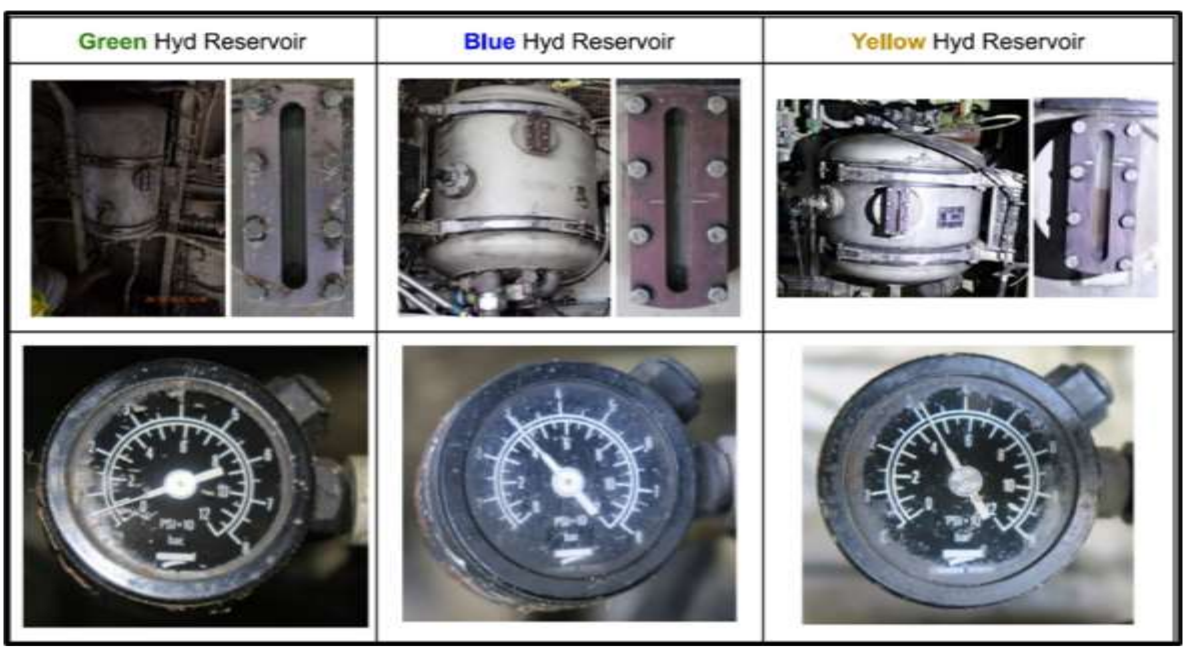


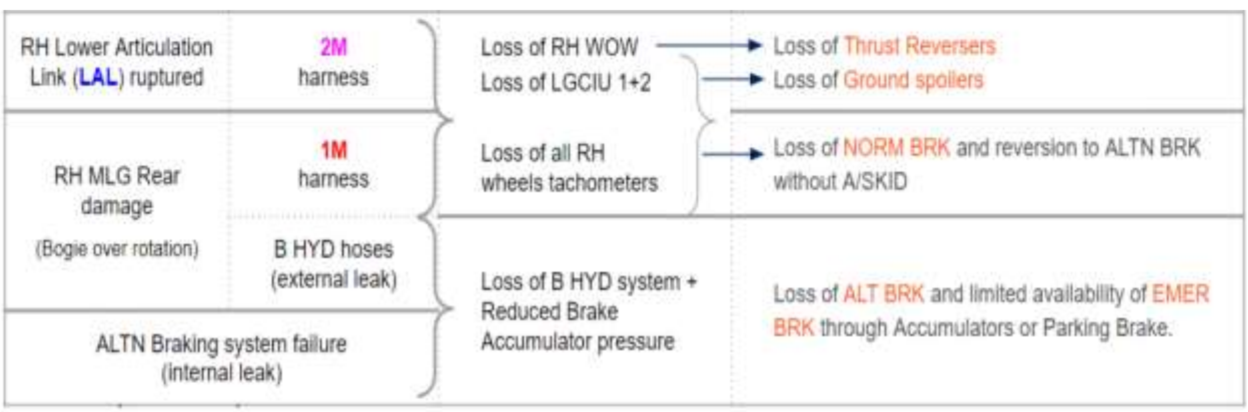
Figure 38 - The hydraulic reservoir and their specific accumulator

2.5 Landing Performance Analysis

Some performance analyses were also performed in order to assess the benefit in terms of landing distance of recovering some of the deceleration means in an aircraft condition similar to the event. In this event all the deceleration means were lost at 103kts during the landing roll due to the following reasons:

- Thrust reversers**:** Weight-On-Wheel (WOW) discrepancy between the two MLGs (in that case, "Flight" condition is taken by default in order to prevent thrust reversers deployment in flight).
- Ground spoilers: Loss of both LGCIUs and all RH MLG wheel tachometers.
- Normal braking: Loss of all RH MLG wheel tachometers.
- Alternate & Emergency braking: Blue hydraulic system and accumulator pressure loss due to the combination of an internal leakage at Park Hydraulic Manifold PRV (dormant" failure) and an external leakage (severed blue hydraulic hoses at RH MLG brake level).

As a summary:



Some performance computations have been done considering the following aircraft conditions:

- Performance database AB322A06 (corresponding to MSN0219)
- Conf FULL
- Max Pedal Braking
- Landing Weight = 155t
- Antiskid FAULT
- Nose Wheel Steering (NWS) FAULT
- No braking on RH MLG
- Alternate braking without anti-skid on LH MLG

The dormant failure on the PRV has not been taken into account as not modelled in the performance tool. Therefore, in these computations, it has been considered that the blue hydraulic system was not lost during the flight before landing (no leakage through the PRV) but also not lost at landing during brake application. Thanks to the activation of the safety valves (preventing the blue hydraulic fluid from leaking from the two ruptured hoses at the RH MLG level). This results in an asymmetrical braking (i.e. alternate braking without antiskid only on the LH MLG side).

Note: *In terms of landing performance, Alternate braking without antiskid and braking on accumulators are very close.*

And the following external conditions:

- Runway slope: -0.09%
- Runway condition: 5-GOOD (equivalent to WET up to 3 mm of water),
- OAT: 25°
- Wind: 9kt Headwind,
- Pressure Altitude: 115 ft

It has to be noted also that in these computations, the pilot inputs (i.e. brake and rudder pedal applications) are optimized in order to keep the aircraft trajectory on the RWY axis. In case of alternate braking without antiskid (as tire bursts are not guaranteed in such a situation), the performance tool computed two (2) scenarios: a landing distance with normal tires (called "ALTN A/S OFF" and a landing distance with all tire bursts. All the combinations of deceleration means recovery (i.e. with GS and/or REV available) have been computed.

The results are shown in Figure below.

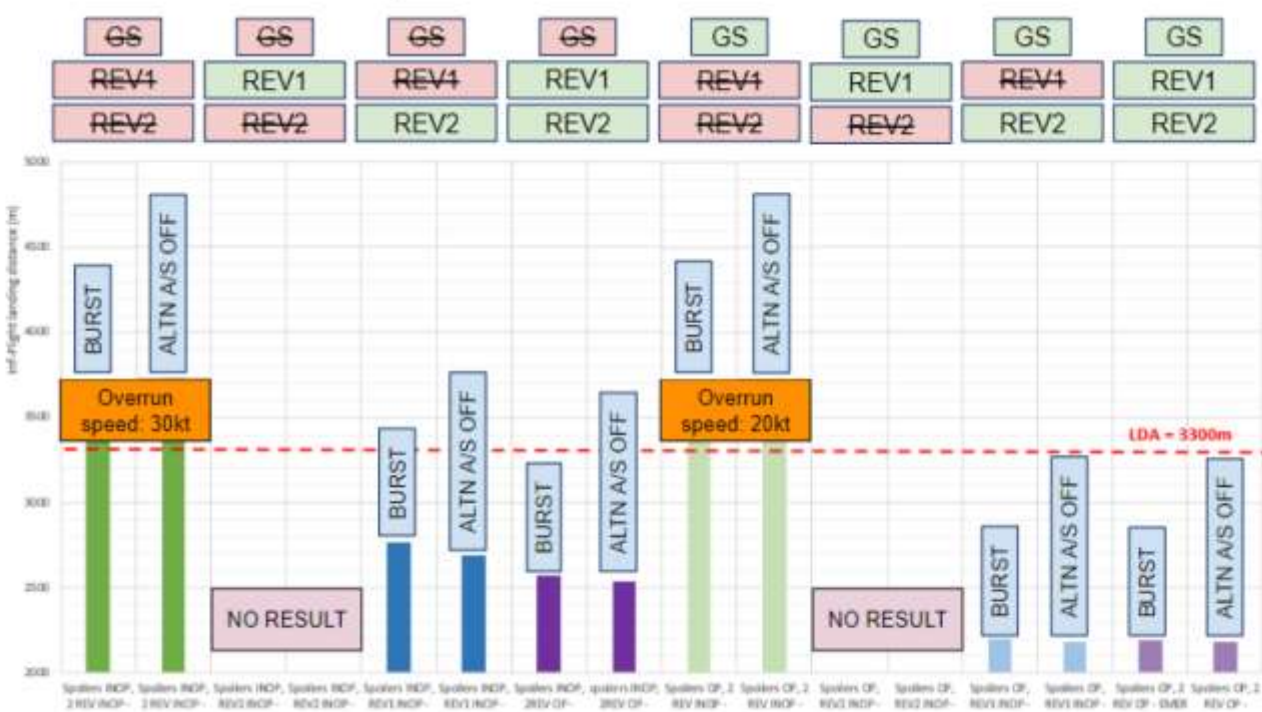


Figure 39 - The result.

The conclusions are the following:

- Keeping the blue hydraulic system (i.e. alternate braking without anti-skid) in the HL7525 event would not have prevented the runway excursion.

- Recovering both thrusts reversers (or even only REV2) prevents the aircraft from exiting the runway (not the case for the ground spoilers only).

Note: *Computations with REV1 recovery only did not converge as it is not possible to decelerate and keep the runway axis since all the available deceleration means are on the same side (i.e. LH side).*

2.6 Approach to Ground Contact

Analysis of the pilot's side stick inputs and wind condition during approach to ground contact resulted to the following and further shown on the figure below:

1. Starting from RA 319 ft, the aircraft started to be above than the normal glide path with the Side Stick Pull Back input.

2. To return to the normal glide path, the captain applied Side Stick Forward input for about three (3) seconds below RA 289 ft, resulting in a decrease in pitch attitude and an increase in descent rate from -400 fpm.

3. When passing RA 216 ft, the aircraft was still above the glide path, and the pitch attitude decreased to 1.8 degrees. Although a Side Stick Pull Back input was applied to adjust the descent rate, it did not decrease and exceeded -900 fpm.

4. At RA 202 ft, the captain applied a Side Stick Forward input, but the pitch attitude increased from 1.8 degrees to 3.9 degrees. In an attempt to lower the nose, the captain applied Side Stick Forward for one (1) second, resulting in a descent rate exceeding -1000 fpm and beginning to lower below the normal path.

5. To stabilize the aircraft, the captain maintained a consistent Side Stick Pull Back input for two seconds at RA 150 ft to reduce the descent rate; However, the descent rate did not decrease.

6. During this process, the pitch attitude increased to 4.2 degrees at RA 76 ft. The captain again applied Side Stick Forward input for 1 second to lower the nose. At this point, the first officer called out "Sink rate," and followed by the GPWS "Sink rate" alert.

7. The captain pulled back the Side Stick up to 80% for a go-around, but the aircraft made contact with the ground.

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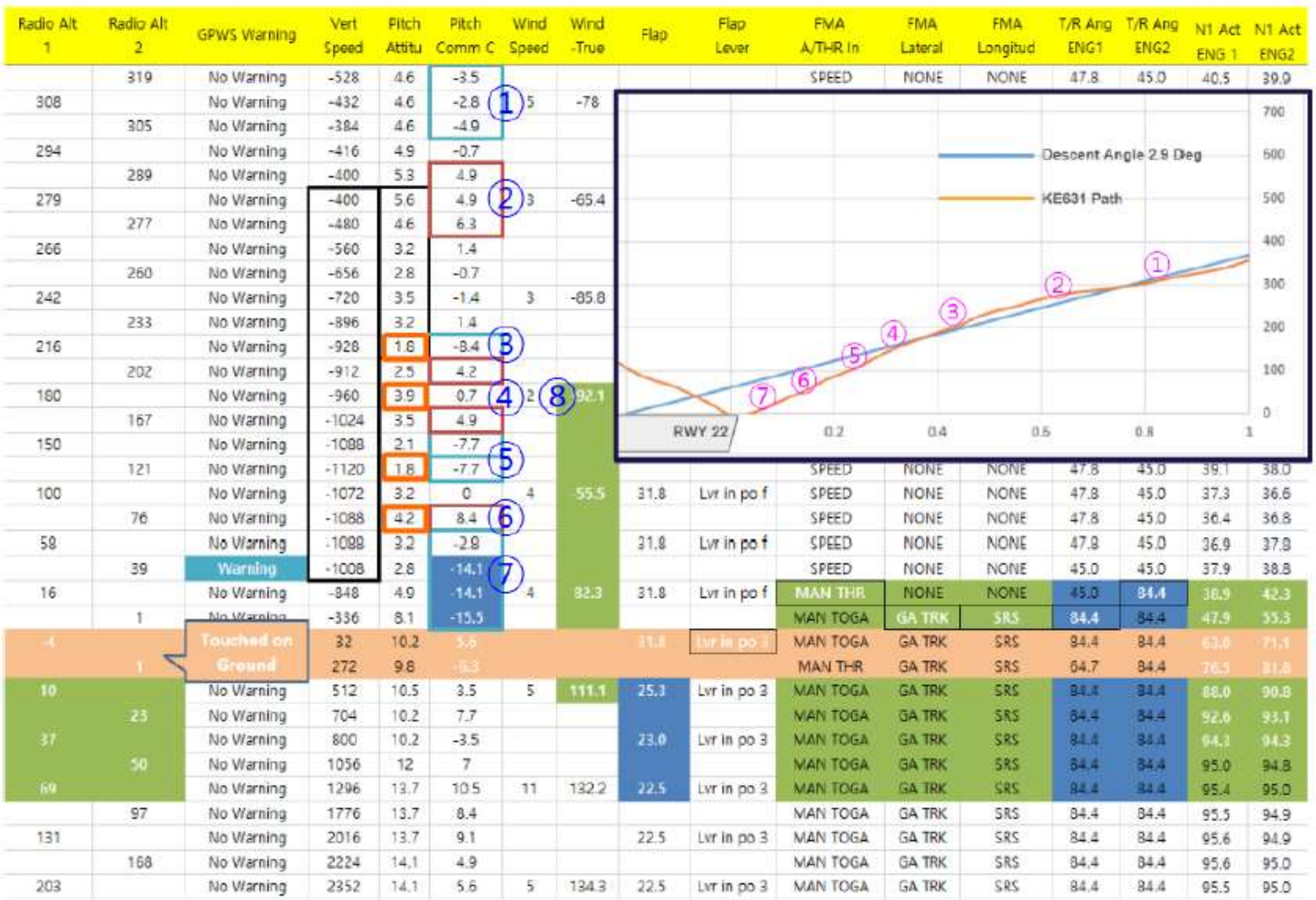
8. From RA 180 ft to the ground contact, the wind direction changed from a right crosswind to a side tail wind by approximately 180 degrees. During this period, the captain made at least three (3) attempts to reduce the descent rate, yet the aircraft's descent rate remained unchanged due to uncontrollable factors. Additionally, this timing coincided with the captain's statement regarding sensing strong downdrafts, and it aligns with the analysis indicating the presence of Vertical Wind Factor (Multiple downdrafts).



Radio Alt 1	Radio Alt 2	GPWS Warning	Vert Speed	Pitch Attitu	Pitch Comm C	Wind Speed	Wind -True	Flap	Flap Lever	FMA A/THR In	FMA Lateral	FMA Longitud	T/R Ang ENG1	T/R Ang ENG2	N1 Act ENG 1	N1 Act ENG2
	319	No Warning	-528	4.6	-3.5					SPEED	NONE	NONE	47.8	45.0	40.5	39.9
308		No Warning	-432	4.6	-2.8	5	-78									
	305	No Warning	-384	4.6	-4.9											
294		No Warning	-416	4.9	-0.7											
	289	No Warning	-400	5.3	4.9											
279		No Warning	-400	5.6	4.9	3	-65.4									
	277	No Warning	-480	4.6	6.3											
266		No Warning	-560	3.2	1.4											
	260	No Warning	-656	2.8	-0.7											
242		No Warning	-720	3.5	-1.4	3	-85.8									
	233	No Warning	-896	3.2	1.4											
216		No Warning	-928	1.8	-8.4											
	202	No Warning	-912	2.5	4.2											
180		No Warning	-960	3.9	0.7	2	92.1									
	167	No Warning	-1024	3.5	4.9											
150		No Warning	-1088	2.1	-7.7											
	121	No Warning	-1120	1.8	-7.7					SPEED	NONE	NONE	47.8	45.0	39.1	38.0
100		No Warning	-1072	3.2	0	4	-55.5	31.8	Lvr in po f	SPEED	NONE	NONE	47.8	45.0	37.3	36.6
	76	No Warning	-1088	4.2	8.4					SPEED	NONE	NONE	47.8	45.0	36.4	36.8
58		No Warning	-1088	3.2	-2.9			31.8	Lvr in po f	SPEED	NONE	NONE	47.8	45.0	36.9	37.8
	39	Warning	-1008	2.8	-14.1					SPEED	NONE	NONE	45.0	45.0	37.9	38.8
16		No Warning	-848	4.9	-14.1	4	82.3	31.8	Lvr in po f	MAN THR	NONE	NONE	45.0	84.4	36.9	42.3
	1	No Warning	-336	8.1	-15.5					MAN TOGA	GA TRK	SRS	84.4	84.4	47.9	55.3
-4		Touched on Ground	32	10.2	5.6			31.8	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	63.0	71.1
	1		272	9.8	-6.3					MAN THR	GA TRK	SRS	64.7	84.4	76.5	81.8
10		No Warning	512	10.5	3.5	5	111.1	25.3	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	88.0	90.8
	23	No Warning	704	10.2	7.7					MAN TOGA	GA TRK	SRS	84.4	84.4	92.6	93.1
37		No Warning	800	10.2	-3.5			23.0	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	94.3	94.3
	50	No Warning	1056	12	7					MAN TOGA	GA TRK	SRS	84.4	84.4	95.0	94.8
69		No Warning	1296	13.7	10.5	11	132.2	22.5	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	95.4	95.0
	97	No Warning	1776	13.7	8.4					MAN TOGA	GA TRK	SRS	84.4	84.4	95.5	94.9
131		No Warning	2016	13.7	9.1			22.5	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	95.6	94.9
	168	No Warning	2224	14.1	4.9					MAN TOGA	GA TRK	SRS	84.4	84.4	95.6	95.0
203		No Warning	2352	14.1	5.6	5	134.3	22.5	Lvr in po 3	MAN TOGA	GA TRK	SRS	84.4	84.4	95.5	95.0

Figure 40 - DFDR Analysis

2.7 Handling Quality (HQ) Analysis

As mentioned, between 14:26:06 UTC (300 ft RA) and 14:26:22 UTC (70 ft RA), there was high-pitch sidestick activity and high roll sidestick activity. The calibrated airspeed (CAS)remained stable around speed target (Vapp) and the aircraft passed durably below the 3° flight path at 150 ft RA. In these regards, the aircraft vertical flight path versus the PAPI profile (2.9°) during the last 400 ft AGL was reconstructed as shown (Figure 41).

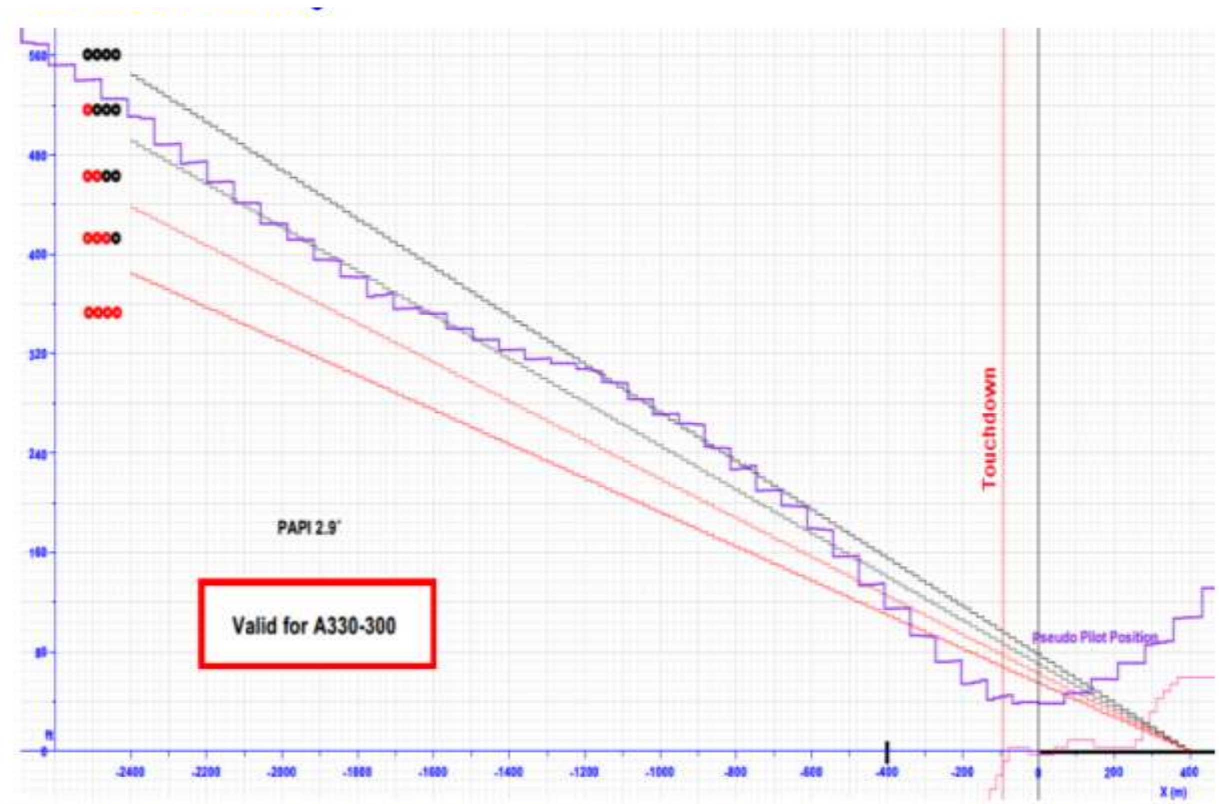


Figure 41 - The vertical flight path.

According to this reconstruction, the PAPI indications were the following:

- Three red lights around 130 ft RA,
- Four red lights around 100 ft RA.

Further, based on FDR analysis, the contributing factor to the aircraft's descent during the second approach was identified as an increase in vertical wind factor. A specific HQ analysis on the second approach on RWY22 was done to determine the contributing factors of the late destabilization of the aircraft that flew below the published flight path and touched down before the runway threshold. This analysis includes the following:

A. Wind Re-computation

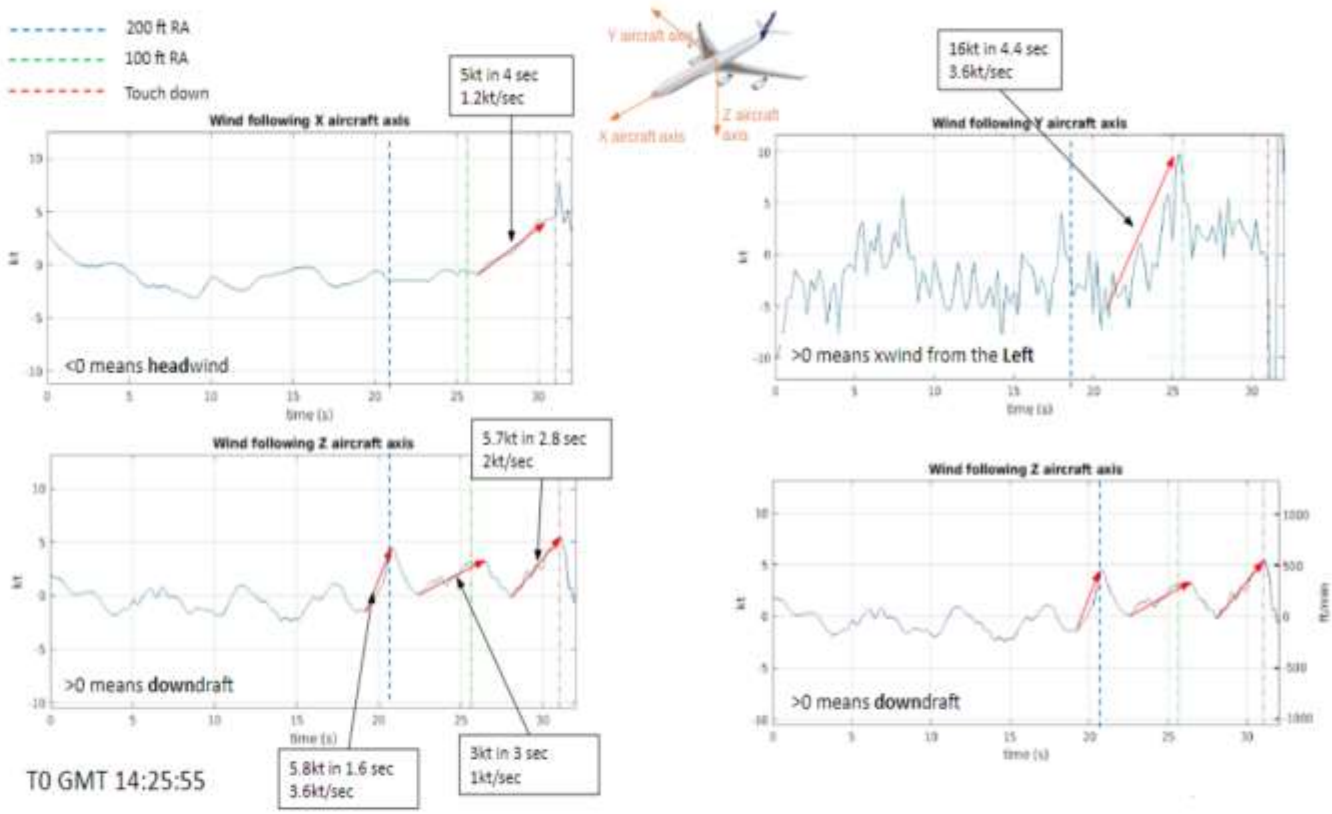


Figure 42 - The wind re-computation.

Based on these results, it can be concluded that the aircraft experienced:

- On longitudinal (X axis), a 5kt tailwind increase just before and during the flare leading to CAS and lift decrease.
- On lateral (Y axis), a significant left wind gradient (16kt in 4.4sec) just before and during flare.
- On vertical (Z axis), multiple downdrafts around 200ft (max 500ft/min), 100 ft RA and during the flare which contributed to increase the vertical speed.

B. Re-computation of the aircraft vertical speed

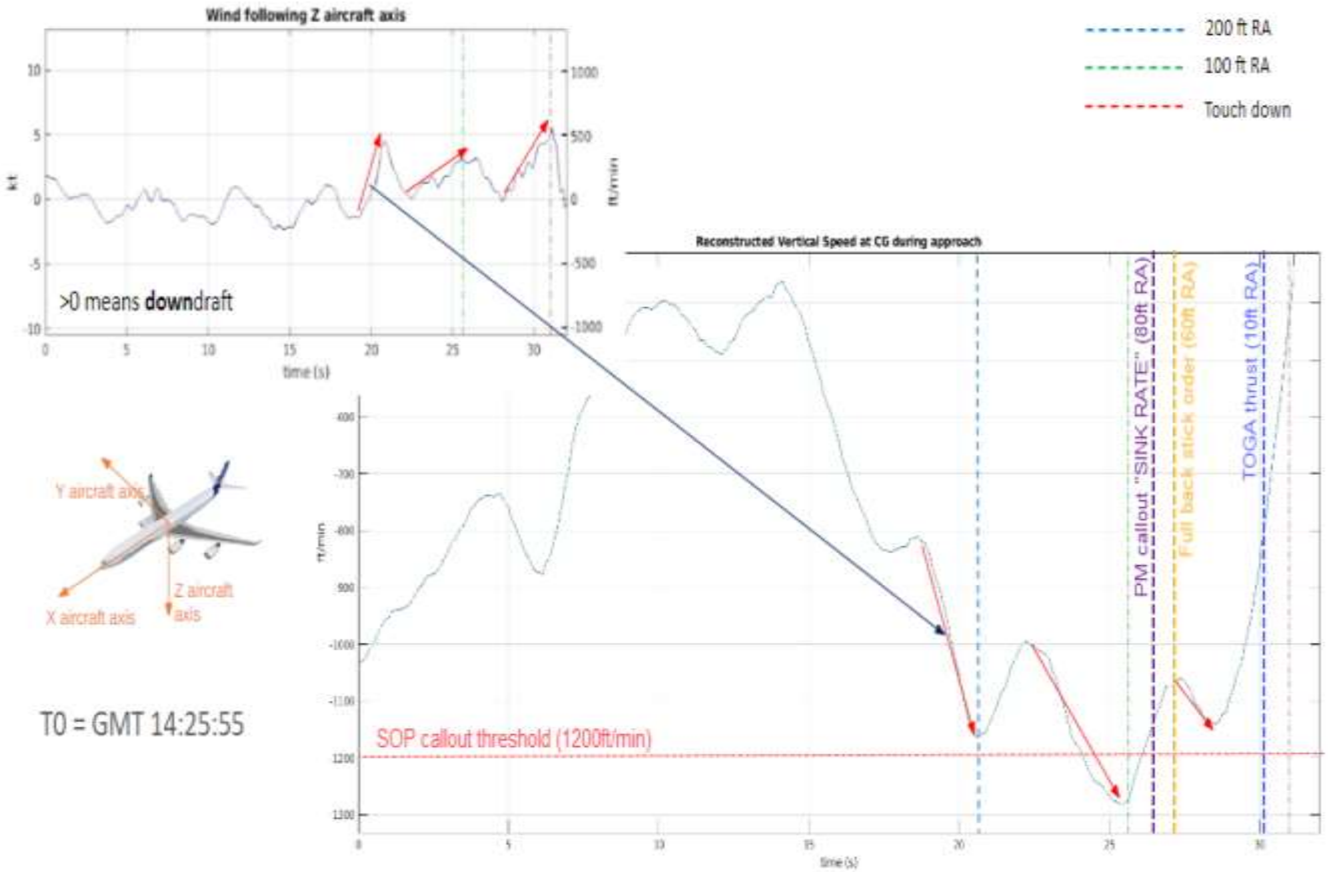


Figure 43 - Vertical Speed re-computation

This vertical speed recomputation shows that the two first downdrafts increased the Vz from 800ft/min to almost 1300ft/min reached at 100 ft RA. The PM callout occurred about 2sec after the Vz increased above 1200ft/min.

C. Replay of the approach using desktop simulation tool

The following simulations allowed to review different “what if” scenarios in order to identify:

- The contributing factors of the late destabilization.
- When the G/A should have been performed to avoid touching the ground.

For the destabilization contributing factors, the three following simulations were done focusing on the aircraft vertical trajectory (i.e. radio altitude):

1. A nominal replay of the approach with sidestick inputs and recomputed wind:

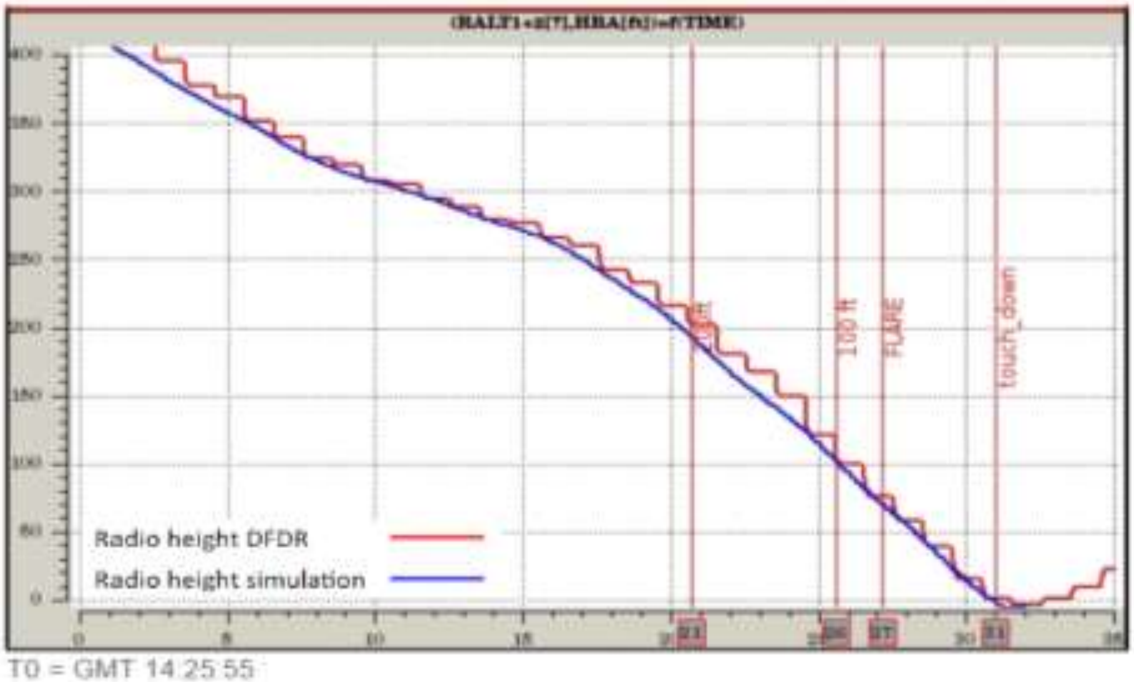


Figure 44 - Sidestick input

This shows that this simulation matches pretty well the event validating the settings of the computation.

2. A simulation with the same pilot sidestick inputs as in the event but with no more wind variation in the last 10 seconds before touchdown (i.e. from 200 ft RA):

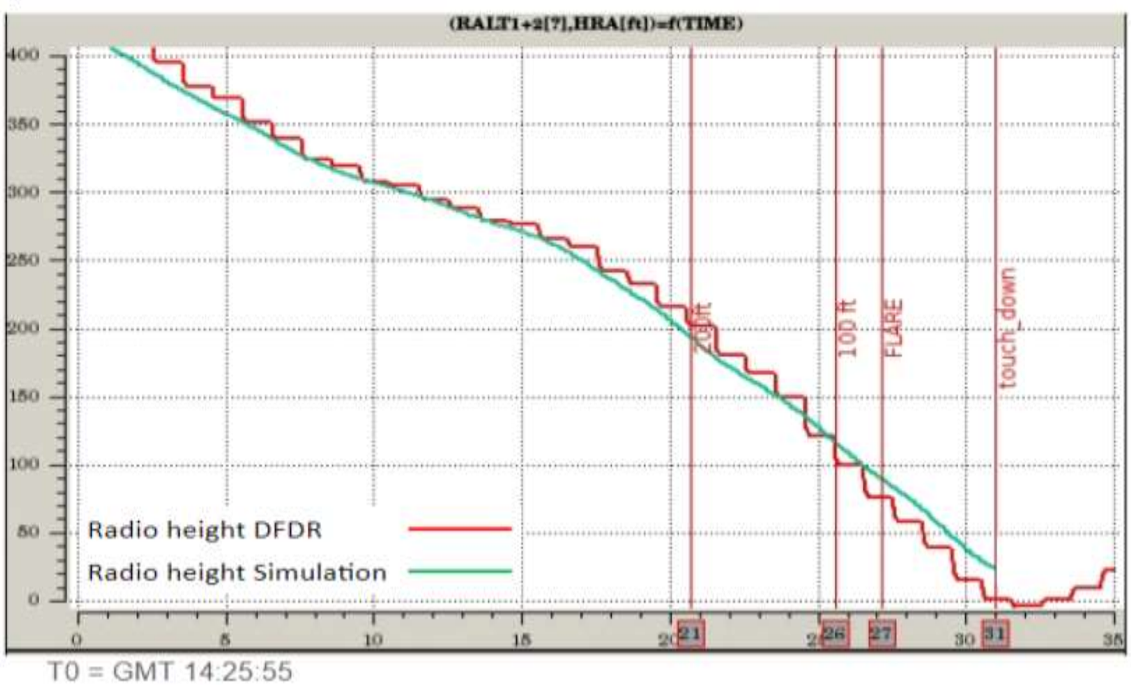


Figure 45 - Sidestick input with no wind.

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This simulation shows that the wind was a contributing factor that led the aircraft flying below the correct fly path in the last 100 ft RA (25 ft RA at event touchdown).

3. A simulation with the wind variations of the event (recomputed), but with no pilot sidestick inputs in the last 10 seconds before touchdown (i.e. from 200ft RA).

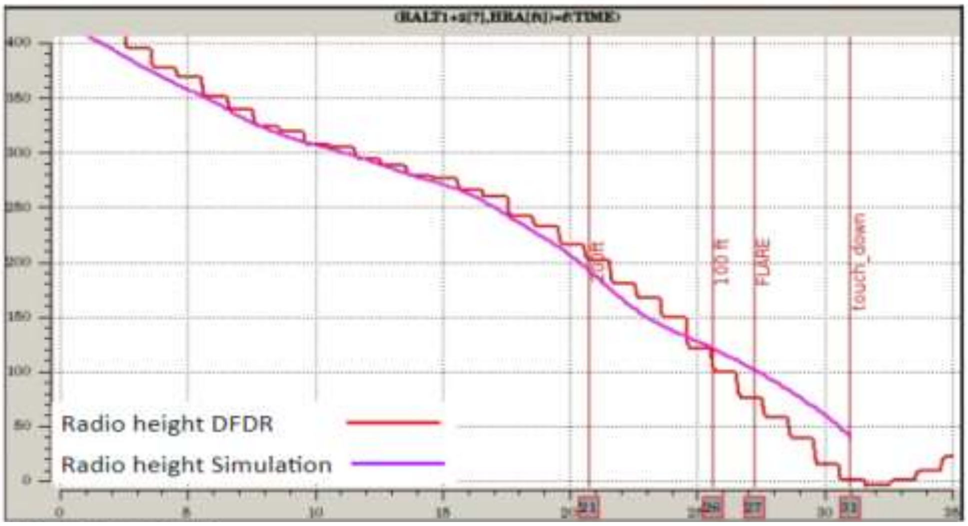

Figure 46 - Sidestick with wind.

The simulation shows that the pilot sidestick input was also a contributing factor with a higher impact on the trajectory than the wind: 40ft RA (iso 25ft RA) at event touchdown. The following simulations were done to assess when the G/A should have been performed to avoid the touch with the ground:

- A simulation with TOGA thrust applied at the time of the Full Back Stick (FBS) input (i.e. 60ft RA) as requested by the Go-Around Standard Operating Procedure (vs event where TOGA was applied about 3sec after the FBS order).
- A simulation with a G/A initiated at 80ft RA (i.e. ~1sec before the actual initiation).

The results of these two simulations are presented in the following graph:

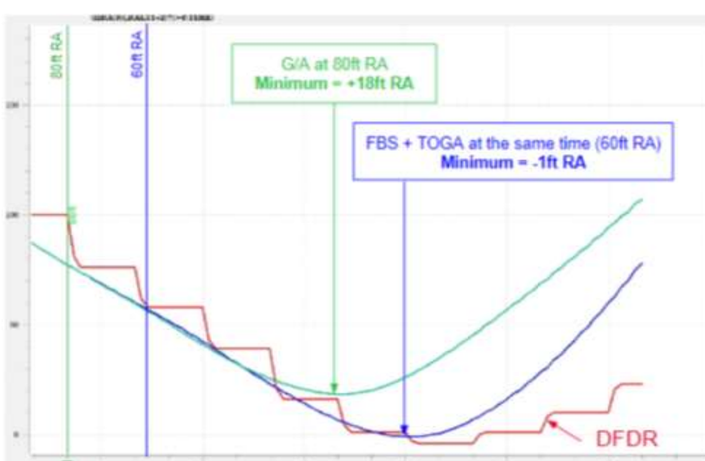

Figure 47 - Graph 1.

As a conclusion, the Handling Qualities analysis shows that:

- The aircraft experienced several downdrafts during the last 200ft RA.

- Both wind and pilot sidestick inputs contributed to the late destabilization, with a higher contribution from the pilot inputs,

- If the G/A was initiated 1sec before (i.e. 80ft instead of 60ft), the aircraft would not have touched the ground.

2.8 Situational Awareness

Based on interviews with the flight crew, in consideration of the arrival airport weather conditions, during the briefing at Incheon, an extra 3,000 lbs. of fuel were added before departure. There were no unusual occurrences until the CEB approach. After receiving clearance from ATC for an RNAV RWY 04 approach, the pilots noticed CBs along the route. The crew discussed avoidance routes, considering the surrounding CB. Before passing the initial approach fix (TONYO), the variable winds shifted direction from RWY 04 to RWY 22. While passing on short finals with the runway in sight, the weather became heavy with rain, and the runway was no longer visible even when the wiper was used. The captain aborted their approach since the situation was getting worse and a safe landing was not possible.

Additionally, while performing the go-around, ATC instructed, “Climb 4,000 ft, direct Almar.” The flight crew then requested to hold over Almar. In preparation to hold in Almar, the ATC asked, “Say intention?” In response, the flight crew requested information on the weather and precipitation status. Upon receiving a moderate rain report from ATC, the crew determined that weather was improving and a safe landing would be possible on the second approach.

Further, after the second go-around and ground contact at RWY22, the crew, based on interviews and CVR, discussed with the OCC the possibility of diverting to Davao in case another go-around is conducted after one more attempt at the CEB approach. Being aware that the fuel was sufficient, the crew and OCC agreed to divert to Davao. The crew checked the remaining fuel quantity for diversion. On the other hand, the crew was not aware that the landing gear was locked in an extended position after the second go-around.

Operational briefings are required based on the company FCTM AOP-20 P3/10 (Figure 45) as an integral element of the Threat and Error Management (TEM) process for each flight. In this case, this procedure was evident based on the CVR file.

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HOW TO CONDUCT BRIEFINGS

Applicable to: ALL

Ident.: AOP-20-A-00024897.0001001 / 09 NOV 21

OBJECTIVE OF OPERATIONAL BRIEFINGS

Operational briefings are an integral element of the Threat and Error Management process for each mission. Briefings should focus on the identification of threats that affect the intended operations and agreement on mitigation (avoidance, management) of those identified threats.
The second purpose of the flight crew briefing should be the identification of significant differences or deviations to "routine" operations.
At the end of the briefing, the flight crew should have a shared mental model of the intended operations, the identified threats, their mitigations and deviations from routine operations.
The flight crew briefing should provide the PM the expected monitoring framework.
The briefing should create more capacity in thinking and acting. It should enable team confidence building and minimize the startle effect when non-standard situations are encountered. This increases resilience of the flight crew.
A briefing is complementary to SOPs but is not a repetition of SOP items. A briefing is not to be confused with setting and checking of the aircraft systems for the intended flight phase. In order to perform these tasks, the flight crew must follow the SOPs.

KAL A330/A340 FLEET AOP-20 P 3/10

FCTM C to D → 23 NOV 21

Figure 48 - A330 FCTM extract section on briefing.

In addition, due to the R/H MLG unsafe condition, the flight crew was focusing on controlling the aircraft and was not able to recognize the malfunction of the accumulator brake due to Blue Hydraulic Low-Level Fault until landing. Apparently, there was deficiency in Airbus's Crew Operating Procedure and Alerting in relation to the A330 Blue Hydraulic Low-Level Fault.

2.9 Aircraft Maintenance Information

The maintenance and continuing airworthiness of the Airbus A330-322 aircraft with registration HL7525 was provided by the Korean Air Maintenance & Engineering Division of Korean Air in compliance to manufacturer's documents.

The maintenance log book was retrieved last October 28, 2022 from the aircraft on site contains the maintenance log information from the previous flights as listed below:

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- 21 Oct 2022 during flight ICN- XMN: ELEC C/B TRIPPED after landing "LT taxi/TOR… D48". Deferred as per MEL 33-40-09A CAT C rev 37.

- 18 Oct 2022 during flight SGN-ICN: While taxing ELEC C/B TRIPPED message displayed after landing. No maintenance message; Replaced taxi/take-off lamp and LT per AMM 33-46-11-960-801-A.

- 17 Oct 2022 at ICN: N°4 BRK WORN OUT. Replaced No. 4 wheel brake.

- 16 Oct 2022 flight NGO-ICN: ELEC C/B TRIPPED message while departing. No maintenance message; Replaced taxi/take-off lamp and light check per AMM task 33-46-11-960-801A.

- 14 Oct 2022 flight DPS-ICN: No. 2 main tire thread worn. Replaced wheel/tire assembly per 330-AMM-32-41-11-800-001.

2.9.1 Aircraft Recovery

After the AAIIB-CAAP site investigators completed the initial documentation of the aircraft and accident site, a notification was made to the designated airport incident commander to initiate the recovery/repositioning of the aircraft. Likewise, the Korean Air (KE) Station Manager and Line Maintenance Engineer were also advised by AAIIB-CAAP of the requirement to retrieve and secure the DFDR and CVR.

The procedures for the removal are guided by the MCIAA Disabled Aircraft Removal Plan of the Mactan Airport Emergency Plan (MAEP). On October 26, 2022, the preparation work for the removal of the aircraft was conducted in parallel to the onsite investigation. A road was prepared around the aircraft to remove the aircraft from the accident site. A lifting bag was initially planned to be used to recover the aircraft. Under published RPVM capability for removal of disabled aircraft, lifting bags and movement systems for B747-type aircraft are available, however, the existing lifting bag was not used on the recovery operations.

After the initial preparation of relocating the disabled aircraft, the plan did not proceed immediately since there were some documentations required prior for MCIAA to commence with the relocation. It was later found that the MCIAA-DARP 1st edition dated March 2019, 3.9 (c) p23., states that one of the responsibilities of AAIIB-CAAP was to *"Give the Aircraft Operator/Owner and Airport Management a written release from custody to remove the disabled aircraft. This release shall permit the removal of the aircraft wreckage…"* Although such a recovery plan was available since 2019, the AAIIB-CAAP is not aware of such a requirement, and this was not properly communicated to AAIIB-CAAP during its publication. This resulted in the interruption of the immediate repositioning of the said aircraft. Moreover, as per PCAR part 13, para 13.210 (a) (1) (iii), the release of aircraft custody from AAIIB-

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CAAP is only given to the aircraft operator/owner. It is recommended that MCIAA-DARP 1st edition, dated March 2019, 3.9 (c) p23, be amended, particularly the words "…release from custody to remove the disabled aircraft…" to "…written authority to MCIAA to remove the disabled aircraft….". It is further recommended in coordination with AANSOO-CAAP that AAIIB-CAAP should be consulted when drafting procedures related to aircraft accidents and the removal of aircraft involved in an occurrence being investigated by AAIIB prior to the publication of the procedures.

Korean Air also began their survey of the aircraft in preparation for the removal procedures after obtaining clearance from AAIIB-CAAP. Defueling of the aircraft was started, followed by Korean Air personnel retrieval of hand-carry baggage at the cabin and unloading of baggage/cargoes from the aircraft aft hold.

Together with CAAP, MCIAA, and Korean Air Maintenance Engineer Department surveyed, planned, and prepared for the actual aircraft recovery, taking into consideration the state and weight of the aircraft. With the aircraft nose landing gear collapsed on the soft ground, the use of a crane was recommended. A third-party service provider located within the airport's immediate vicinity was then contracted by Korean Air.

While the surface preparation was in progress, the contracted 3rd party, after establishing the recovery plan, started to commence the mobilization of equipment. A final briefing of the recovery plan was also done by the contracted party to CAAP, MCIAA, and Korean Air, showing the detailed illustration of the recovery procedure (Figure 49). During the relocation, the disabled aircraft was hoisted on the multi-axle flatbed trailer using a telescopic crane. After being secured, the flatbed trailer bearing the disabled aircraft was transferred towards a temporary relocation area within the MCIAA Compound (Figures 50 and 51).

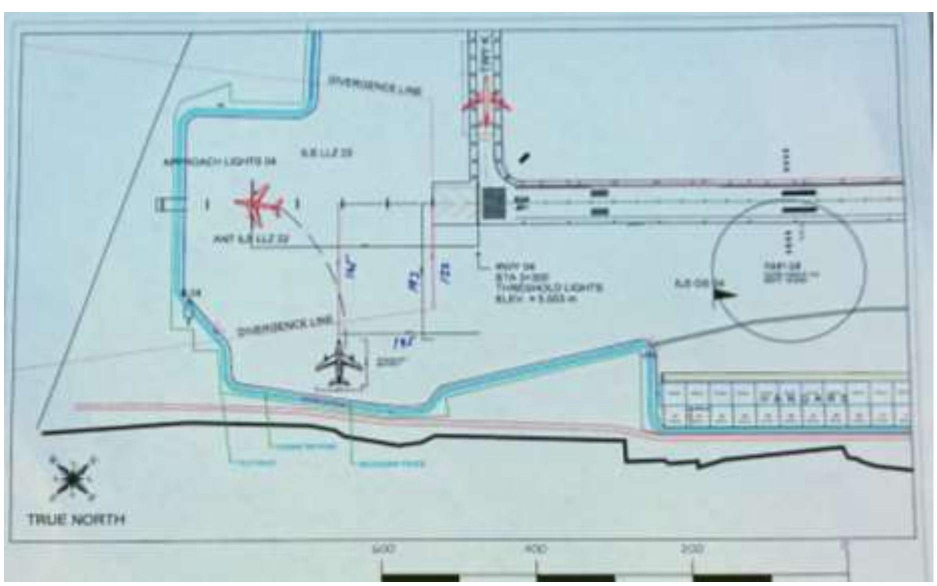

Figure 49 - A330 relocation site map.

Figure 50 - The aircraft with collapsed NLG at the temporary relocation area.

Figure 51- The aircraft temporary relocation area.

3. CONCLUSIONS

3.1 Findings

3.1.1 Aircraft

a. The aircraft has a valid Certificate of Airworthiness, Registration and had been maintained in compliance with Republic of Korea Ministry of Land Infrastructure and Transportation (MOLIT).

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b. The maintenance records indicated that the aircraft was equipped and maintained in accordance with Airbus approved procedures and was provided by the aircraft Maintenance and Engineering Department of Korean Air.

3.1.2 Flight Operations

a. The flight crew carried out normal radio communications with Mactan Approach and Control Tower.

b. The captain was the pilot flying during all the approaches to RWY 22 of Mactan-Cebu International airport.

c. On the first (1^{st}) approach for landing at RWY 22, after descending below the minima, the crew encountered heavy rain and elected to go-around as they lost runway visibility.

d. On the second (2^{nd}) approach for landing at RWY 22, a system call out of “100” was heard, followed by a call out of “sink rate” from the FO seconds later.

e. The aircraft made ground contact before the threshold of RWY 22.

f. RWY 22 threshold showed visible tracks of both Main Landing Gears six (6) meters before the pavement of RWY 22.

g. After the go-around, Electronic Centralized Aircraft Monitor warning was received informing of the Landing Gear Control Interface Unit 1 and 2 fault, and Brakes Anti-Skid Fault Message.

h. During the third (3^{rd}) approach at RWY 22, while starting to align with runway heading upon selecting landing gear lever down, only two (2) out of the three (3) landing gear lights illuminated green.

i. The flight crew aborted the approach and decided to make another holding pattern.

j. During holding, the crew performed the procedure for landing gear gravity extension.

k. While on landing roll, the aircraft failed to stop and overran the end of RWY 22.

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l. After colliding with the localizer antenna and runway approach lighting system, the aircraft came to a complete stop at the grassy portion about 235 meters from the end of RWY 22.

3.2 Cause Factor

3.2.1 Primary Cause Factor

a. The increase of VSI was attributed to the forward pitch control from the captain that resulted in the ground contact before the runway.

b. The increase in vertical wind factor during the aircraft's descent on the second approach.

c. The right hand MLG hit a 15cm step of the cemented edge of RWY 22 resulting in multiple damage/faults to the said landing gear and consequently the loss of most of the deceleration means, specifically aircraft braking failure resulting in runway overrun.

3.2.2 Contributory Cause Factors:

a. Loss of spoilers and reversers
b. Aircraft brake system dormant failure
c. The deficiency in Airbus's Crew Operating Procedure and Alerting in relation to the A330 Blue Hydraulic Low-Level Fault.

4. SAFETY RECOMMENDATION

4.1 For CAAP-AANSOO to ensure that:

a. Mactan-Cebu International Airport Authority (MCIAA)

1. To amend MCIAA-DARP 1st edition dated March 2019, 3.9 (c) page 23 particularly the words "…release from custody to remove the disabled aircraft…" to "…written authority to MCIAA to remove the disabled aircraft…". It is further recommended in coordination with AANSOO-CAAP, that AAIIB-CAAP be consulted when drafting procedures related to aircraft accident and removal of aircraft involved in an occurrence being investigated by AAIIB prior to publication of the procedures.

2. The availability of the lifting bag for aircraft recovery based on Mactan-Cebu International Airport Authority (MCIAA) disabled aircraft recovery procedure (DARP).

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3. Comply with the published CAAP-AANSO Manual of Standards, 2nd Edition dated February 2017, chapter 6.4.1.13, ICAO Annex 14 Volume 1, chapter 3.5.8 and ICAO Doc 9157 Aerodrome Design Manual Part 1 which states that "a RESA must be prepared or constructed so as to reduce the risk of damage to an aeroplane undershooting or overrunning the runway. The said aerodrome operator has to consider improving the conditions of the threshold end of Runway 04/22 to meet the CAAP and ICAO requirements.

5. SAFETY ACTIONS

5.1 As a result of the accident, Korean Air initiated safety corrective actions to mitigate the probability of the accident:

1. Recovery Program for the Involved Pilots such as;

a. Undergone Requalification Training.
b. Attended Psychological and Mental Support,
c. Undergone Evaluation of Flight Operational Readiness.
d. Provided with Flight Operation Support

2. Operations Control Center was renamed Operations and Customer Center wherein four (4) sub-centers namely: Network Operation Center, Load Control Center, Flight Control Center, and Maintenance Control Center started to operate as one integrated unit under one location last December 2023.

3. Aircraft manufacturer-oriented dispatch group was implemented with Airbus and Boeing dedicated dispatchers for flight planning and following. Previously, they were managed based on areas of operations (i.e., West bound/East bound, America, Europe/China, South East Asia/Oceania, Japan and Domestic);

4. Implementation of a platform for communication sharing using an Integrated Company Radio System (ICRS) wherein a one-touch SATCOM/VHF/Phone was made available to contact any aircraft under operations;Flight Following was further enhanced by having a system in monitoring PVA (Plan vs. Actual) discrepancy such as position, altitude, fuel, etc. With this system, an aircraft icon alert is available when a discrepancy is noted. Likewise, Korean Air is currently developing an EDR-based turbulence sharing platform which will automatically send an alert to other aircraft when such condition exists.

5. Korean Air's Training Center for cabin crew has simplified the emergency evacuation commands and being implemented as part of enhancing their internal procedures in response to the subject accident.

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6. Korean Air's Flight Operations actions in relation to the subject accident:

a. Training

i. Initial Qualification.

ii. Teaching method transformed from lecture based to self-directed.

iii Curriculum based on individual needs/requirement.

b. Recurrency

i. Increased frequency of non-precision approach training and enhance crew's ability to cope with adverse weather conditions.

ii. Reducing the gap of individual crew performance.

c. Line Instructor

i. Improving line instructor ability.

d. CRM

i. Improving CRM Instructors.

ii. CRM enhancement course.

e. Flight Standard

i. Take-Off/Landing Briefing Improvement - Emphasis on the importance of communication was added in the Take-off/Landing briefing card.

ii. Extract and Improve Deficiencies During Check Ride;

- For identified Grade 2 ETR (Extra Training Required) Item, CAR will be carried out and results are thoroughly verified (Unscheduled check ride).
- For Grade 3 (Minor Error) Item, the trainee will be provided with both a debriefing in reference to Flight Phase Evaluation Standard & Individual Analysis Results of the evaluation.

f. Operation

i. Strengthening of Operational Qualification for CEB Airport.

ii. Timely Dissemination of Safety Hazards Utilizing Visual Aids.

iii. Proactive Safety Management of High-Risk Airports.

g. Safety Management

i. Enhancement of SMS.

ii. Enhancement of Cockpit Safety Culture.

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