Final Report

BOEING B777-300ER, REGISTRATION 9V-SWD
EGPWS INCIDENT

2 SEPTEMBER 2019

TIB/AAI/CAS.190

Transport Safety Investigation Bureau
Ministry of Transport
Singapore

12 April 2021

The Transport Safety Investigation Bureau of Singapore

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GLOSSARY OF ABBREVIATIONS

ACARS	Aircraft Communication Addressing and Reporting System
AIMS	Aircraft Information Management System
AGL	Above Ground Level
A/P	Autopilot
ATC	Air Traffic Control
CDU	Control Display Unit
CPDLC	Controller-Pilot Data Link Communication
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
ENG	Engine
EGPWS	Enhanced Ground Proximity Warning System
EICAS	Engine Indicating and Crew Alerting System
EXEC	Execute
FLCH	Flight Level Change
FMA	Flight Mode Annunciation
FMC	Flight Management Computer
FO	First Officer
FPA	Flight Path Angle
LNAV	Lateral Navigation
LT	Local Time
MCP	Mode Control Panel
MEL	Minimum Equipment List
ND	Navigation Display
Nm	Nautical Mile

OFP	Operational Flight Plan
PDC	Pre-departure Clearance
PFD	Primary Flight Display
PIC	Pilot-in-Command
PM	Pilot Monitoring
PTH	Path
QAR	Quick Access Recorder
RTE	Route
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
TO/GA	Take-Off /Go-Around
UTC	Coordinated Universal Time
VNAV	Vertical Navigation
V/S	Vertical Speed
WAC	Walk-around Check
ZFW	Zero Fuel Weight

SYNOPSIS

On 2 September 2019 at about 0133 local time, a Boeing B777-300ER took off from Pudong Airport in Shanghai, China. The flight crew engaged the autopilot[1] (A/P) after the take-off. The pitch mode selected at the time of A/P engagement was Vertical Navigation (VNAV). Shortly after, the "DON'T SINK" caution alert from the Enhanced Ground Proximity Warning System (EGPWS) was activated three times.

The flight crew carried out troubleshooting and engaged the Flight Level Change mode on the Mode Control Panel to climb the aircraft. After the caution alert had stopped, the flight crew reverted to the VNAV mode. Subsequently, another "DON'T SINK" caution alert was activated, followed by a “PULL UP” warning alert. In response to the warning alert, the flight crew disengaged the A/P, increased the engine thrust and pitched the aircraft to climb. The warning alert stopped and the flight proceeded without further incident.

The Transport Safety Investigation Bureau classified this occurrence as an incident.

AIRCRAFT DETAILS

Aircraft type	:	Boeing B777-300ER
Operator	:	Singapore Airlines
Aircraft registration	:	9V-SWD
Numbers and type of engines	:	2 x General Electric 90-115
Engine hours/cycles since new	:	ENG (1) 1,870.14 / 259, ENG (2) 15,176.36 / 2024
Engine hours/cycles since last shop visit	:	ENG (1) N/A ENG (2) 1,808.19 / 253
Date and time of incident	:	1 September 2019 / 1737UTC
Location of occurrence	:	Climb out of Pudong Airport, Shanghai
Type of flight	:	Scheduled
Persons on board	:	120

[1] The flight crew engaged the autopilot to fly the aircraft based on the Lateral Navigation (LNAV) and Vertical Navigation (VNAV) flight modes, which controlled the heading and pitch of the aircraft respectively.

1 FACTUAL INFORMATION

All times used in this report are Shanghai, China local time (LT) unless otherwise stated. Shanghai's LT is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

1.1.1 On 2 September 2019, a Boeing B777-300ER was scheduled to fly from Pudong Airport in Shanghai, China to Singapore. The flight crew comprised a Pilot-in-Command (PIC) and a First Officer (FO). The flight was scheduled to depart at 0035LT, but the departure time was delayed to 0105LT because of bad weather.

1.1.2 According to the PIC, the flight crew had many issues to deal with prior to the departure:

(a) The bad weather had caused delays to many arrival and departure flights at Pudong Airport. Many aircraft, including the incident aircraft, had to park at remote bays and there was a very high demand for the airport's transport resource for airlines' flight crew and cabin crew to reach their aircraft. The PIC had to intervene to secure transport to his aircraft to avoid further departure delay.

(b) On arriving at the aircraft, both the PIC and FO reviewed the aircraft electronic logbook. They noted that there were five defects that were deferred for rectification using the Minimum Equipment List (MEL)[2]. The most significant one being MEL item 36-22-01-05A. This concerned an inoperative pneumatic manifold temperature sensor on the right-hand engine bleed system. While maintenance personnel had, as a pre-flight requirement per the MEL, already locked the High Pressure Shut-off Valve (HPSOV) on the right-hand engine in the "closed" position, the PIC needed to go through the relevant pages in the MEL to take note of the MEL engine bleed action items that he and the FO had to perform during the flight. To the PIC, MEL 36-22-01-05A was not a straightforward item as it required the flight crew to refer to five other MEL items for actions related to other affected aircraft systems. The FO then went to perform an exterior walk-around check (WAC). The PIC made a mental note that he would need to discuss with the FO, when the FO returned from the WAC, to ensure

[2] An MEL was an approved list, established by the operator for a particular aircraft type based on the Master MEL established by the aircraft manufacturer and approved by the aircraft certification authority concerned, which identified aircraft components that individually might be unserviceable at the commencement of a flight, but for which there might be special aircraft operating conditions, limitations or procedures in respect of each of these unserviceable components.

proper coordination when flying with this MEL condition[3].

(c) Before going for the WAC, the FO experienced difficulty in requesting for the Pre-Departure Clearance (PDC)[4]. He noted that the connection to the Controller-Pilot Data Link Communications (CPDLC) was intermittent. The FO decided to try again after completing the WAC. While the FO was performing the WAC, the PIC tried and experienced difficulties in requesting for the zero-fuel weight (ZFW) and the FMC flight route from the operator via the Aircraft Communication Addressing and Reporting System (ACARS). The PIC noted from the hard copy of their Operational Flight Plan (OFP) that the departing runway would be Runway 34L[5] and Standard Instrument Departure (SID)[6] HSN 22X. As he had difficulties downloading the FMC flight route, the PIC manually input the flight route, as per the operator's standard operating procedure (SOP)[7], and SID HSN 22X into the FMC as Route (RTE) 1 and activated RTE 1. The PIC noted on the FMC display that the first waypoint of SID HSN 22X was HSH and there was a speed/altitude crossing constraint of "250/1970A" pre-programmed for this waypoint (see **Figure 1**), i.e. the aircraft speed should not be more than 250 knots and the aircraft altitude should be at or above 1,970 feet (as suggested by the letter "A" in "250/1970A") when crossing HSH. All this was accomplished while the FO was performing the WAC.

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[3] The PIC was mindful of the following implications of the MEL condition for the engine bleed system:

(1) The wing anti-ice system would not function automatically. If wing anti-ice was needed, the flight crew would have to turn it on manually. Given the bad weather along the departure route, the PIC was quite certain that anti-ice would be needed.

(2) The locking of the HPSOV in the closed position would entail a certain procedure to be followed by the flight crew which required the cycling of the related bleed switch when the engine power was set at 55% N1 or greater before take-off. Flight crew would normally carry out this procedure on the runway after being cleared for take-off.

[4] The flight crew would send a request for and receive the PDC from the Air Traffic Control via the CPDLC. The PDC contained information additional to that in the flight plan, such as the departure runway and standard instrument departure (SID) to be used.

[5] Pudong Airport had four parallel runways, numbered as, from the east to the west: 34R-16L, 34L-16R,35R-17L and 35L-17R.

[6] SID routes (also known as departure procedures) were published flight procedure for aircraft to follow, after take-off from an airport. These published flight procedures helped to maintain an orderly departure of flights out of the airport and to maintain separation. Thereafter, the flights would proceed to their destination based on the filed flight plan.

[7] According to the operator's procedure, the steps for inputting the flight route into the FMC were: (1) to enter the Operational Flight Plan (OFP) route via the Route (RTE) page and to select ACTIVATE after cross-checking, (2) to choose the correct runway/SID from the list of runways/SIDs in the Departure (DEP) page, and (3) to view all the legs of the SID via the LEGS page, with speed/altitude constraints of all the waypoints shown.

Figure 1. Picture reconstruction (for illustration purpose) showing the programmed speed/altitude constraint of "250/1970A" on SID HSN 22X

(d) After the FO returned to the cockpit, the PIC discussed with him in depth the MEL engine bleed action items and explained how they needed to dispatch the flight under the MEL requirement. The PIC spent some time addressing the FO's requests for clarification.

(e) The FO then tried again and managed to download the PDC[8]. The PIC noted that instead of runway 34L, the runway assigned was 35R (a parallel runway to the west of 34L) and the assigned SID was HSN 12X (see **Figure 5** in paragraph 1.4.1). Thus, the PIC needed to amend his earlier inputs to the FMC. Instead of amending the active route, the PIC used the ROUTE COPY function of the FMC to duplicate a copy of RTE 1 into RTE 2 and thereafter amended the RTE 2 SID to HSN 12X. The PIC then briefed the FO on the SID and the flight route. During the briefing, the PIC noticed on the FMC that the first waypoint of SID HSN 12X was PD062 and that, unlike waypoint HSH on SID HSN 22X, there was no speed/altitude crossing constraint indicated for PD062 (the FMC display was "---/-----") (see **Figure 2**). The PIC was aware that this "---/-----" was not abnormal[9] but he preferred to have the speed constraint explicitly

[8] The flight crew did not manage to download the ZFW and FMC flight route. They worked using the hardcopy of OFP and the operator's traffic staff provided them with a printed copy of ZFW.

[9] The PIC was aware that at below 10,000 feet, although the speed constraint was not explicitly displayed on the line corresponding to the waypoint PD062 nor on any line before this waypoint, the FMC was programmed to limit the aircraft speed to 250 knots.

displayed[10], so he decided to input the speed constraint of 250 knots (as published in the Departure Navigation Chart[11]) into the FMC and he keyed in a speed/altitude constraint of “250/0500”[12] for PD062 using the CDU. The FO observed the PIC’s inputs, as part of the cross-checking process, and accepted the inputs as correct[13]. Upon completion of this verification and briefing, the PIC then activated RTE 2 by pressing the “ACTIVATE” button followed by the “EXEC” (execute) button.

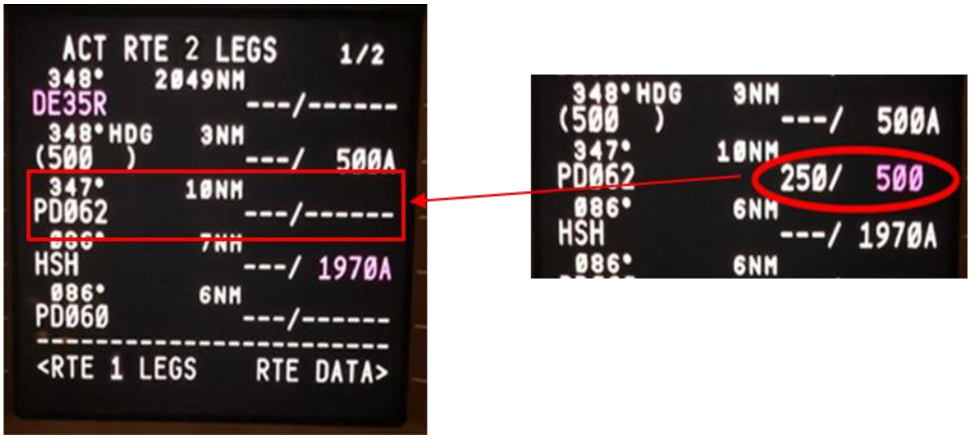

Figure 2. Picture reconstruction (for illustration purpose) – the left picture showing the default speed/altitude constraint of “---/-----” at PD062 on SID HSN 12X and the right picture showing the PIC’s inputs.

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[10]The altitude constraint (“500A”) was not indicated on the display line corresponding to PD062, but it was explicitly displayed on the line just before the display line corresponding to PD062. From the FO’s experience of flying out of Pudong with other PICs, he never had to programme the speed in the FMC and he accepted what the PIC chose to do and did not query or seek clarification from the PIC. The FO recalled that the FMC defaulted to maintain a speed of 250 knots below 10,000 feet as indicated on the FMC VNAV CLIMB page.

[11]The official navigation chart for each airport published in each country’s Aeronautical Information Publication.

[12]On the B777 FMC, a speed constraint input required a corresponding altitude constraint. According to the PIC, he intended to key in “250/0500A”, i.e. the aircraft speed should not be more than 250 knots and the aircraft altitude should be above 500 feet when crossing PD062. The PIC told the investigation team that he had pressed the “A” button twice. The first time he pressed, the “A” was not captured by the FMC. He pressed the “A” button a second time and did not notice that the “A” was not captured by the FMC. Thus, the PIC’s input into the FMC was captured as “250/0500”. This meant that the FMC would, up to PD062, limit the aircraft altitude to no more than 500 feet.

[13]According to the FO, it was usually his habit to scan through the inputs one more time to look for discrepancies after the PIC had completed his inputs, but he said he did not carry out the scan in this instance due to the time pressure.

(f) After the flight plan and SID were input into the FMC, the FO asked for further clarification on the MEL engine bleed action items. The PIC was concerned that the FO might not have fully understood the MEL issue and he spent some more time explaining his plan and the actions that each of them needed to perform.

(g) While the flight crew were preparing the aircraft for departure, the ground staff came into the cockpit repeatedly to ask them when the aircraft door could be closed for departure. The ground staff was most probably concerned that a delay in the cockpit preparation could further delay the flight. The PIC had to tell the ground staff to wait outside the cockpit and that he would call for her after they had completed their departure preparation.

(h) As Air Traffic Control in China gave altitude clearances in metric system (metres instead of feet), the flight crew needed to convert these altitude clearances to feet by using a conversion table. Both the PIC and FO had to agree on the converted altitude in feet before the figure was input into the aircraft systems.

(i) In accordance with SOP, the PIC planned to engage the autopilot (A/P)[14] early after the take-off in order to use the auto-flight system[15] to reduce the workload in managing the flight. This was because he was mindful of the need to convert altitude clearances given in metres to feet and of the potential weather to the east of the airport. However, the FO did not recall that the PIC communicated his plan to engage the A/P early.

1.1.3 After all the pre-flight preparation had been completed and the many issues mentioned above settled, the flight crew obtained clearance for pushback. After pushback, they started the engines and taxied the aircraft to Runway 35R.

1.1.4 While taxiing to Runway 35R, the PIC again reviewed the MEL action items with the FO. The aircraft took off at 0133LT. The MEL action items were executed smoothly during the take-off.

1.1.5 After the aircraft was established in a climb with the landing gear retracted, the PIC called for A/P engagement as the aircraft climbed through an altitude of approximately 360 feet. The FO engaged the A/P.

[14] The flight crew's intention for engaging the A/P was to fly the aircraft based on the Lateral Navigation (LNAV) and Vertical Navigation (VNAV) flight modes, which controlled the heading and pitch of the aircraft respectively.

[15] Auto-flight system in this report referred to the use of A/P, auto-throttle and Flight Management System to fly the aircraft.

1.1.6 According to the FO, when the aircraft was climbing past 400 feet above ground level (AGL), the Flight Mode Annunciation (FMA) on the Primary Flight Display (PFD) changed from "HOLD / LNAV / TO/GA" to "SPEED / LNAV / VNAV PTH[16]" (see **Figure 3**). The FO called out "SPEED, VNAV PTH[17]". He made the callout twice. However, according to the PIC, he did not hear the FO's callouts. The FO did not pursue in seeking a response from the PIC.

1.1.7 The aircraft continued to climb. The PIC noted from his PFD that the aircraft had climbed past 500 feet AGL. Both the PIC and FO then noticed the increasing speed trend arrow on the speed tape located on the left side of the PFD. This indicated that the aircraft was accelerating. At this time, the PIC believed that the aircraft had crossed 1,000 feet AGL[18], and he called for flaps to be retracted. The FO retracted the flaps in stages as commanded.

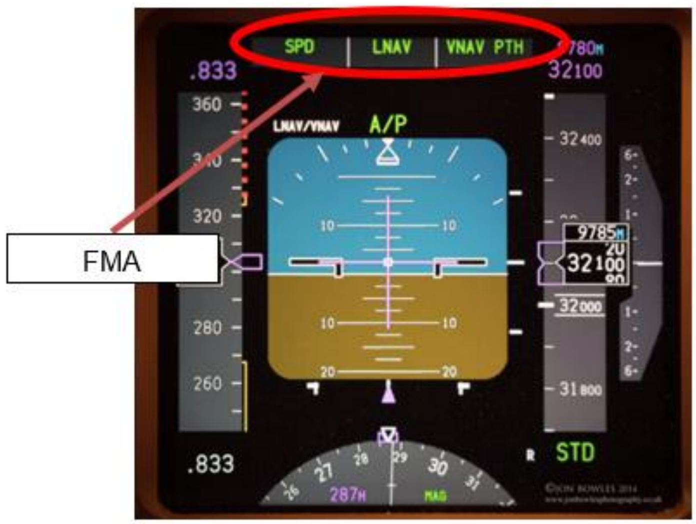

Figure 3. Picture (for illustration purpose) showing FMA

1.1.8 However, the flight crew did not verify the altitude information available from the altitude tape located on the right side of the PFD. According to data from the quick access recorder (QAR), the aircraft did not attain 1,000 feet AGL. After the A/P was engaged, the aircraft climbed from about 360 feet to 750 feet AGL before descending back towards 500 feet AGL which was the altitude constraint that the PIC had input into the FMC. The PIC did not realise that the aircraft had stopped climbing and had commenced a descent towards 500

[16]VNAV PTH indicated that the A/P mode was manoeuvring the aircraft to an FMC altitude.

[17]The FO earlier called out LNAV at LNAV engagement when the aircraft climbed past 50 feet AGL and the PIC acknowledged. Here the FO only called out VNAV engagement as there was no change to the Lateral Navigation mode.

[18]1,000 feet AGL was the normal flap retraction and aircraft acceleration altitude for departures.

feet AGL.

1.1.9 During the initial stage of the flap retraction, a “DON’T SINK” caution alert[19] from the Enhanced Ground Proximity Warning System (EGPWS) was activated. The PIC and FO were startled as they were not expecting a caution alert during the climb phase of the flight[20]. Nevertheless, according to the PIC, he did not rush into reacting to the caution alert as he deemed the flight was stable and he decided to first complete the flap retraction. At that time, the PIC also noticed a tailwind on his Navigation Display (ND). The PIC voiced out to the FO that the caution alert could be due to the aircraft decreasing its pitch as a result of the tailwind. The FO did not think so but did not comment[21].

1.1.10 Nine seconds after the “DON’T SINK” caution alert, a second “DON’T SINK” caution alert was activated. At this time, the flaps were still being retracted and the flight crew were still troubleshooting the first caution alert. This was followed by a third “DON’T SINK” caution alert a further nine seconds later. The flight crew then realised that the aircraft had levelled off and they needed to reinitiate a climb.

1.1.11 The PIC engaged the Flight Level Change (FLCH) on the Mode Control Panel (MCP) (see **Figure 4**)[22]. However, two seconds later, he re-engaged the VNAV mode[23] by engaging the VNAV switch, which removed the FLCH mode. The PIC thought that he had resolved the issue as the “DON’T SINK” caution alert had ceased. However, according to the QAR data, the short FLCH engagement resulted in no appreciable change in altitude as the aircraft was oscillating between 480 to 500 feet AGL.

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[19]Caution alert - a category of alerts that would require the flight crew’s immediate awareness but not necessarily their immediate response action.

[20]The “DON’T SINK” caution alert - was normally associated with approaches for landing and not expected during a climb.

[21]The FO told the investigation team that he thought the reduction in the rate of climb and pitch was likely associated with the VNAV PTH.

[22]The MCP was used to manage the flight path system during a flight.

[23]The FLCH mode flew the aircraft towards the altitude pre-set by the flight crew in the altitude window on the MCP. In this case, with FLCH switch engaged, the aircraft would fly to 3,000 feet AGL as this was set by the flight crew in the altitude window before the event take-off.

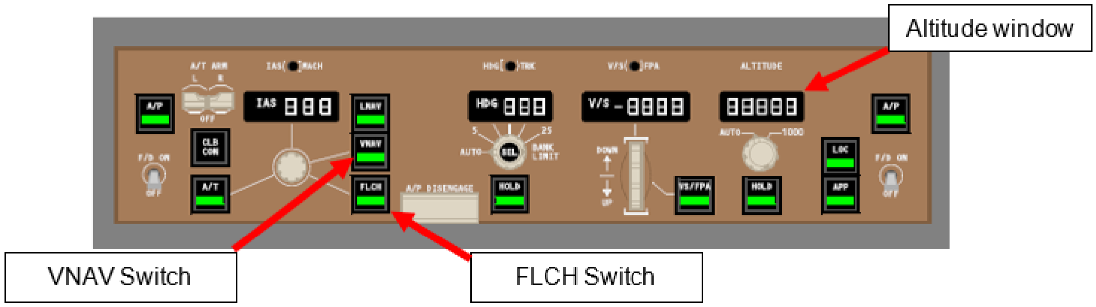

Figure 4. Picture (for illustration purpose) of MCP

1.1.12 As mentioned in paragraph 1.1.11, the PIC after engaging FLCH on the MCP thought he had resolved the issue, and he re-selected the VNAV switch. Another "DON'T SINK" caution alert was activated nine seconds after the VNAV was re-selected. Shortly after, an EGPWS "PULL UP" warning alert[24] was activated. In response, the PIC disconnected the A/P, manually pushed the thrust levers forward to increase the engine thrust and pitched[25] the aircraft up into a climb. As the aircraft climbed, the warning alert ceased.

1.1.13 As the aircraft was passing about 1,600 feet, the PIC called for the A/P to be re-engaged and the FO engaged the A/P. As the MCP had not been reset and VNAV PTH was still active, the aircraft then pitched down to regain the previously programmed target altitude of 500 feet. The maximum altitude reached was about 1,780 feet before the aircraft started descending again. At this time the FO noticed on his ND that there was a "250/0500" speed/altitude constraint set for the waypoint PD062. He realised that it was this altitude constraint that had been causing the aircraft to attempt to maintain 500 feet when VNAV was engaged.

1.1.14 The FO alerted the PIC that they needed to cancel the speed/altitude constraint and the FO pushed the altitude selector button on the MCP to delete the programmed speed/altitude constraint. After doing so, there was no more issue with the aircraft climbing to the intended altitude and the flight proceeded to Singapore without further incident.

[24]Warning alert - a category of alerts that would require the flight crew's immediate response action.
[25]The PIC increased the pitch of the aircraft to 15 degrees. He did not increase the pitch angle to 20 degrees nor disengage the auto-throttle as required by the EGPWS escape manoeuvre. The PIC explained that this was because he had noticed that the aircraft was climbing positively and hence, he did not think it was necessary to increase the pitch further.

1.2 Personnel information

1.2.1 Commander (Pilot Flying)

Gender	Male
Age	55
Licence	Airline Transport Pilot Licence issued by the Civil Aviation Authority of Singapore
Licence validity	31 October 2020
Medical certificate validity	26 September 2019
Last base check	26 July 2019
Total flying experience	18,369 hours 52 minutes
Total hours on B777	11,085 hours 24 minutes
Flying in last 24 hours	5 hours 31 minutes
Flying in last 7 days	18 hours 42 minutes
Flying in last 90 days	218 hours 54 minutes
Total rest time	22 hours 05 minutes

1.2.2 First Officer (Pilot Monitoring)

Gender	Male
Age	29
Licence	Multi-crew Pilot Licence issued by the Civil Aviation Authority of Singapore
Licence validity	30 April 2020
Medical certificate validity	22 March 2019
Last base check	1 May 2019
Total flying experience	1,744 hours 18 minutes
Total hours on B777	1,744 hours 18 minutes
Flying in last 24 hours	5 hours 31 minutes
Flying in last 7 days	21 hours 43 minutes
Flying in last 90 days	242 hours 54 minutes
Rest Time before flight	22 hours 05 minutes

1.3 Meteorological information

1.3.1 The weather at Pudong Airport was in Visual Meteorological Condition. Before and around the time of the departure of the incident aircraft, there had been two massive weather systems at the South China Sea which resulted in a wide area of thunderstorms about 20-30 Nm to the east of the airport and on the departure route of the incident aircraft.

1.4 Aerodrome information

1.4.1 **Figure 5** shows SID HSN 22X and HSN 12X.

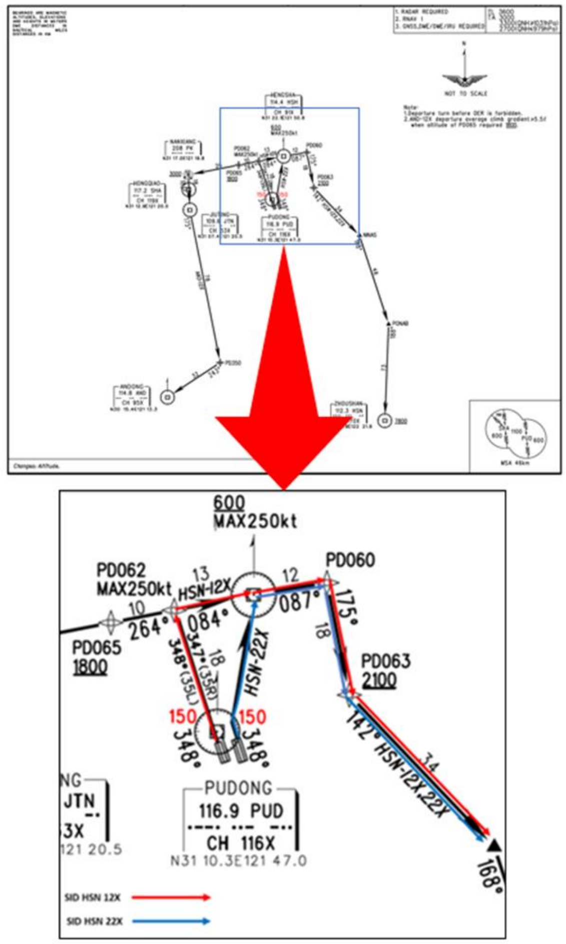

Figure 5. Chart for Pudong Radio Navigation Departure extracted from the Aeronautical Information Publication. Note: Altitudes in meters as published

1.5 Flight recorders

1.5.1 The QAR data relating to the event flight was provided by the operator. It contained recorded parameters that were useful for the investigation in developing the sequence of events during the EGPWS activations.

1.5.2 The QAR data was provided to the aircraft manufacturer for analysis to determine the cause of the EGPWS "DON'T SINK" caution alerts and "PULL UP" warning alert.

1.6 Tests and research

1.6.1 EGPWS software

1.6.1.1 The aircraft manufacturer's analysis of the QAR data indicated the following:

(a) The EGPWS "DON'T SINK" caution alerts were triggered as a result of the aircraft losing altitude during take-off and was consistent with the system design.

(b) The cause of the EGPWS "PULL UP" warning alert could not be determined. It was suspected that the EGPWS mode that compared radio altitude and terrain closure rate had entered into the "PULL UP" warning envelope due to the combination of the low altitude, descent rate and flight path angle required to capture the 500 feet altitude constraint that had been set in the FMC.

(c) There was no maintenance record of any defect relating to the EGPWS before the incident and there had been no report of any problem with the EGPWS since.

1.6.2 FMC navigation database

1.6.2.1 The B777 FMC was programmed to only display a speed constraint when there was an associated altitude constraint at the waypoint. Although the speed constraint of 250 knots for waypoint PD062 was programmed in the database, it was not displayed on the FMC LEGS page as there was no altitude constraint programmed for waypoint PD062.

1.7 Additional Information

1.7.1 Around the time that the PIC engaged FLCH mode there was an ATC clearance to climb to 6,000 metres AGL. However, there were differences in the accounts of the PIC and FO as regards this clearance and the actions thereafter.

(a) According to the FO, he read back the ATC clearance and thereafter noted from the conversion chart that 6,000 metres was equivalent to 19,700 feet and he called out "197" to the PIC. The FO recalled that the PIC set an altitude figure into the altitude window on the MCP and said something unintelligible[26]. The FO did not ask the PIC to clarify what he had said.

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[26]The PIC said that he had informed the FO that the clearance was not meant for them. It was probable that this communication by the PIC was what the FO heard as being unintelligible.

The FO saw that the figure[27] set by the PIC into the altitude window was not what he had called out. The FO then repeated the callout two more times, but the PIC did not respond to him and the FO did not pursue further. Although the PIC stated that there was a subsequent ATC clearance (see (b)), the FO could not recall that there was another ATC clearance of 6,000 metres for them[28].

(b) According to the PIC, he believed that the ATC clearance of 6,000 metres that the FO had read back was meant for another flight with a similar sounding callsign and not for them[29]. The PIC recalled informing the FO (after the FO called out "197") that the FO had replied to a wrong callsign. The PIC said that there was a subsequent ATC clearance for them to follow the SID profile to 6,000 metres. The PIC recalled that the FO read back the clearance to the ATC and again called out "197" which the PIC acknowledged this time. The PIC then checked the conversion chart to confirm that 6,000 metres was equivalent to 19,700 feet. He then initiated a climb by setting an intermediate altitude in the altitude window on the MCP, with the intention of fine-tuning and setting "197" after initiating the climb, but he did not communicate this intention to the FO.

1.7.2 The investigation team could not reconcile the differences in the accounts from the PIC and FO. The CVR recording would have been useful in providing insight into the interaction at the time. However, the CVR recording was not available as it had been overwritten.

[27]The FO recalled that the altitude figure which he saw the PIC set was something like 110 or 120 and certainly not 197. This prompted him to call out the figure again.

[28]The investigation team was unable to determine if there was a subsequent ATC clearance as the CVR was overwritten.

[29]The investigation team obtained the list of flight numbers that were operating at that time. The list did not appear to have any callsign that sounded similar to that of the incident aircraft.

2 ANALYSIS

2.1 It was clear that the events encountered by the flight crew were the result of the FMC having registered a speed/altitude constraint of “250/0500” for the waypoint PD062. The PIC had inadvertently keyed in “250/0500” instead of the intended “250/0500A”. This meant that, when the armed VNAV mode became active at 400 feet AGL, it would provide guidance commands to the A/P to maintain the programmed altitude of 500 feet. Given the high rate of climb and aircraft inertia, it was not possible for the auto-flight system to immediately capture 500 feet. Hence the aircraft climbed through this altitude before commencing a descent in an attempt to maintain the programmed altitude until PD062.

The investigation looked into the following aspects:

(a) Compliance with procedures

(b) Cause of EGPWS “PULL-UP” warning alert

(c) Crew resource management (CRM)

  i. Communication between the PIC and FO

  ii. Loss of situational awareness

(d) Issues affecting PIC’s workload

(e) PIC’s auto-flight mode management and training

2.2 Compliance with procedures

2.2.1 Compliance with standard operating procedures (SOPs) is a safety strategy during flight operations to minimise unintended missteps by flight crew or misunderstanding among flight crew members. In particular, adherence to SOPs pertaining to callouts and responses is important as proper callouts and responses would ensure that flight crew members acquire a common situational awareness and maintain flight mode awareness. This would enable them to better manage an abnormal condition that surfaces.

2.2.2 There were a number of instances in this occurrence where the flight crew did not comply with the operator’s SOPs:

(a) Before the departure runway was assigned and while the FO was not in the flight deck, the PIC manually set up RTE 1 on LEGS page in the FMC based on the hardcopy of OFP they received. This practice was not in accordance with the operator’s SOP whereby manual OFP entries into the FMC were to be made by both the flight crew together as cross-checking was required. (See paragraph 1.1.2 (c))

(b) After ascertaining the departure runway from the PDC, the PIC copied RTE 1 to RTE 2 and then changed the runway and SID to Runway 35R and SID HSN 12X respectively, but he did not select ACTIVATE after doing so and started briefing the FO on the flight route. During the briefing, he noticed that the speed/altitude constraint for waypoint PD062 displayed only as "---/-----" and proceeded to manually enter the constraints. After briefing the FO regarding the flight route, the PIC then pressed ACTIVATE and executed RTE 2 into the FMC. This was not in accordance with the procedure where the route should have been activated prior to selecting the SID (see Footnote 7). Had RTE 2 been activated prior to selecting the SID, the FMC would have automatically displayed the predicted speed and altitude of all the waypoints when the SID was selected. When the PIC did not follow the steps in the procedure, the PD062 waypoint was presented as "---/-----", which led the PIC to manually enter the speed/altitude constraints for PD062. The manual entry would take precedence over FMC's predicted speed and altitude.

(c) When the aircraft was climbing past 400 feet AGL after take-off, the FO observed the VNAV engagement on the FMA and announced "SPEED / VNAV PTH" twice. However, the PIC did not acknowledge the FO's callouts as he did not hear them. The FO did not challenge the PIC to acknowledge his callout as required by the procedure. (See paragraph 1.1.6)

(d) In response to the EGPWS "PULL UP" warning alert, the PIC disconnected the A/P and manually increased the engine thrust and pitched the aircraft up into a climb at 15 degrees. While the PIC had carried out the recovery manoeuvre in a timely manner, he did not adhere fully to the EGPWS escape manoeuvre by disengaging the auto-throttle and pitching the aircraft to 20 degrees as required. (See paragraph 1.1.12)

2.3 Cause of EGPWS "PULL-UP" warning alert

2.3.1 The investigation team was unable to determine the reason of the activation of the EGPWS "PULL UP" warning alert. However, the aircraft manufacturer suspected that the warning could be as a result of the combination of the low radio altitude, descent rate and flight path angle required to capture the 500 feet altitude constraint that had been entered into the FMC. The investigation team noted that that there was no maintenance record of any defect relating to the EGPWS before the incident and there had been no report of any problem with the EGPWS following the incident.

2.4 Crew resource management (CRM)

2.4.1 CRM is the application of a team management concept and the effective use of all available resources to operate a flight safely. It requires ongoing monitoring, communication, questioning, cross-checking, and refinement of perception. In a glass cockpit where flight crew members have their individual and independent access to most of the controls, a concerted effort and systematic coordination is needed to ensure that flight crew members inform each other of their respective intentions and actions in the cockpit. Thus, it is important that all flight crew members identify and communicate any situation that appears unsafe or out of the ordinary. In this respect, the role of the Pilot Monitoring (PM) is important in monitoring and cross-checking what the other flight crew member is doing, as well as adhering to recommended callouts to ensure shared crew situational awareness.

2.4.2 Communication between the PIC and FO

2.4.2.1 There were a number of instances in this occurrence where the flight crew's performance in terms of CRM had not been optimal:

(a) The FO's own experience was that it was not necessary for the PIC to input the speed constraint in respect of PD062 on SID HSN 12X when the FMC displayed a speed/altitude constraint of "---/-----". However, he did not raise any query with the PIC on the need to do so. Also, while he observed the PIC's input of the speed/altitude constraint, he did not notice that the PIC had keyed in "0500" instead of "0500A". (See paragraph 1.1.2(e))

(b) The PIC planned to engage the A/P early after take-off in order to use the auto-flight system to reduce the workload in managing the flight and had informed the FO. However, the FO did not recall that the PIC communicated his plan to engage the A/P early. (See paragraph 1.1.2(i))

(c) With respect to the first "DON'T SINK" caution alert, the PIC thought that it could be due to a tailwind. The FO did not think so and was more inclined to believe that it had something to do with the VNAV PTH flight mode. However, the FO did not challenge the PIC. (See paragraph 1.1.9)

(d) Following ATC's clearance for the aircraft to climb to 6,000 metres AGL (19,700 feet), the FO called out "197" and saw the PIC set a different altitude figure on the MCP. The FO did not hear the PIC's callout for the altitude that the PIC set although he heard the PIC mutter something unintelligible. The FO then repeated the callout two more times, but the PIC did not respond to him and the FO did not pursue the matter further with the PIC. (See paragraph 1.7.1 (a)) The PIC's intention of starting the aircraft to climb by setting an intermediate altitude followed by the final setting of "197" was not communicated to the FO. (See paragraph 1.7.1(b))

2.4.2.2 The investigation team opined that the FO was not assertive in eliciting the PIC's response to his callouts or in questioning the PIC when he had doubts about the PIC's actions. The investigation team felt that the FO should have applied the escalation technique[30] taught in CRM training to alert the PIC of the FO's concern regarding the lack of responses from the PIC. Good communication can serve to maintain a shared understanding and situation awareness.

2.4.3 Loss of situational awareness

2.4.3.1 There were instances where the flight crew lost situational awareness:

(a) After the aircraft had climbed past 500 feet AGL, the flight crew saw the speed trend arrow indicating that the aircraft was accelerating, and the PIC commanded for flaps to be retracted as he believed that the aircraft had crossed 1,000 feet AGL. They did not cross check the altitude tape on the PFD for the altitude information. (See paragraphs 1.1.7 and 1.1.8)

(b) The flight crew were startled by the first EGPWS "DON'T SINK" caution alert. This likely caused a sudden increase in workload in their trying to troubleshoot. While focusing on troubleshooting, they did not notice that the aircraft had stopped climbing and was descending towards 500 feet AGL. Two more "DON'T SINK" caution alerts were activated before they realised that the aircraft had levelled off and that they needed to reinitiate a climb. (See paragraphs 1.1.9 and 1.1.10)

(c) The "DON'T SINK" caution alert was activated during the flap retraction. The PIC thought that the caution alert could be due to the tailwind. The PIC did not recognise that the caution alert was related to the VNAV PTH flight mode descending to capture a programmed altitude constraint in the FMC.

[30] The escalation technique is a process requiring the FO to use more assertive language to intervene with a view to alerting and prompting the PIC to take corrective actions.

2.5 Issues affecting PIC's workload

2.5.1 As mentioned in paragraph 1.1.2, the PIC had to deal with a number of issues prior to the departure:

(a) Bad weather

(b) Aircraft departure delay

(c) Having to intervene personally to secure transport to the remote bay where the aircraft was parked in order to avoid further departure delay

(d) Delay in downloading the PDC owing to intermittent CPDLC datalink connectivity

(e) Manual input of the flight route into FMC

(f) Need to note the MEL engine bleed action items and subsequent in-depth discussion and coordination with the FO to ensure smooth execution during take-off

(g) Need to convert ATC altitude clearance given in metres to feet

(h) Ground staff pressuring for closing of aircraft doors in order to minimise further departure delays while the flight crew were still going through their pre-flight preparation

2.5.2 Each of these issues, by itself, would have been just a minor issue for the PIC. However, together, these out-of-the-normal pre-flight circumstances had the potential of perturbing the PIC. The extent of any perturbation on the part of the PIC could not be ascertained and the investigation team could only suspect that they could have added up to some significant stress on the PIC and contributed to his lapses in FMC programming and decision-making during the flight.

2.6 PIC's auto-flight mode management and training

2.6.1 During the initial stage of the flap retraction, there was a series of three EGPWS "DON'T SINK" caution alerts. Moments after the third caution alert, the flight crew realised that the aircraft had levelled off and the PIC engaged the FLCH mode. The caution alert ceased thereafter, and the PIC thought that he had resolved the issue and re-selected the VNAV switch two seconds after the FLCH engagement. As the FLCH mode was only engaged for two seconds, there was no appreciable change in aircraft vertical path. Nine seconds after the re-selection of the VNAV, another "DON'T SINK" caution alert was activated, followed by an EGPWS “PULL UP” warning alert.

2.6.2 This occurrence is an apt reminder of the guidance given in the Flight Crew Training Manual (FCTM) that, when automation does not perform as expected, the flight crew should reduce the level of auto-flight and identify and resolve the condition and that the original level of auto-flight should only be resumed after they have regained proper control of the flight path and performance level.

2.6.3 Notwithstanding that the PIC had achieved an above-average grade and been considered good in the area of auto-flight management during his line and base checks, the investigation team felt that it might be desirable for the operator to review its auto-flight management assessment programme to ensure that it is robust.

3 CONCLUSIONS

From the information gathered, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 The EGPWS "DON'T SINK" events encountered by the flight crew were the result of the FMC having registered a speed/altitude constraint of "250/500" for the waypoint PD062. The PIC had inadvertently keyed in "250/0500" instead of the intended "250/0500A".

3.2 As to the activation of the EGPWS "PULL UP" warning alert, the investigation team was unable to determine the reason of the activation. However, the aircraft manufacturer suspected that the warning could be as a result of the combination of the low radio altitude, descent rate and flight path angle required to capture the 500 feet altitude constraint that had been entered into the FMC. The PIC did not identify that there was an abnormal condition with the auto-flight system despite the series of "DON'T SINK" alerts over a period of relatively short time.

3.3 This occurrence also revealed many instances where the flight crew did not comply with the operator's standard operating procedures, where the flight crew lost situational and flight mode awareness, and where the flight crew's crew resource management performance in terms of communication had not been optimal.

3.4 The PIC had to deal with a number of issues prior to the departure. Each of these issues, by itself, would have been just a minor issue for the PIC. However, together, these out-of-the-normal pre-flight circumstances might have perturbed the PIC. The extent of any perturbation could not be ascertained, and the investigation team could only suspect that they could have added up to some significant stress on the PIC and contributed to his lapses in FMC programming and decision-making during the flight.

3.5 Notwithstanding that the PIC's training and assessment record did not indicate any issues in the area of auto-flight management, there might be room for improvement on the part of the operator to ensure that its auto-flight management assessment programme is robust.

4 SAFETY ACTIONS

Arising from discussions with the investigation team, the organisations have taken the following safety actions.

4.1 Actions by the Operator

4.1.1 The operator has shared the lessons learnt from the occurrence as follows:

(a) Sharing with its B777 flight crew during the Fleet Meeting on 24 October 2019

(b) Sharing with the flight crew of its other aircraft fleets during the Safety Focus Forum on 20 November 2019

In addition, the operator has also emailed these lessons learnt to all its flight crew on 10 December 2019.

4.1.2 The operator has reminded its flight crew of the following:

(a) That the SOP requires both the PIC and his or her co-pilot to be present on the flight deck when they make inputs to the FMC (e.g. pre-flight FMC set-up, changes to SIDs where necessary).

(b) That, instead of making changes to SIDs in the FMC setting, if the changes can be managed simply through manually adjusting the aircraft flight settings, then the method of manual adjustment should be used.

4.1.3 The operator has improved its flight crew training as follows:

(a) Emphasising automation mode awareness and mode management in its recurrent training of flight crew.

(b) Increasing the number of multiple and randomised scenarios to enhance the training of flight crew in their handling of startle effect.

(c) Requiring all simulator instructors to observe for correct and timely FMA callouts and proper operation of FMC during flight crew recurrent training in the simulator. The simulator sessions will also emphasise the proficient and judicious use of A/P.

4.2 Actions by the aircraft manufacturer

4.2.1 The operator has consulted the aircraft manufacturer on the possibility of modifying the FMC software such that a flight crew could input a speed constraint during climb and descent phases of a flight without having to also input an altitude constraint. The aircraft manufacturer has responded that it will consider such a feature for a possible future Aircraft Information Management System (AIMS) avionics software update.

5 SAFETY RECOMMENDATIONS

A safety recommendation is for the purpose of preventive action and shall in no case create a presumption of blame or liability.

It is recommended that:

5.1 The operator review its auto-flight management training programme with a view to ensuring that the programme is robust. [TSIB RA-2021-001]