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AAIA

Air Accident Investigation Authority

Deviation from Intended Flightpath

Investigation Report

Incident to

Boeing 787-9, G-VBOW

Waypoint RIVER of Hong Kong

18 October 2019

06-2023

AAIA Investigations

Pursuant to Annex 13 to the Convention on International Civil Aviation (Annex 13) and the Hong Kong Civil Aviation (Investigation of Accidents) Regulations (Cap. 448B), the sole objective of the investigation and the Investigation Report is the prevention of accidents and incidents. It is not the purpose of the investigation to apportion blame or liability.

The Chief Inspector ordered an inspector's investigation into the incident in accordance with the provisions in Cap. 448B.

This incident Investigation Report contains information of an occurrence involving a Boeing 787-9 aircraft, registration G-VBOW, operated by Virgin Atlantic Airways (VAA), which occurred on 18 October 2019.

The Air Accidents Investigation Branch of the United Kingdom (AAIB), being the investigation authority representing the State of Operator and the State of Registry, the National Transportation Safety Board of the United States of America (NTSB) being the investigation authority representing the State of Design and the State of Manufacture, the Civil Aviation Department (CAD), Boeing and the aircraft operator, provided assistance to the investigation.

Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities of the State or Administration having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken.

This Investigation Report supersedes all previous Preliminary Report and Interim Statements concerning this incident investigation.

All times in this Investigation Report are in Hong Kong Local Times unless otherwise stated.

Hong Kong Local Time is Coordinated Universal Time (UTC) + 8 hours (hrs).

Chief Accident and Safety Investigator
Air Accident Investigation Authority
Transport and Logistics Bureau
Hong Kong
March 2023

Synopsis

At 1549 hrs on 18 October 2019, a VAA Boeing 787-9 aircraft, with registration G-VBOW and flight number VIR206, deviated from the localizer (LOC) course during the Instrument Landing System (ILS) approach to Hong Kong International Airport (VHHH).

During the ILS approach to the then Runway (RWY) 25R[1] of VHHH in Visual Meteorological Conditions (VMC), the aircraft with the autoflight system engaged intercepted the LOC but then overshot the intended heading (HDG), diverging from the LOC course towards the terrain in the north. No Enhanced Ground Proximity Warning System (EGPWS) warnings were triggered.

The Pilot Flying (PF) disengaged the autoflight system and assumed manual control of the aircraft, re-establishing the aircraft on the ILS HDG approximately 12 nautical miles (NM) from the RWY threshold and landed the aircraft uneventfully. There was no damage to the aircraft and no one was injured.

The investigation team found that this incident was caused by a software problem embedded in the flight control module (FCM) of the autoflight director system.

The investigation team has made two safety recommendations.

[1] Under the Three-runway system (3RS) Project, a new RWY to the north of and parallel to the original duel RWYs was being constructed at VHHH at the time of the incident. The original North RWY (RWY 07L/25R) was re-designated as the Centre RWY (RWY 07C/25C) on 2 December 2021, to prepare for the commissioning of the new North RWY in 2022, which would then be designated as the new RWY 07L/25R. The incident in this Investigation Report occurred on 18 October 2019; hence the designation of RWY 07L/25R in this Investigation Report refers to that of the original North RWY prior to its re-designation on 2 December 2021.

Contents

1. Factual Information

1.1. History of the Flight

(1) On 18 October 2019, a Boeing 787-9 (B787-9) with registration G-VBOW was operated by VAA for a scheduled passenger flight from London Heathrow Airport (EGLL) to VHHH. It was cleared by Air Traffic Control (ATC) of Hong Kong to fly direct to waypoint RIVER and descend to 4,500 feet (ft) for an ILS approach to the then RWY 25R of VHHH.

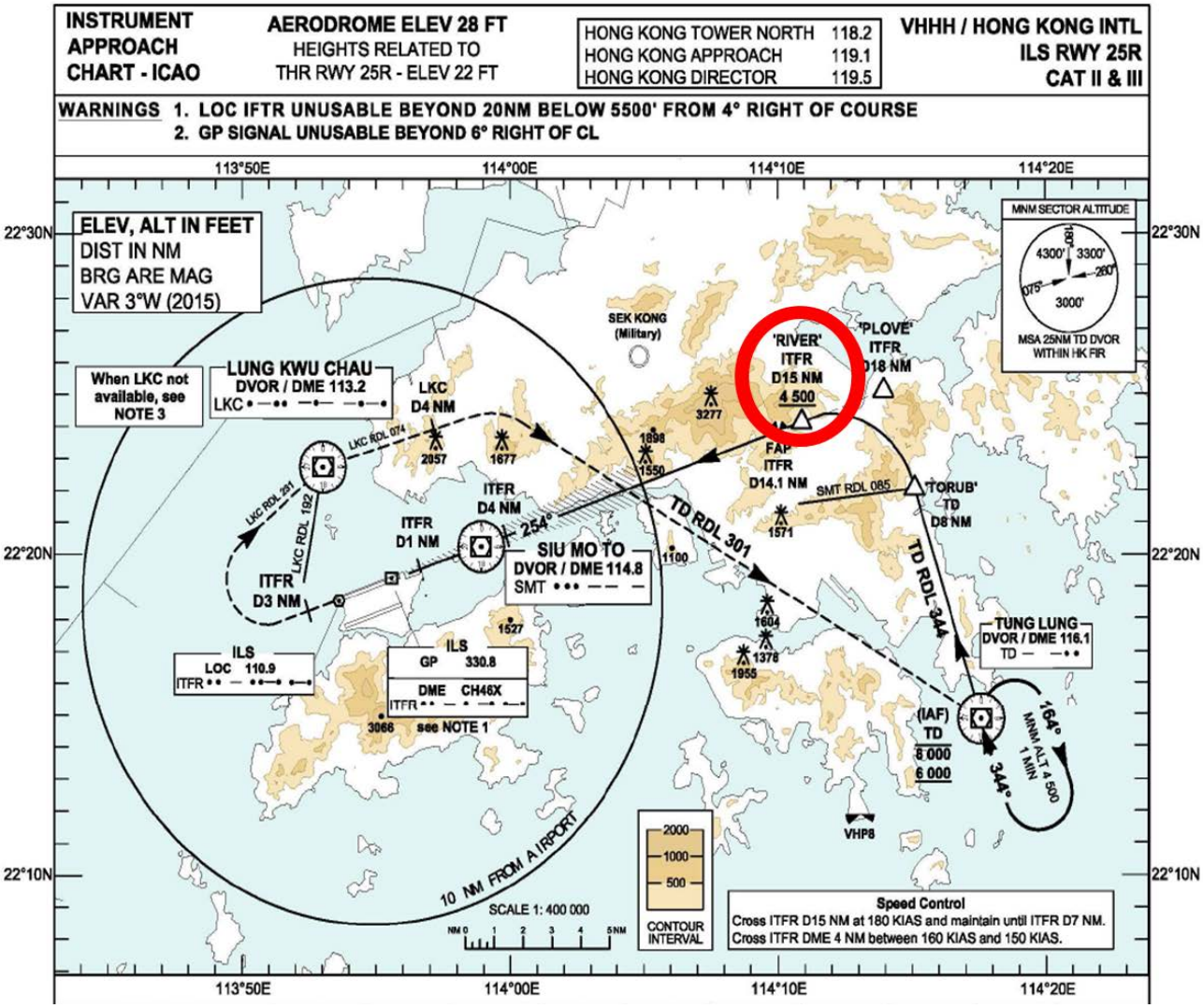

Figure 1: Instrument Approach Chart Published in Aeronautical Information Publication Hong Kong (AIP Hong Kong)

(2) During this ILS approach to RWY 25R in VMC, the aircraft with the autoflight system engaged proceeded to intercept the LOC at waypoint RIVER, which was 15 NM from the RWY, from the southeast on a HDG of 300 degrees. The aircraft made an initial turn to the left to capture the LOC.

(3) Prior to the flight, the VAA issued a crew communication to brief the crew on the lessons learned from the first incident on 29 September 2019, related to LOC capture anomalies, regarding the possibility of a LOC deviation and the appropriate response actions. Details are in Section 4.2.1. Issue of Notice to Aircrew (NTA) and Notice to Airmen (NOTAM).

(4) While the movement of the LOC pointer was slow, there was a brief discussion in the flight deck between the PF and the Pilot Monitoring (PM), referring to the previous incident, as whether the gentle bank was sufficient to properly capture the centreline. When the aircraft crossed the LOC centreline at 15:48:54 and it did not completely turn onto the RWY, it was immediately agreed by both pilots that a pilot action was necessary, once the aircraft overshot the intended HDG, diverging from the LOC course towards the terrain in the north. No EGPWS warnings were triggered.

(5) The PF disengaged the autoflight system and assumed manual control of the aircraft, re-establishing the aircraft on the ILS HDG approximately 12 NM from the RWY threshold and landing the aircraft uneventfully.

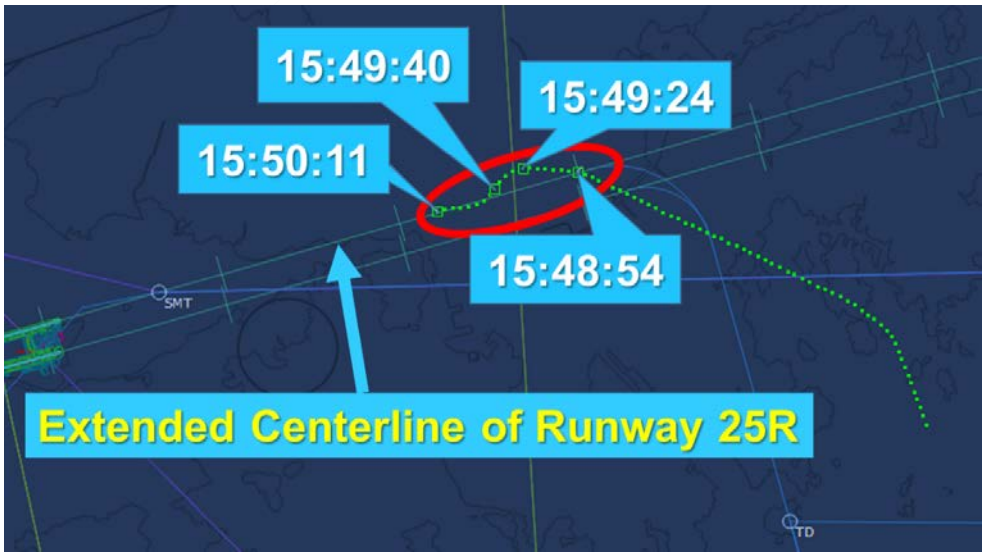

Figure 2: Radar Plot of Flight Track

1.2. Injuries to Persons

The aircraft carried 13 crew members and 258 passengers. The crew was composed of 3 pilots and 10 cabin attendants. There were no injuries to persons as a result of this occurrence.

Injuries to Persons						
Persons on board:	Crew	13	Passengers	258	Others	0
Injuries:	Crew	0	Passengers	0		

Table 1: Injuries to Persons

1.3. Damage – Aircraft

There was no damage to the aircraft.

1.4. Other Damage

No other damage was caused.

1.5. Personnel Information

1.5.1. Flight Crew

(1) The flight crew consisted of the captain, the first officer and the relief pilot. The first officer was PF in the right seat. The captain was PM in the left seat.

(2) Crew licence information is in Section 7.2 Pilot Information.

1.6. Aircraft Information

1.6.1. Aircraft

The B787-9 is a wide-body twin-engine aircraft manufactured by The Boeing Company. The aircraft is powered by two Rolls-Royce Trent 1000 engines. The aircraft has been operated by VAA since 2017. The aircraft held a valid

Certificate of Airworthiness, Certificate of Registration and Airworthiness Review Certificate. Details are in Section 7.3 Aircraft Details.

1.6.2. Autopilot Flight Director System (AFDS)

(1) The AFDS consists of three autoflight computing systems and a mode control panel (MCP) to control the attitude of the Boeing 787.

(2) It provides full flight A/P control during the primary flight control normal mode operation. It can control all flight phases except takeoff. It includes the features of Category IIIB autoland capability and backdrive of pilot controls during A/P operation.

1.6.2.1. Display of AFDS Indication

The AFDS indication is displayed on the primary flight displays (PFDs) and head-up displays (HUDs).

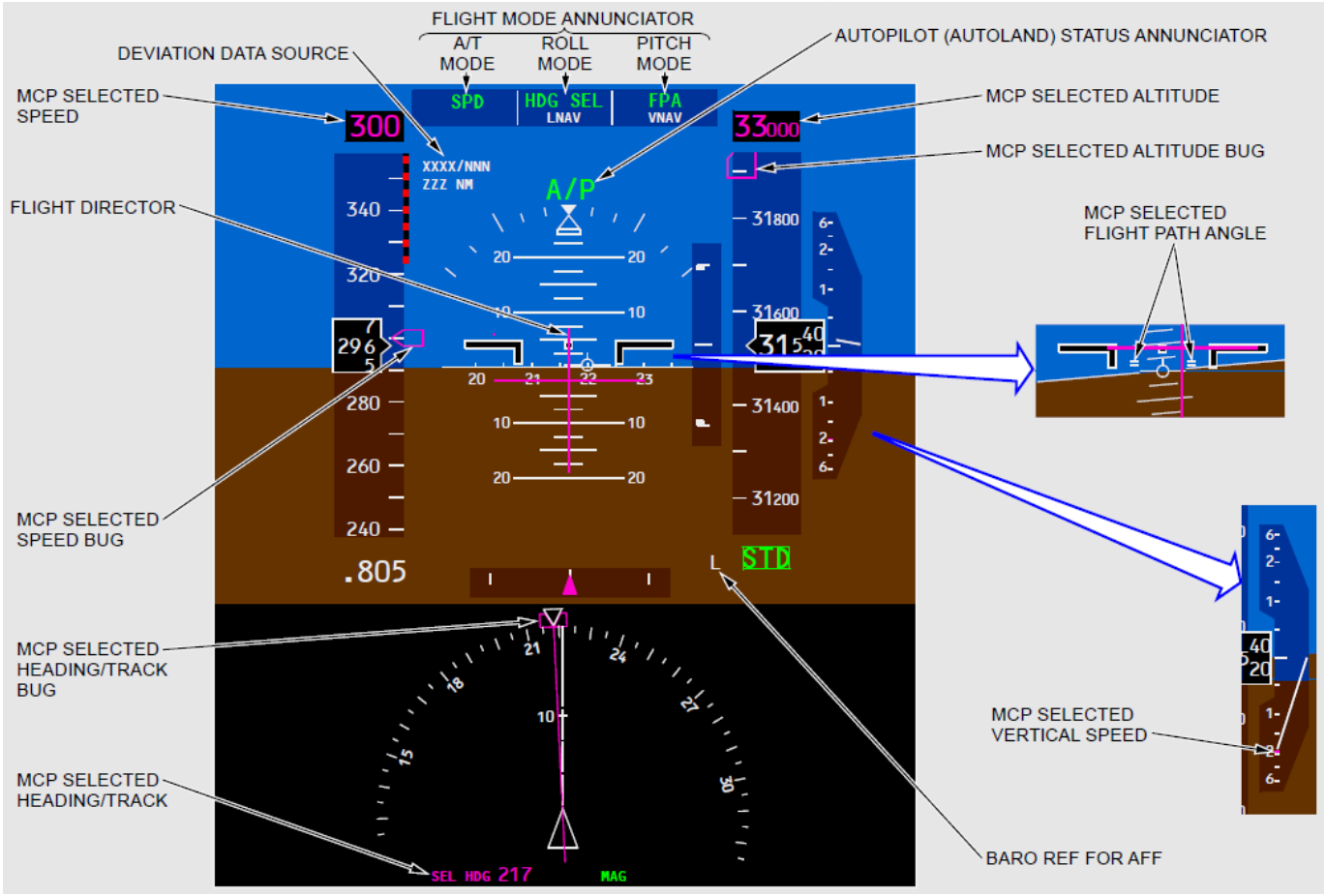

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Figure 3: AFDS Indication on PFD

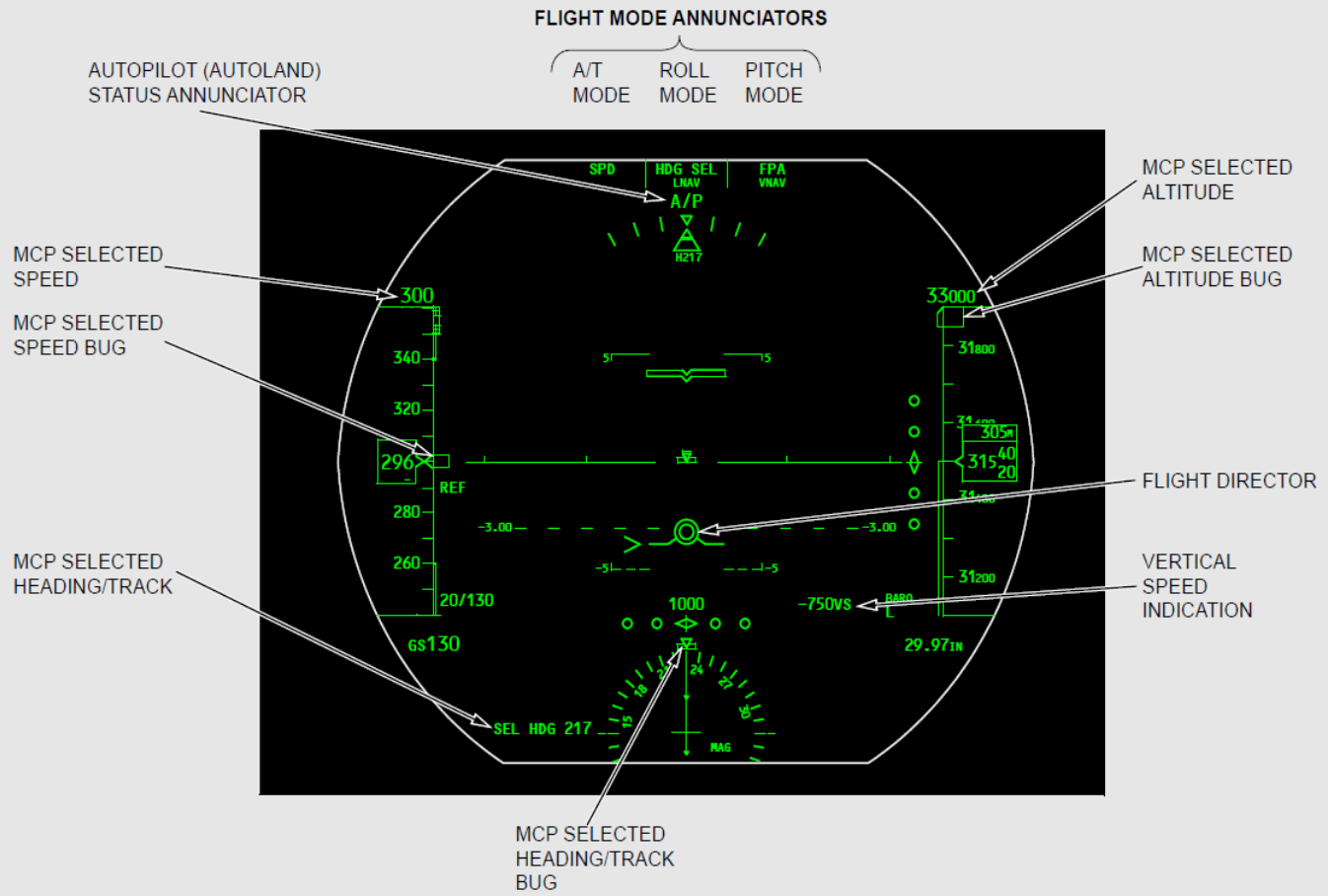


Figure 4: AFDS Indication on HUD

1.6.2.2. MCP

The MCP provides control of the A/P, flight director, altitude alert, and autothrottle systems. The MCP is used to select and activate AFDS modes, and establish altitudes, speeds, and climb/descent profiles. Mode select switches of the MCP are shown in Figure 5.

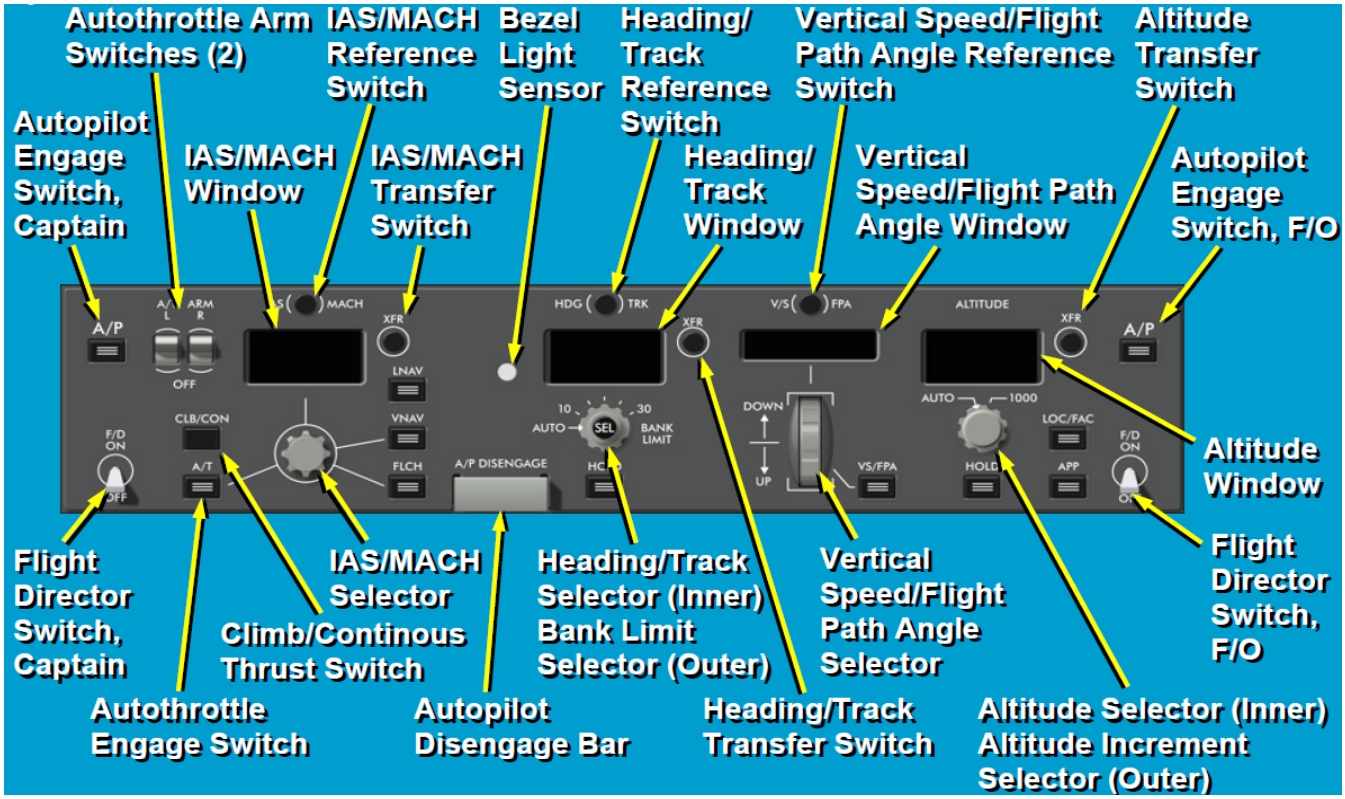


Figure 5: MCP

1.6.2.3. Flight Mode Annunciator (FMA)

(1) The FMA is located at the top of the PFD and HUD. The FMAs show the armed and engaged AFDS and autothrottle modes as follows:

(a) Autothrottle mode (left)

(b) Roll mode (centre)

(c) Pitch mode (right)

(2) The active modes are shown in “green” while the armed modes are displayed in “white” under the active modes.

(3) A line through the mode shows a mode failure.

(4) Temporary loss of data can cause a mode failure. These mode failures can be reset automatically.

(5) If there is a permanent mode failure, the pilot must select another mode. Without pilot selections, the aircraft flies in the basic pitch and roll modes, VS and HDG Hold, respectively.

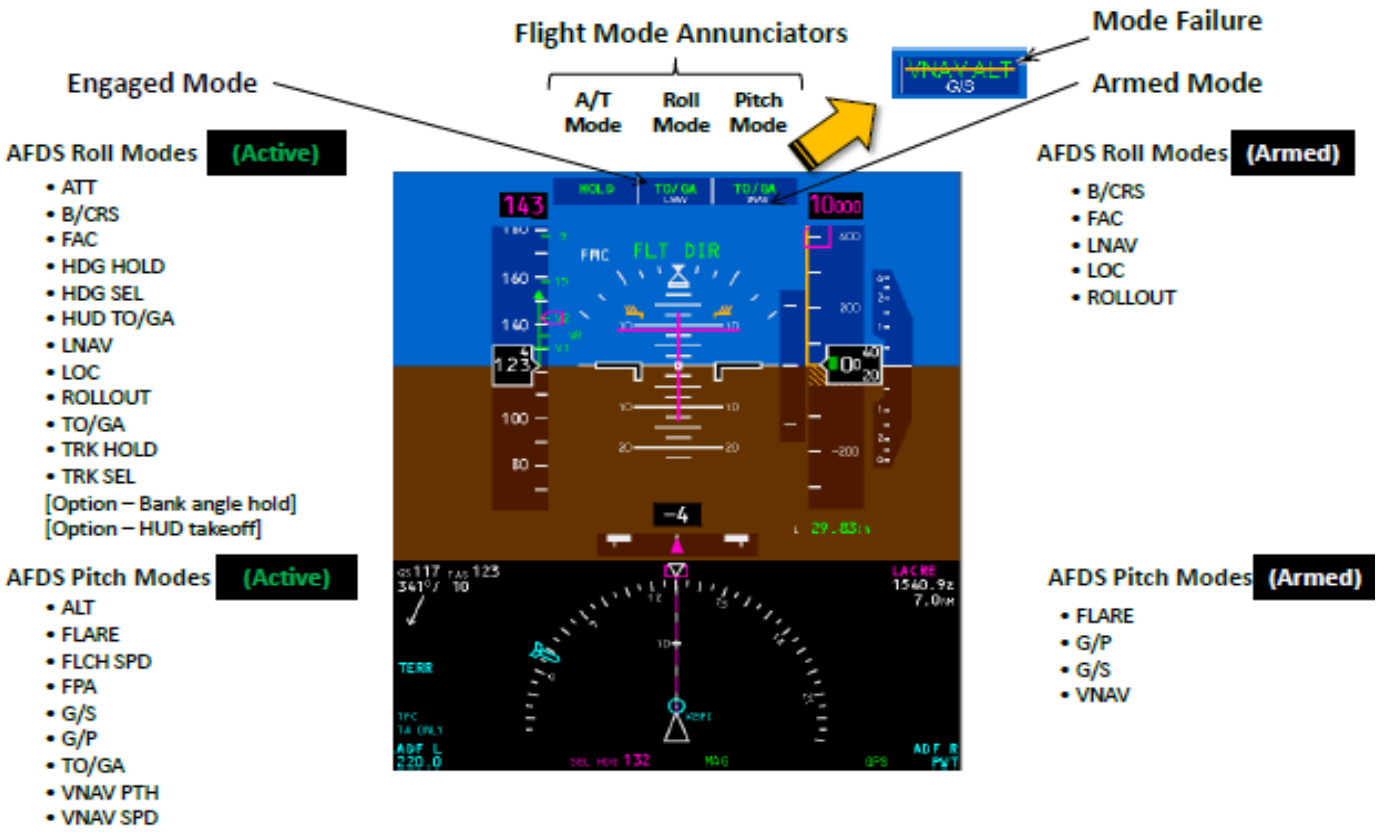


Figure 6: AFDS - FMA

(6) The AFDS does not have direct control of the flight control surfaces. The A/P controls the flight control surfaces through the fly-by-wire flight control system.

1.6.2.4. Flight Control Electronics (FCE) Cabinets

(1) The FCE cabinets provide the calculations for the A/P, flight director, and backdrive functions.

(2) The FCE cabinets calculate control surface commands based on input signals from control columns, control wheels, rudder pedals, pitch trim switches and aircraft sensors.

(3) There are four FCE cabinets (L, C1, C2, and R). Each FCE cabinet has a power conditioning module, actuator control electronics (ACE) and a FCM. Only FCE C2 does not have an FCM.

1.6.2.5. Autoflight Function (AFF) in FCM of FCE Cabinet

(1) The AFF is a software application in the FCM of each FCE cabinet. There is one copy of the AFF software in each FCM.

(2) The AFDS uses the AFF software in the three FCMs. The AFF receives crew inputs from the MCP and aircraft systems inputs from flight management function. It uses these inputs to calculate AFF pitch, roll, and yaw commands and sends A/P command data to the primary flight control function (PFCF) in the FCMs.

(3) The PFCF generates flight control surface commands and sends them to the ACE. The ACEs then send the commands to the flight control surfaces.

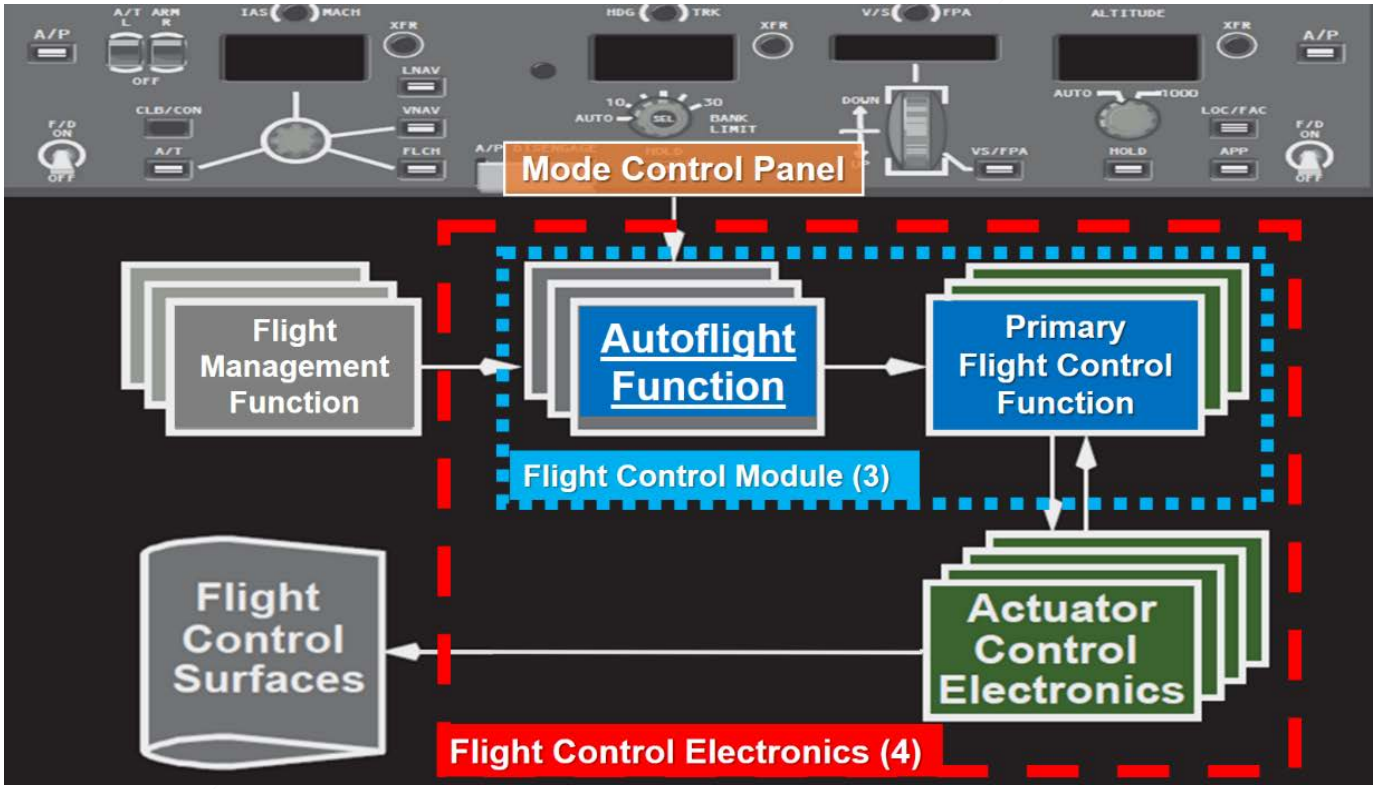


Figure 7: Schematic Diagram of AFDS

1.6.3. Consistent Localizer Capture (CLC)

(1) The AFF contains a CLC control law function. The intent of the CLC function is to begin the LOC capture turn of an ILS approach early during certain conditions to avoid or reduce trajectory overshoot and subsequently transition to the LOC mode resulting in a smooth transition in a single turn toward LOC null.

(2) ILS approach LOC captures that occur too close to the RWY can result in LOC trajectory overshoots as shown in the graphic below.

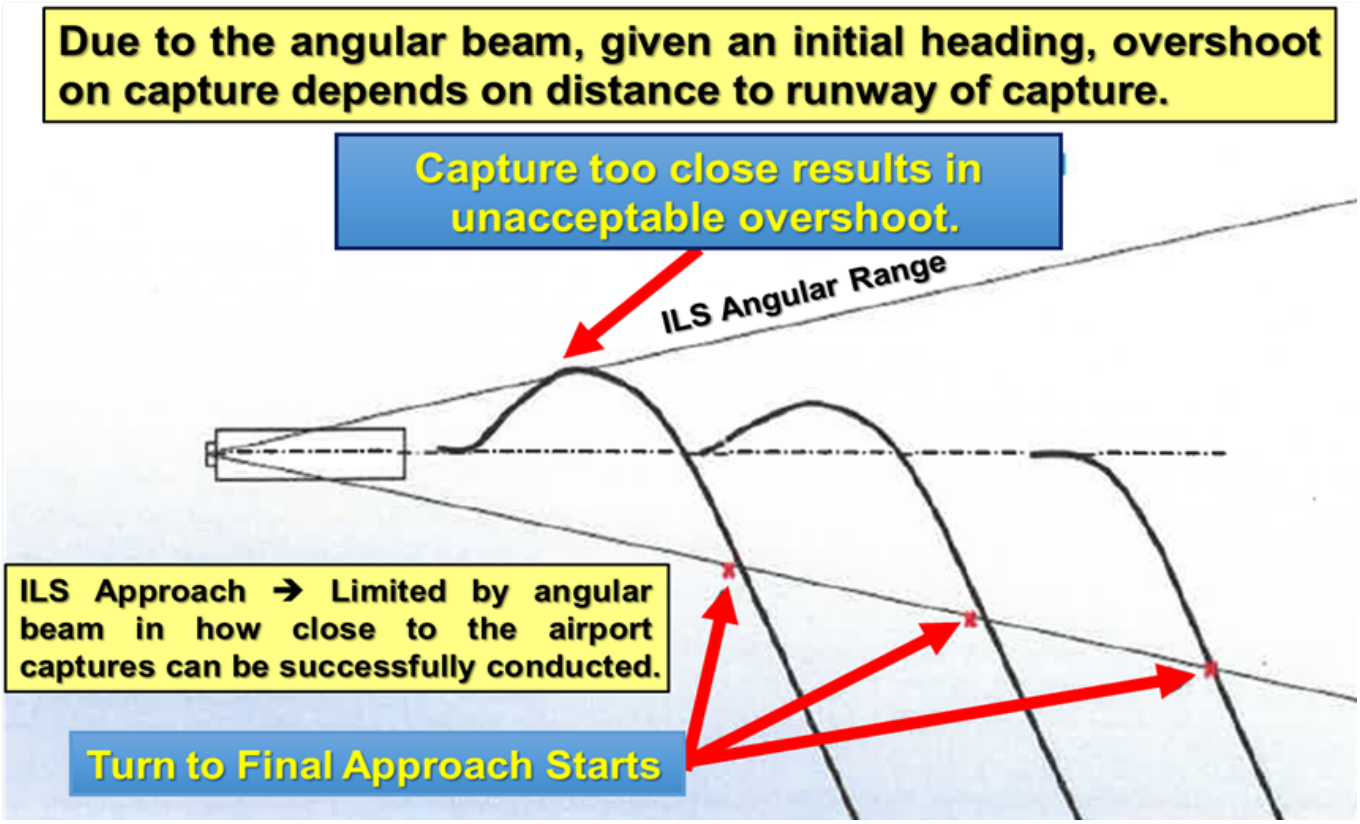


Figure 8: Effect of Intercept ILS Close to RWY

(3) The CLC mode reduces the risk of LOC course overshoot in A/P-enabled approaches that require a large turn (>40 degrees) onto the LOC course.

(4) During an ILS approach, and when tracking a LOC intercept path angle greater than 40 degrees to the RWY extension line, the CLC mode will become active prior to capturing the LOC.

(5) Using aircraft position (latitude/ longitude) and RWY information from the flight management function, CLC will turn the aircraft towards the LOC course before the LOC is within parameters for capture, in order to avoid overshoot and maximize the chance of capturing the LOC in one turn.

(6) "LOC" will be annunciated on the FMA when a CLC turn begins and remains annunciated through the transition to LOC capture.

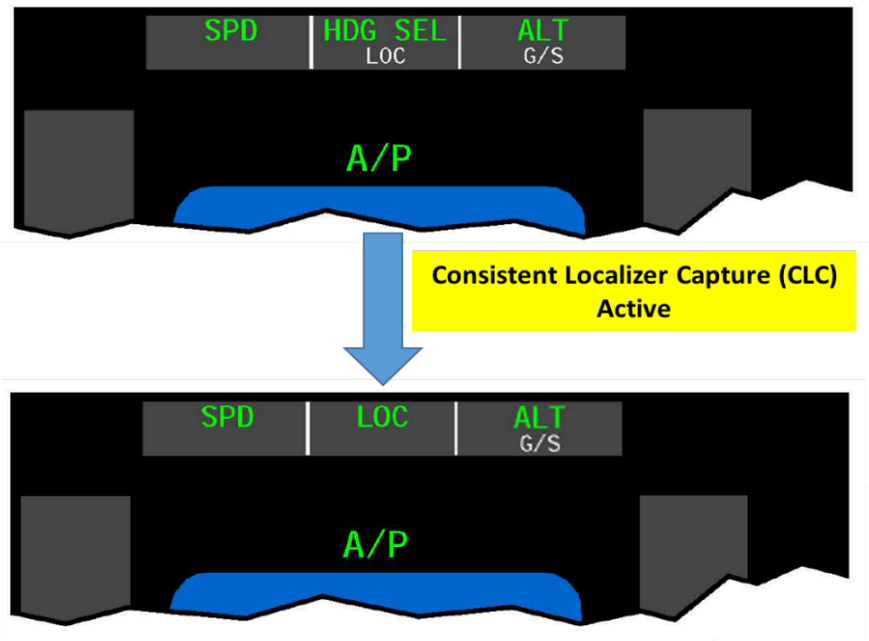


Figure 9: FMA on PFD with CLC Mode Active

(7) CLC has enough authority to turn the aircraft up to 20 degrees off of the LOC course. This results in the aircraft turning to a LOC intercept angle of approximately 20 degrees.

(8) During the turn, CLC will automatically transit to the LOC capture control law when the LOC is within parameters for capture and "LOC" will continue to be visible on the FMA.

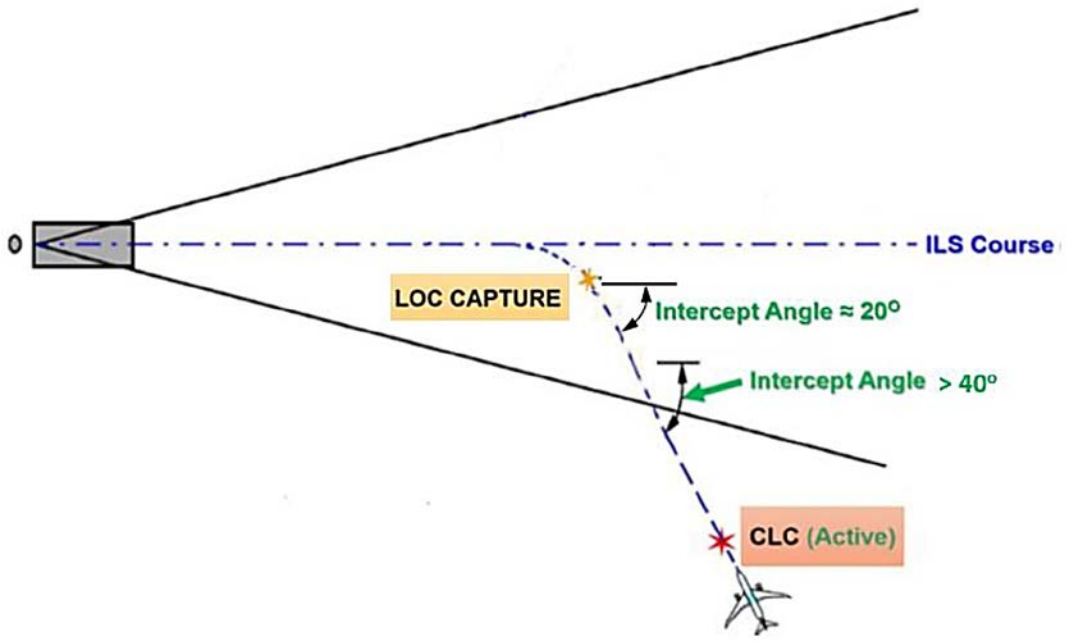


Figure 10: CLC Mode to LOC Capture Mode

1.6.4. Maintenance History

A review of the aircraft's maintenance history did not identify any defects or recent maintenance actions that could have contributed to the occurrence.

1.7. Meteorological Factors

The Meteorological Aerodrome Report (METAR) for VHHH at 1530 hrs indicated that the wind speed was 10 knots. The surface wind direction was 300 degrees. The visibility was 10 km or above. There were a few clouds at 3,500 ft above mean sea level. The air temperature was 29 degrees Celsius and the dew point was 17 degrees Celsius. No significant changes in weather conditions were expected for the next two hrs.

1.8. Navigation Aids

There was no report of abnormal operation of any ground-based navigation aids or aerodrome visual ground aids at the time of the occurrence.

1.9. Communications

The aircraft was equipped with three Very High Frequency (VHF) radio communication systems that were serviceable. All communications between ATC of Hong Kong and the aircraft were recorded by ground-based automatic voice recording equipment. There was no interruption to such communications.

1.10. Aerodrome Information

Information on the VHHH is listed in Section 7.4 Aerodrome Information.

1.11. Flight Recorders

(1) The aircraft was equipped with two Enhanced Airborne Flight Recorders (EAFR), one installed at the front of the aircraft and the other at the rear. The EAFR is a multifunction crash-protected

recorder that records 25 hrs of Flight Data Recorder (FDR)[2] data and 120 minutes of Cockpit Voice Recorder (CVR)[3] audio into a solid-state memory.

(2) Both EAFRs were functional. Flight data was available for the entire event flight and the recording of cockpit audio commenced shortly before the aircraft started its descent to Hong Kong Airport, and ended after the aircraft had landed.

(3) The downloaded flight data captured the relevant cockpit conversations during the occurrence and all of the flight parameters required for the analysis of this occurrence.

(4) Both EAFRs recorded the same information with normal operation.

(5) From the CVR audio, the crew can be heard monitoring the LOC intercept, diagnosing the problem with reference to the first occurrence on 29 September 2019 and intervening promptly to re-establish on the LOC.

1.11.1. Quality Issue of CVR Audio Recording

The EAFR data from G-VBOW was replayed with the support from the AAIB. During an initial review of the CVR audio by the AAIB, it was identified that the pilots' speech captured by the headset microphones was frequently distorted.

1.12. Wreckage and Impact

Not applicable in this investigation.

1.13. Medical/Pathological Information

No medical or pathological investigations were conducted as a result of this occurrence, nor were they required.

[2] FDR – a device used to record specific aircraft performance parameters. The purpose of an FDR is to collect and record data from a variety of aircraft sensors onto a medium designed to survive an accident.

[3] CVR - a device used to record the audio environment in the flight deck for accident and incident investigation purposes. The CVR records and stores the audio signals of the microphones and earphones of the pilots' headsets and of an area microphone installed in the cockpit.

1.14. Smoke, Fire, and Fumes

There was no smoke or fire on the aircraft during the flight or after the occurrence.

1.15. Survival Aspects

No injury was reported, therefore no investigation into the survival aspects was required.

1.16. Tests and Research

1.16.1. Testing the Effect of Windscreen Not Fitted on Headset

(1) To find out the cause of the quality issue of CVR audio recording, in April 2020, VAA carried out a flight in one of its Boeing 787 aircraft, during which the co-pilot's headset was fitted with a microphone windscreen but the commander's one was not.

Figure 11: Typical Windscreen

(2) The CVR audio showed that the co-pilot's speech was clear of distortion, whereas the commander's speech was not, with large variations in signal amplitude when speaking.

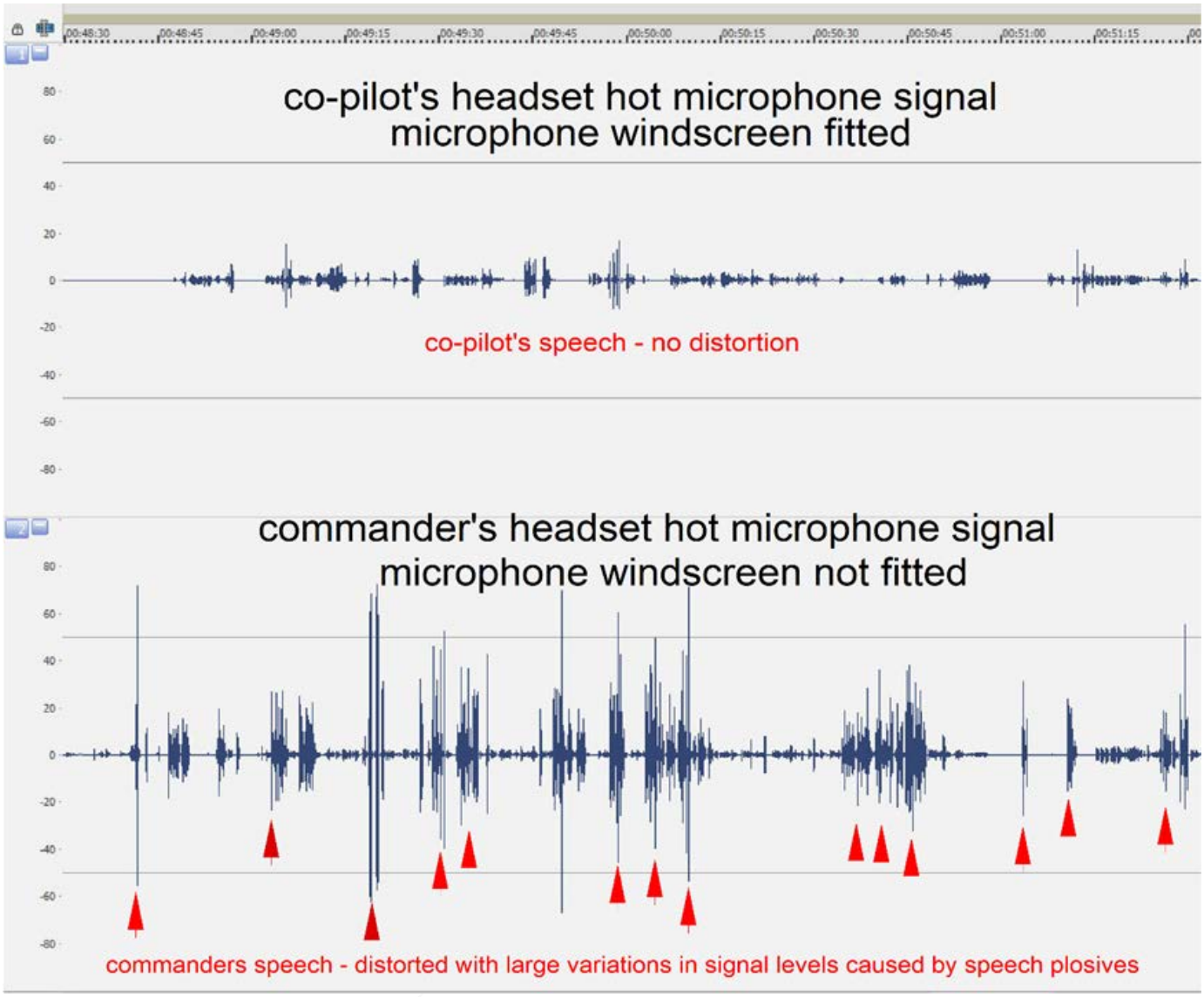


Figure 12: Headset Microphone Signals with Windscreen Fitted/Not Fitted

(3) The distortion of the commander's speech was consistent with the CVR recordings from G-VBOW aircraft.

(4) This evidence showed that during the event flight, neither of the pilots' headsets were fitted with a microphone windscreen.

(5) The flight crew were unaware that the absence of the windscreen could be an issue to the CVR recording.

1.17. Organisation, Management, System Safety

1.17.1. CAD

The CAD is the regulatory authority responsible for regulating and monitoring of all matters relating to civil aviation in Hong Kong. Apart from the regulatory role in aviation safety, the CAD provides air navigation services, including ATC services, for the flights at the VHHH and in the Hong Kong Flight Information Region as designated by the International Civil Aviation Organization (ICAO). The CAD is also responsible for the safety oversight of the provision of air navigation services in Hong Kong.

1.17.2. Federal Aviation Administration (FAA)

The FAA is the regulatory authority responsible for the airworthiness and environmental certification of all aeronautical products, parts, and appliances designed, manufactured, maintained or used by persons under the regulatory oversight of the United States. It carries out the functions and tasks of the State of Design and State of Manufacture of Boeing 787 aircraft.

1.17.3. VAA

VAA held the Air Operator's Certificate issued by the United Kingdom Civil Aviation Authority. The operator has been using EGLL as the main base for passenger and cargo operations since 1984. The fleet consists of Airbus A330, A350 and Boeing 787 aircraft types for operations.

1.18. Additional Information

1.19. LOC Capture Anomalies

(1) Boeing 787 operators have reported numerous events that the AFDS did not provide proper guidance to capture the LOC when intercepting the LOC at large angles (40 degrees or more).

(2) During these events, the AFDS reduced the intercept angle, but continued flying through the LOC course, even when the FMA showed "LOC" as the active roll mode.

(3) In all events, the deviation from the LOC was accurately shown by both the LOC pointer and scale on the PFD, HUD, and by the aircraft symbol on the navigation display (ND).

(4) The failure to properly capture the LOC could take place at any airport.

(5) In the reported events at Hong Kong, the aircraft initially turned toward the LOC with a 20 to 30 degrees intercept angle, but continued flying through the LOC course on that track.

(6) It should be noted that "LOC" remained on the FMA despite the failed capture and, in some circumstances, the aircraft might begin to descend below the glideslope while the aircraft was 20 degrees offset from the LOC course.

(7) There was no indication on board the aircraft to notify the crew of the LOC capture anomalies.

1.19.1. Issuance of Related Technical Publications

(1) Based on the in-service experiences, Boeing and the FAA had published different technical publications to provide operators with up to date information on the development/availability status of product improvements.

(2) The timeline of issuance of technical publications related to LOC Capture Anomalies of the AFDS is shown in Figure 13.

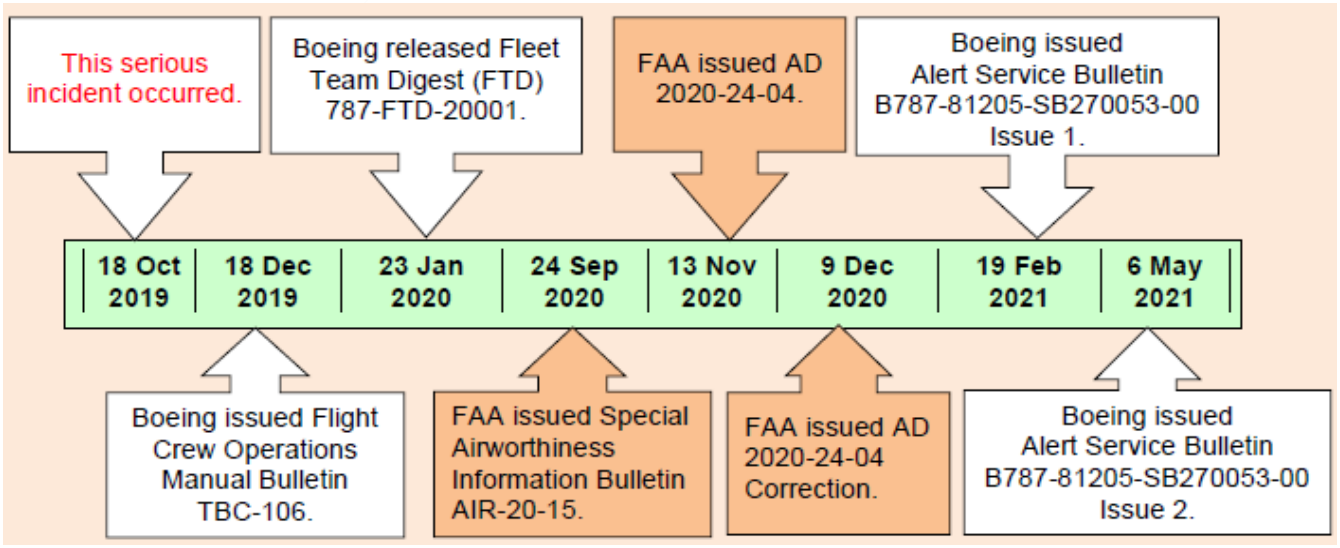


Figure 13: Timeline of Issuance of Related Technical Publications

1.19.1.1. Boeing Flight Crew Operations Manual Bulletin

(1) Boeing issued Flight Crew Operations Manual Bulletin TBC-106 (LOC Capture Anomalies) dated 18 December 2019 to inform flight crew of reports of the AFDS not capturing the LOC.

(2) Some operators reported to Boeing that the AFDS did not provide proper guidance to capture the LOC when intercepting the LOC at large angles (40 degrees or more).

(3) Boeing confirmed with flight data that during these events, the AFDS reduced the intercept angle, but continued flying through the LOC course, even when the FMA indicated "LOC" as the active roll mode.

(4) In all events, the deviation from the LOC course was accurately shown by both the LOC pointer and scale on the PFD and by the aircraft symbol on the ND.

(5) Boeing had been able to reproduce the anomaly in an engineering simulator and determined the root cause. Boeing planned to correct the anomaly in FCE software blockpoint 5.1.

(6) The bulletin also provided the Operating Instructions of the AFDS to handle such LOC capture anomalies as follows:

"*When conducting an approach with a LOC-based navigation aid, monitor LOC raw data and call out any significant deviations. If AFDS performance is not satisfactory, the flight crew must intervene. Perform an immediate go around if the aircraft has not intercepted the final approach course as shown by the LOC deviation.*"

1.19.1.2. Boeing Fleet Team Digest (FTD)

(1) Boeing released FTD 787-FTD-22-20001 on 23 January 2020. The purpose of the FTD was to provide the following information:

(a) Operators were informed about the issue of LOC capture anomaly, in which A/P-engaged approaches in a specific LOC window could result in an insufficient turn towards the LOC course, resulting in the aircraft continuing to fly through the LOC course rather than properly capturing the LOC. In some circumstances, the aircraft could subsequently capture the glideslope and begin descent.

(b) The condition could occur at any airport but had been reported multiple times for approach ILS RWY 25R into VHHH.

(c) Boeing had opened a service-related problem investigation for this condition and the root cause had been identified and explained as follows:

"The B787 AFF contains a CLC control law that reduces the risk of localizer course overshoot in autopilot-engaged approaches that requires a large turn (40 degrees) onto the localizer course. CLC provides the B787 with ILS performance consistent with a Ground-Based Augmentation System (GBAS) Landing System (GLS) approach. Using Global Positioning System (GPS) and runway information from the flight management function. CLC will turn the aircraft towards the localizer course before the localizer is within parameters for capture. In order to maximize the chance of capturing the localizer in one turn. "LOC" will annunciate on the FMA when a CLC turn begins and remain annunicated through the transition to localizer capture. Normally, CLC will automatically transition to the localizer capture control law when the localizer is within parameters to capture and "LOC" will continue to be visible on the FMA.

Boeing has received reports that suggest, depending on the geometry and groundspeed of the approach, CLC may activate for such a short time that the three FCMs fail to synchronize the engaged autopilot mode and fail to transition to the localizer capture mode. This may result in the aircraft turning to a localizer intercept angle of approximately 20 degrees and flying through the localizer on this track, rather than properly capturing the localizer. "LOC" will remain on the FMA despite the failed capture and, in some circumstances, the aircraft may begin descent down the glideslope while 20 degrees off of the localizer course."

(d) Interim actions refer to the 18-DEC-2019 Flight Crew Operations Manual Bulletin for flight crew guidance and necessary actions were introduced to prevent the anomaly from occurring.

(2) Later, the FTD was updated to inform operators that:

(a) In March 2020, Boeing selected a solution for the condition. New logic would separate the LOC entry criteria from the CLC entry criteria and also add robustness to remove time sensitivity.

(b) The FAA released Airworthiness Directive (AD) 2020-24-04 to require operators to add related flight crew procedures to the Aircraft Flight Manual (AFM) with the effective date 18 December 2020.

(3) The final update of the FTD was released on 10 March 2021 to encourage operators to install FCE Common Block Point (CBP) 5.1 software per Boeing Alert Service Bulletin (SB) B787-81205-SB270053-00 that was released on 19 February 2021 as the final action.

1.19.1.3. FAA Special Airworthiness Information Bulletin

(1) The FAA issued Special Airworthiness Information Bulletin AIR-20-15 on 24 September 2020 to advise registered owners and operators of The Boeing Company Model 787-8, -9, and -10 airplanes of the potential for AFDS failure to capture the LOC during ILS approach.

(2) The FAA recommended that all owners and operators of affected airplanes notify flight crew of this issue and incorporate the actions outlined in the referenced Flight Crew Operations Manual Bulletin at the earliest opportunity.

1.19.1.4. FAA AD

(1) The FAA issued AD No. 2020-24-04 on 13 November 2020 to address the AFDS failing to transition to the ILS LOC beam, which could result in LOC overshoot leading to glideslope decent on the wrong HDG.

(2) Combined with a lack of flight deck effects for a CLC mode failure, this condition could result in a controlled flight into terrain.

(3) As the unsafe condition was identified, mandatory measures in the form of an AD had to be issued.

(4) The FAA issued AD No. 2020-24-04 Correction dated 9 December 2020 to correct errors in AD related to certain references to the AFM.

(5) This AD required revising the existing AFM to incorporate procedures for conducting an approach with a LOC-based navigation aid, monitoring LOC raw data, calling out any significant deviations, and performing an immediate go around if the airplane has not intercepted the final approach course as shown by the LOC deviation.

(6) The AD mandated the following changes made by Boeing in the Operating Instructions of the AFM with the effective date of 18 December 2020.

(Required by AD 2020-24-04)

Autopilot Flight Director System – Operating Instructions:

When conducting an approach with a localizer-based navigation aid, monitor localizer raw data and call out any significant deviations. If AFDS performance is not satisfactory, the flight crew must intervene. Perform an immediate go-around if the airplane has not intercepted the final approach course as shown by the localizer deviation.

Figure 14: Operating Instructions of AFDS

(7) When the FAA AD 2020-24-04 was issued, the FAA considered this AD as an interim action. The manufacturer was developing a modification that would address the unsafe condition identified in this AD. Once this modification was developed, approved, and available, the FAA might consider additional rulemaking.

1.19.1.5. Boeing Alert SB

(1) Boeing issued Alert SB B787-81205-SB270053-00 Issue 1 (FLIGHT CONTROLS - General - FCE CBP 5.1 Software Change) dated 19 February 2021 with a compliance time of 6 months after the issue date.

(2) This Alert SB dealt with the CLC mode failure of the AFF to capture the LOC by upgrading the software of all three FCMs.

(3) The new software addressed timing in the A/P logic for transitions from a short duration CLC mode to LOC mode and addressed consolidation of the mode between the FCMs.

(4) Also, during ILS signal fluctuations, changes in the new software reduced potential deviation from glidepath and eliminated potential misleading flight director guidance subsequent to A/P disconnect.

(5) This Alert SB was revised as B787-81205-SB270053-00 Issue 2 dated 6 May 2021 to update the effectivity.

(6) The FAA, the primary certification authority of Boeing 787 aircraft, advised the investigation team that the FAA was currently planning to issue an AD to mandate the incorporation of FCE CBP 5.1 Software modification as a requirement for all Boeing 787 aircraft.

1.20. Useful or Effective Investigation Techniques

Not applicable in this investigation.

2. Safety Analysis

The Safety Analysis provides a detailed discussion of the safety factors identified during the investigation, providing the evidence required to support the findings, contributing factors and the safety recommendations.

2.1. General

(1) The event occurred as a LOC course deviation on a VAA Boeing 787-9, registration G-VBOW, while conducting an ILS approach to VHHH.

(2) During the ILS approach to RWY 25R of VHHH in VMC, the aircraft with the autoflight system engaged intercepted the LOC, it then overshot the intended HDG, diverging from the LOC course towards the terrain to the north.

(3) The PF disengaged the autoflight system and assumed manual control of the aircraft, re-establishing the aircraft on the ILS HDG approximately 12 NM from the RWY threshold and landing the aircraft uneventfully. There was no damage to the aircraft.

(4) This analysis discusses the cause of the LOC course deviation.

2.2. Flight Operations

2.2.1. Crew Qualification

The flight crew were properly licensed, medically certified in accordance with the European Union's licensing requirements, and adequately rested to operate the flight.

2.2.2. Operational Procedures

According to the flight data analysis, the flight crew adhered to the procedures of the company's Operations Manual to handle the situation of LOC course deviation.

2.3. Flight Data Analysis

AAIA analysed the flight data from the EAFR in conjunction with AAIB and Boeing. The main purpose of the analysis was to establish the cause of the LOC course deviation during approach. A ground track analysis was generated to show the aircraft's path during the approach as shown in the figure below.

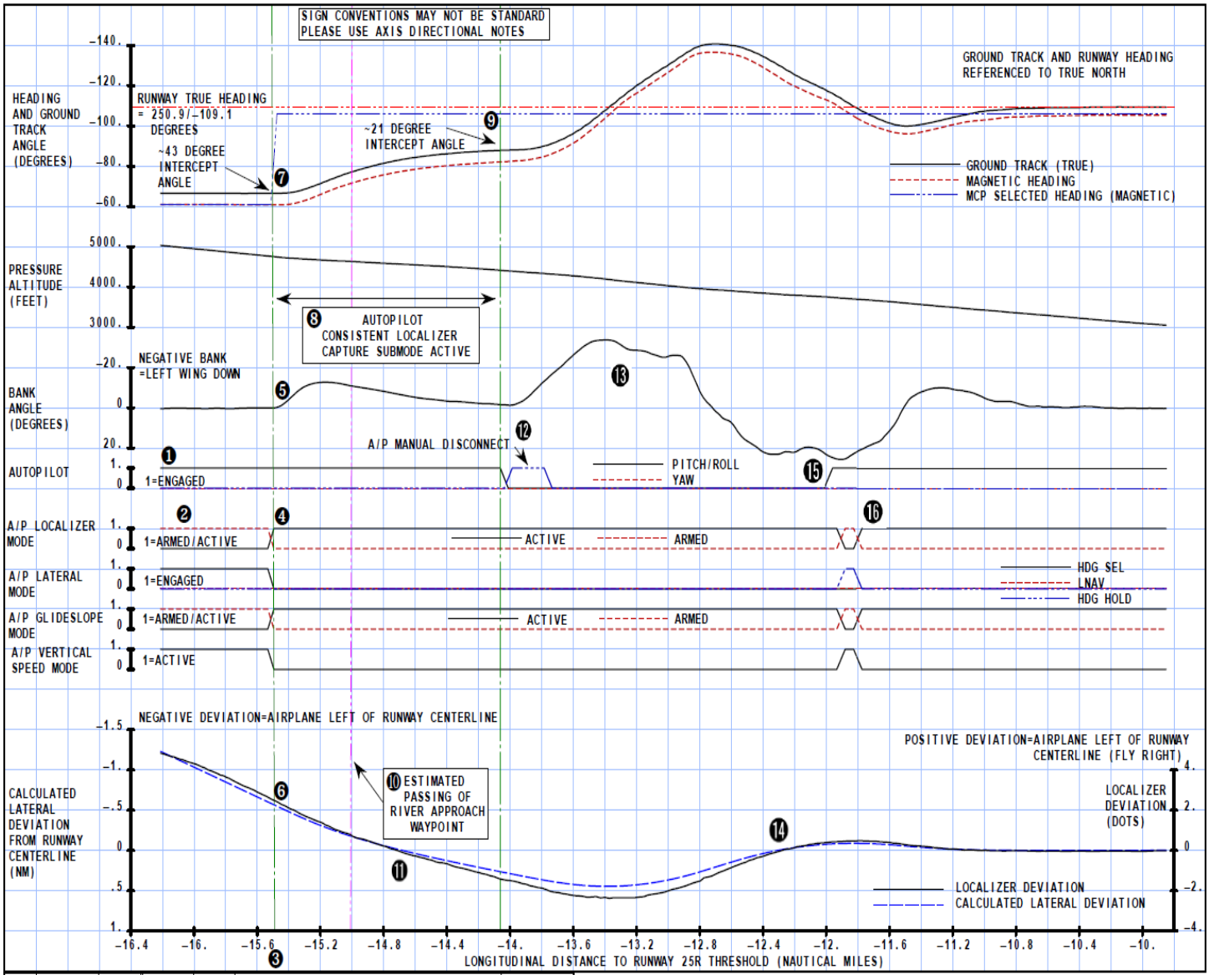


Figure 15: Ground Track of EAFR Data

2.3.1. Flight Data Observations

(1) The flight data showed the aircraft on approach to RWY 25R at VHHH on 18 October 2019. The aircraft was approaching the waypoint RIVER, which is 15 NM from the RWY threshold. The A/P was engaged. See ❶ in Figure 15.

(2) The A/P LOC mode was armed at the time 15:46:52. See ❷ in Figure 15.

(3) When the aircraft was approximately 15.5 NM from the RWY threshold (See ❸ in Figure 15), the A/P LOC mode became active at the time 15:48:36. See ❹ in Figure 15.

(4) Shortly after that, the aircraft began a turn to the left, in the direction of the active RWY. See ❺ in Figure 15.

(5) The LOC deviation indicated approximately 2.6 dots left of RWY centreline. See ❻ in Figure 15.

(6) Based on the ground track and RWY HDG, the aircraft established a LOC intercept angle of approximately 43 degrees. See ❼ in Figure 15.

(7) The A/P CLC submode was probably active from the time of LOC capture at approximately the time 15:48:36 until 15:49:07. See ❽ in Figure 15.

(8) However, this was determined, based upon the expected region, that CLC would be active as there are no recorded flight data parameters to definitively determine regions of flight where CLC was active.

(9) The CLC submode became disengaged, that was coincident with the A/P disconnect occurred at near the time 15:49:07 with a LOC intercept angle of around 21 degrees. See ❾ in Figure 15.

(10) While the A/P is in CLC submode, the mode annunciation on the PFD would be shown as “LOC”, known to the flight crew as LOC mode being an active mode. This is to avoid confusion as the aircraft starts rolling when CLC submode is active, prior to the transition to the actual LOC mode.

(11) The aircraft flew over the waypoint RIVER 15 NM from the RWY threshold. See ❿ in Figure 15. Near this time the LOC deviation was gradually reducing from left of RWY centreline towards zero as the aircraft continued in a left bank to capture the extended centreline.

(12) While the aircraft was in a left bank that was gradually reducing towards wings-level, the aircraft crossed the extended RWY centreline as evidenced by LOC deviation passing through zero at the time 15:48:53 approximately 14.7 NM from the RWY threshold. See ⓫ in Figure 15.

(13) The aircraft continued to move right of the LOC beam as the left bank was further reduced towards wings-level.

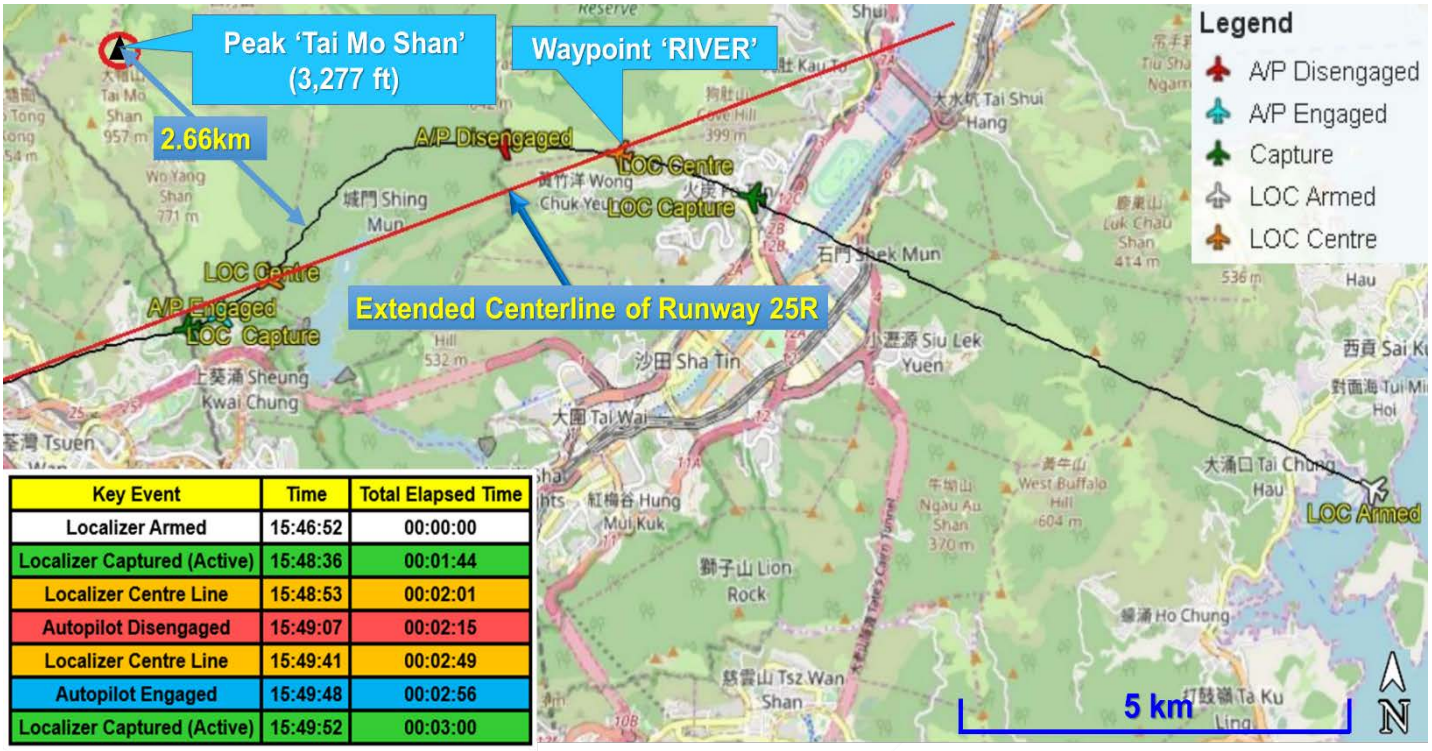
(14) The A/P was disconnected manually by the flight crew near time 15:49:07 slightly more than 14 NM from the RWY threshold. See ⓬ in Figure 15.

(15) Then left control wheel was input by the flight crew and the aircraft was banked left wing down to re-capture the LOC. See ⓭ in Figure 15.

(16) The aircraft crossed the LOC beam a second time (deviation value of zero) at the time 15:49:41. See ⓮ in Figure 15.

(17) The A/P pitch/roll channel was re-engaged at the time 15:49:48. See ⓯ in Figure 15.

(18) The aircraft was re-established on the LOC at the time 15:49:52 and about 11.1 NM from the RWY threshold without further incident and landed on RWY 25R. See ⓰ in Figure 15.



Key Event	Time	Total Elapsed Time
Localizer Armed	15:46:52	00:00:00
Localizer Captured (Active)	15:48:36	00:01:44
Localizer Centre Line	15:48:53	00:02:01
Autopilot Disengaged	15:49:07	00:02:15
Localizer Centre Line	15:49:41	00:02:49
Autopilot Engaged	15:49:48	00:02:56
Localizer Captured (Active)	15:49:52	00:03:00

Figure 16: Flight Track with AFDS Status

2.3.2. Flight Data Evaluation

(1) Evaluation of the flight data suggested that the CLC AFF initiated the turn towards the RWY 25R LOC, as LOC annunciated the active roll mode.

(2) After the CLC AFF had initiated the turn, the A/P transition to the LOC mode did not occur. This resulted in the aircraft HDG stabilised 20 degrees short of the LOC course and flying through the LOC course on this track, rather than properly capturing the LOC.

(3) The recorded flight data was consistent with the LOC capture anomaly of the AFDS as described in the FTD 787-FTD-22-20001.

(4) The LOC course deviation observed was due to the LOC capture anomaly of the AFDS.

(5) The FTD stipulated that the issuance of a Flight Crew Operations Manual Bulletin and related FAA AD 2020-24-04, associated with the software modification released by Boeing via Alert SB B787-81205-SB270053-00 addressed this anomaly.

2.4. Analysis of LOC Capture Anomalies

(1) Boeing was able to reproduce the anomalies experienced in Hong Kong and other events in an engineering simulator.

(2) The analysis indicated that depending on the geometry and groundspeed of the approach, CLC might activate for such a short time that the three FCMs failed to synchronize the engaged A/P roll mode.

(3) When the FCMs disagreed on the engaged roll mode, the FCM in command could remain in CLC mode and failed to transition to the LOC capture mode.

(4) This might result in the aircraft turning to a LOC intercept angle of approximately 20 degrees and flying through the LOC course on this track, rather than properly capturing the LOC.

(5) "LOC" would remain on the FMA despite the failed capture and, in some circumstances, the aircraft might begin descent down the glideslope while it was deviating 20 degrees off the LOC course.

(6) Boeing concluded that the occurrence was due to a software failure of the CLC which was a submode of the auto-flight function in AFDS.

2.5. Solution for LOC Capture Anomalies

(1) After the root cause of the LOC Capture Anomalies in AFDS had been identified and established in December 2019, Boeing planned to develop a software solution for the anomaly in FCE software CBP 5.1. In March 2020, Boeing selected a solution for the anomaly, with new software logic that would:

(a) separate the LOC entry criteria from the CLC entry criteria; and

(b) add robustness to remove time sensitivity.

(2) The change of software was committed in May 2020 and later the flight test was carried out in December 2020.

(3) Boeing released Alert SB B787-81205-SB270053-00 on 19 February 2021 to install FCE CBP 5.1 software with the compliance time of 6 months after the issue date.

(4) The new software included the changes described in 2.5(1)(a) & (b) to mitigate the LOC capture anomaly in AFDS.

(5) The new software addressed timing in the A/P logic for transition from a short duration CLC submode to LOC mode and addressed the consolidation of the mode between the FCMs.

(6) In June 2022, the FAA published a Notice of Proposed Rulemaking (NPRM)[4] (Reference Docket No. FAA-2022-0674) that proposed a new AD to mandate the incorporation of FCE CBP 5.1 Software modification for all Boeing 787 aircraft.

2.6. Quality Issue of CVR Audio Recording

(1) Referring 1.16.1, the testing showed that when the microphone windscreen is fitted to the flight deck headset, the CVR voice recording has no obvious distortion.

(2) It is essential during safety investigations to have access to the highest quality of CVR audio recording as possible.

(3) The flight crew were unaware that the absence of the windscreen would cause distortions to the CVR audio recording.

(4) The investigation team considers appropriate for the aircraft manufacturer to provide such guidance information to avoid any distortion caused to the CVR audio recording.

[4] NPRM is used by FAA to give notice of an intention to change their Regulatory regime for aircraft design, production, maintenance or operation and allow interested parties the opportunity to comment before actual changes are made.

3. Conclusions

From the evidence available, the following findings are made with respect to the occurrence. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1. Findings

(1) The flight crew were licensed and qualified for the flight in accordance with regulations and the operator's requirements. (1.5.1.) (2.2.1.)

(2) The aircraft held valid Certificate of Airworthiness and was maintained in accordance with the regulations. (1.6.1.) (1.6.4.)

(3) The weather conditions were within the limits for the flight. (1.7.)

(4) There was no report of abnormal operation of any ground-based navigation aids or aerodrome visual ground aids. (1.8.)

(5) All communications between Hong Kong ATC and the aircraft were clear and there was no report of defective radio communication system in the cockpit. (1.9.) (1.11.)

(6) There was no indication on board the aircraft to notify the crew of the LOC capture anomalies. (1.18.1. (7))

(7) The FAA issued AD No. 2020-24-04 as an interim action to address the unsafe condition due to the LOC capture anomalies of the AFDS. (1.18.2.4.)

(8) The flight crew handled the situation of LOC course deviation in accordance with the procedures of the company's Operations Manual. (2.2.2.)

(9) The LOC course deviation was due to the LOC capture anomaly of the AFDS. (2.3.2.(4))

(10) The LOC capture anomaly of the AFDS was due to the software failure of the CLC auto-flight function in AFDS to capture the LOC. (2.4. (6))

(11) The software failure of the CLC auto-flight function in AFDS was addressed by Boeing Alert SB 787-27A0053 dated 19 February 2021 to install FCE CBP 5.1 software. (2.5.)

(12) In June 2022, the FAA published a NPRM (Reference Docket No. FAA-2022-0674) that proposed a new AD to mandate the incorporation of FCE CBP 5.1 Software modification for all Boeing 787 aircraft. (1.18.2.5. (6)) (2.5. (6))

3.2. Cause

The LOC course deviation was caused by the software failure of the CLC auto-flight function in the AFDS. (3.1. (10))

3.3. Other Findings

During the course of the investigation, any findings, other than that associated with safety factors, considered important to include in an investigation report will be listed here. These findings may play an important role in the safety investigation or in reducing the risk associated with the occurrence.

(1) An audio quality issue was identified during the review of the CVR audio recording. This audio quality issue was caused by the flight deck headset not fitted with a microphone windscreen. (1.11.1.) (1.16.1.) (2.6. (1))

(2) No explicit guidance information on the fitment of microphone windscreen was provided by the operator or aircraft manufacturer. The flight crew were unaware that the absence of the windscreen could be an issue to the CVR recording. (1.16.1. (5)) (2.6. (3))

4. Proactive Safety Actions

Whether or not AAIA identifies safety issues in the course of an investigation, relevant organisations may proactively initiate safety action in order to reduce their safety risk.
AAIA has been advised of the following proactive safety action in response to this occurrence.

4.1. Proactive Safety Actions Taken by Boeing

Boeing implemented the following safety actions after the incident.

4.1.1. Issue of Flight Crew Operations Manual Bulletin

Boeing released a Flight Crew Operations Manual Bulletin TBC-106 on 18 December 2019 titled "LOC Capture Anomalies" to provide operating instructions to flight crew as a mitigation action.

4.1.2. Issue of Alert SB

Boeing has identified the root cause as the software issue of the FCMs. The company developed a software solution for the anomaly in FCE software CBP 5.1 and issued Boeing Alert SB B787-81205-SB270053-00 Issue 1 on 19 February 2021.

4.2. Proactive Safety Actions Taken by VAA

VAA implemented the following safety actions after the incident.

4.2.1. Issue of Notice to Aircrew (NTA) and Notice to Airmen (NOTAM)

(1) This occurrence was published to crew via Safety & Fleet publication to enhance their awareness. The publication included reference to the NTA (NTA B789 19/126) and Company NOTAM (419/19 for HKG specific to HKG arrivals, and 409/19 for all B787 operations).

(2) Crew were advised by the company to:

(a) use HDG mode when intercepting the LOC and not use lateral navigation mode (LNAV).

(b) made a request to ATC of Hong Kong to accept approaches to RWY 25L to increase the proximity between high terrain.

(c) monitor the LOC intercept carefully and discontinue the approach outside of half-scale LOC deflection.

(d) ensure aircraft track aligned with LOC course before descending on the glideslope.

4.2.2. Incorporation of Alert SB

All Boeing 787 aircraft of VAA completed the modification in accordance with the Boeing Alert SB B747-81205-SB-270053-00.

4.2.3. Replacement of Headsets for B787 aircraft

VAA advised that all Telex headsets of its B787 aircraft were replaced by David Clark headsets (Model DC PRO X2) which are an Active Noise Reduction type.

4.3. Proactive Safety Actions Taken by the CAD

Throughout the course of the investigation, the CAD has been closely monitoring the situation and has taken proactive safety actions to address the issue.

4.3.1. Comprehensive Check of ILS

4.3.1.1. Ground Check of ILS

In November 2019, the CAD engaged the original system supplier of the four ILS located at the RWYs of VHHH, including the 07L, 07R, 25L and 25R ILS, to conduct comprehensive review of the performance of the ILS equipment and operations and maintenance (O&M) work. The supplier confirmed that the four ILS were in good working conditions under good O&M work and system performances were in compliance with the ICAO requirements.

4.3.1.2. Flight Check of ILS

(1) Periodic flight checks for all four ILS were carried out in May and November every year. The flight checks were conducted by the Flight Inspection Centre (FIC) of the Civil Aviation Administration of China (CAAC). All the flight checks were conducted in accordance with requirements in the CAD's Flight Inspection

Manual based on the ICAO Doc 8071 - Manual on Testing of Radio Navigation Aids and ICAO Annex 10. There were routine flight profiles taken by the CAAC FIC all along within the concerned region in the periodic flight checks for RWY 07L & 25R ILS.

(2) The last flight checks on RWY 07L/25R ILS were conducted in May 2019, with the reports from the CAAC FIC stating that the measurements of the systems met the ICAO requirements.

(3) Noting the incident of ILS approach RWY 25R since the last flight check in May 2019, the CAD had coordinated with the CAAC FIC to conduct ad-hoc flight checks for RWY 25R ILS on 6 November 2019, with initial flight from station identity code of radio navigation aids at Tung Lung (TD)_[5] to waypoint RIVER to capture RWY 25R ILS LOC signals and break off around 2 NM after ILS establishment. It was confirmed that there was no issue for the flight inspection aircraft to capture both RWY 25R Transmitters 1 and 2 LOC signals and the centreline reference was also correct. During the checks, the measured LOC deviations for both RWY 25R transmitters met the ICAO requirements.

4.3.2. Issue of Aeronautical Information Circular (AIC)

(1) The CAD issued AIC 28/19 “Coverage of ILS Facilities and Warning of False Capture and Signal Deviation at HKIA” on 14 November 2019 and this was superseded by AIC 12/20 dated 24 April 2020, which advised flight crew to confirm the validity of the LOC capture by cross-checking with other sources of navigation information.

(2) The current AIC 32/21 was issued by the CAD on 2 December 2021, which contained the same advisory information in alerting the air operators and flight crew of aircraft arriving at VHHH that they shall remain vigilant and adhere to the approach and descent procedures as promulgated in the Hong Kong Aeronautical Information Publications (AIP). Raw data should be monitored as appropriate.

[5] The identity code of radio navigation aids with station name Tung Lung at Tung Lung Chau, an island located off the tip of the Clear Water Bay Peninsula in the New Territories of Hong Kong.

4.3.3. Issue of CAD Letter to Boeing 787 Operators

The CAD issued a letter on 15 April 2020 to remind all B787 operators and their flight crew flying into Hong Kong to be aware of the information in Boeing Operations Manual Bulletin TBC-106 and AIC 28/19.

4.3.4. Issue of NOTAM

The CAD issued NOTAM A0658-20 on 24 April 2020, drawing the attention of flight crew of arrival aircraft at VHHH to AIC 12/20 that was issued on the same date, with reference to Boeing Flight Crew Operations Manual Bulletin – LOC Capture Anomalies, in order to caution the possible AFDS anomaly upon capturing LOC. When in doubt, the flight crew shall climb back to Minimum sector altitude (MSA), conduct missed approach and contact ATC.

4.3.5. Communication between the CAD and the FAA

In light of the potential safety risk of this event on a Boeing 787 aircraft, the CAD reported the event to the FAA, through the established working arrangement and requested the authority to coordinate with Boeing for the earliest release of the software upgrade and for providing further mitigation measures to operators before the software fix, and considered mandating the SB as AD. The FAA gave due consideration to the CAD and subsequently issued AD 2020-24-04 to mandate the change of the Operating Instructions in the Boeing 787 AFM and approved the certification of the software upgrade.

5. AAIA Safety Recommendation Report

5.1. Issue of Safety Recommendation Report

When a safety issue is identified at any stage of the investigation, AAIA issues Safety Recommendation Report to relevant organisation(s) to recommend preventative action that has to be taken promptly to enhance aviation safety.

(1) With the efforts of the aircraft manufacturer, Boeing, the root cause of this incident had been identified as the software issue of the FCMs of the aircraft.

(2) The target date for the release of FCE software CBP 5.1 was initially scheduled for the fourth quarter of 2020 and was committed to take place in the first quarter of 2021.

(3) AAIA understood that other than the solution to the LOC capture anomalies, CBP 5.1 would also cover many other product improvements.

(4) Due to the rather high frequency of reoccurrence of B787 LOC deviation in Hong Kong, AAIA considered that there was a genuine need to suitably prioritize solutions to address the LOC Capture Anomalies happened on Boeing 787 A/P flight director system.

(5) On 12 June 2020, AAIA issued a Safety Recommendation Report 01-2020 to release Safety Recommendation 02-2020 to the FAA, as follows.

5.1.1. Safety Recommendation 02-2020

It is recommended that the Federal Aviation Administration to urge Boeing to suitably prioritize the development of a FCE software solution so as to achieve early rectification of the Boeing 787 localizer capture anomalies.

Safety Recommendation Owner: The Federal Aviation Administration

5.1.2. Response to Safety Recommendation 02-2020

The FAA advised the investigation team that the following safety actions had been taken to address the Safety Recommendations 02-2020.

5.1.2.1. Issue of AD

(1) As per the AD process stated in Part 39.5 of the Code of Federal Regulations (CFR) Title 14[6], the FAA identified an unsafe condition existed and subsequently mandated a corrective action by issuing an AD.

(2) Boeing changed the Operating Instructions in the Boeing 787 AFM as a mitigation action. The FAA mandated the incorporation of the AFM change via a correction to AD 2020-24-04 effective from 18 December 2020.

5.1.2.2. Issue of Software Approval

The FAA had approved the certification of Boeing 787 FCE CBP 5.1 software, which included changes that resolve the identified LOC capture anomalies in January 2021. Boeing subsequently published two iterations of Alert SB for installing FCE CBP 5.1 software with the compliance time of 6 months after the Issue 001 date:

(a) B787-81205-SB270053-00, Issue 001, was published on 19 February 2021, and

(b) B787-81205-SB270053-00, Issue 002, was published on 6 May 2021.

5.1.3. Closure of Safety Recommendation 02-2020

In consideration of the safety actions taken by Boeing and the FAA, the investigation team confirmed that there were no new discoveries of incomplete safety actions. Hence, Safety Recommendation 02-2020 was closed.

[6] The Code of Federal Regulations Title 14 contains the codified Federal laws and regulations that are in effect as of the date of the publication pertaining to aeronautics, air transportation / aviation (including large and small aircraft, such as commercial airplanes, helicopters, balloons and gliders), and space exploration, including areas overseen by the FAA and National Aeronautics and Space Administration (NASA).

6. Safety Recommendation

6.1. Safety Recommendation 02-2023

It is recommended that Boeing study the effects of the fitment of microphone windscreens to cockpit headsets on the quality of the CVR audio recording. Boeing should inform operators of the significance of the windscreen fitment if the study notes any adverse effects on the CVR recording quality.

Safety Recommendation Owner: The Boeing Company

7. General Details

7.1. Occurrence Details

Date and time:	18 October 2019, 1549 hrs Local (0749 hrs UTC)
Occurrence category:	Incident
Primary occurrence type:	Deviation from Intended Flightpath
Location:	Waypoint RIVER of Hong Kong
Position:	22° 24' 7.55" N, 114° 10' 54.23" E

7.2. Pilot Information

7.2.1. PF (First Officer)

Age:	50
Licence:	Airline Transport Pilot's Licence (ATPL)(A)
Aircraft ratings:	Boeing 777, 787 & 747-400
Date of first issue of aircraft rating on Boeing type:	15.11.2014
Instrument rating (IR):	IR
Medical certificate:	Class 1
Date of last proficiency check on type:	28.12.2018
Date of last line check on type:	03.12.2018
ICAO Language Proficiency:	Level 6 (Valid for life)
Limitation:	Corrective lenses are required
Flying Experience:	
Total all types:	13,140 hrs
Total on type (B787) :	3,384 hrs

Total in last 90 days:	166 hrs
Total in last 28 days :	37 hrs
Total in last 7 days (hrs:Mins):	12:07 hrs
Total in last 24 hrs (hrs:Mins):	12:07 hrs
Duty Time:	
Day prior to incident (hrs:Mins) :	12:07 hrs

7.2.2. PM (Captain)

Age:	54
Licence:	ATPL(A)
Aircraft ratings:	Boeing 777 & 787 Airbus A330 & A350
Date of first issue of aircraft rating on Boeing type:	13.04.2015
Instrument rating (IR):	IR
Medical certificate:	Class 1
Date of last proficiency check on type:	27.04.2019
Date of last line check on type:	20.04.2019
ICAO Language Proficiency:	Level 6 (Valid for life)
Limitation:	Corrective lenses are required
Flying Experience:	
Total all types:	20,980 hrs
Total on type (B787) :	3,210 hrs
Total in last 90 days:	233 hrs
Total in last 28 days :	83 hrs
Total in last 7 days (hrs:Mins):	24:08 hrs
Total in last 24 hrs:	12:07 hrs
Duty Time:	

Day prior to incident (hrs:Mins) :	12:07 hrs

7.3. Aircraft Details

Manufacturer and model:	Boeing 787-9	
Registration:	The United Kingdom, G-VBOW	
Serial number:	37978	
Year of Manufacture:	2017	
Engine:	Two Rolls-Royce Trent 1000	
Operator:	VAA	
Type of Operation:	Scheduled Passenger Service	
Certificate of Airworthiness	Issued on 29 March 2017	
Departure:	EGLL	
Destination:	VHHH	
Maximum Take-off Weight	252,650 kg	
Persons on board:	Crew – 13	Passengers – 258
Injuries:	Crew – 0	Passengers – 0
Aircraft damage:	Nil	

7.4. Aerodrome Information

7.4.1. Aerodrome of Destination

Aerodrome Code	VHHH
Airport Name	Hong Kong International Airport
Airport Address	Chek Lap Kok, Lantau Island
Airport Authority	Airport Authority Hong Kong
Air Navigation Services	Approach Control, Aerodrome Control, Ground Movement Control, Zone Control, Flight Information Service, Clearance Delivery Control, Automatic Terminal Information Service
Type of Traffic Permitted	Instrument Flight Rules (IFR) / Visual Flight Rules (VFR)
Coordinates	22° 18' 32" N, 113° 54' 53" E
Elevation	28 ft
Runway Length	3,800 m
Runway Width	60 m
Stopway	Nil
Runway End Safety Area	240 m x 150 m
Azimuth	07L / 25R, 07R / 25L (At the time of the occurrence)
Category for Rescue and Fire Fighting Services	CAT 10

8. Abbreviations

A/P	Autopilot
AAIA	Air Accident Investigation Authority
AAIB	Air Accidents Investigation Branch of the United Kingdom
ACE	Actuator Control Electronics
ACP	Audio Control Panel
AD	Airworthiness Directive
AFDS	Autopilot Flight Director System
AFF	Autoflight Function
AFM	Aircraft Flight Manual
AIC	Aeronautical Information Circular
AIP Hong Kong	Aeronautical Information Publication Hong Kong
Annex 13	Annex 13 to the Convention on International Civil Aviation
ATC	Air Traffic Control
ATPL	Airline Transport Pilot's Licence
CAAC	Civil Aviation Administration of China
CAD	Civil Aviation Department, Hong Kong
Cap. 448B	Hong Kong Civil Aviation (Investigation of Accidents) Regulations
CBP	Common Block Point
CFR	Code of Federal Regulations
CLC	Consistent Localizer Capture
CVR	Cockpit Voice Recorder
EAFR	Enhanced Airborne Flight Recorder

EGLL	London Heathrow Airport
EGPWS	Enhanced Ground Proximity Warning System
FAA	Federal Aviation Administration
FCE	Flight Control Electronics
FCM	Flight Control Module
FDR	Flight Data Recorder
FIC	Flight Inspection Centre
FMA	Flight Mode Annunciator
ft	Feet
FTD	Fleet Team Digest
GBAS	Ground-Based Augmentation System
GLS	GBAS Landing System
GPS	Global Positioning System
HDG	Heading
hrs	Hours
HUD	Head-up Display
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IR	Instrument Rating
LNAV	Lateral Navigation
LOC	Localizer
MCP	Mode Control Panel
METAR	Meteorological Aerodrome Report

MSA	Minimum Sector Altitude
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NM	Nautical Miles
NOTAM	Notice to Airmen
NTA	Notice to Aircrew
NTSB	National Transportation Safety Board of the United States of America
O&M	Operations and Maintenance
PF	Pilot Flying
PFCF	Primary Flight Control Function
PFD	Primary Flight Display
PM	Pilot Monitoring
RWY	Runway
SB	Service Bulletin
TD	Station Identity Code of Radio Navigation Aids at Tung Lung
UTC	Coordinated Universal Time
VAA	Virgin Atlantic Airways
VFR	Visual Flight Rules
VHF	Very High Frequency
VHHH	Hong Kong International Airport
VMC	Visual Meteorological Conditions

9. Table of Figure, Photo, Table