



Air Accident Investigation Sector

Accident

- Final Report -

AAIS Case N°: AIFN/0008/2016

Runway Impact during Attempted Go-Around

Operator:	Emirates
Make and Model:	Boeing 777-31H
Nationality and Registration:	The United Arab Emirates, A6-EMW
Place of Occurrence:	Dubai International Airport
State of Occurrence:	The United Arab Emirates
Date of Occurrence:	3 August 2016



This Investigation was conducted by the Air Accident Investigation Sector of the United Arab Emirates pursuant to Civil Aviation Law No. 20 of 1991, in compliance with Air Accident and Incident Investigation Regulations, and in conformance with the requirements of Annex 13 to the Convention on International Civil Aviation.

This Investigation was conducted independently and without prejudice. The sole objective of the investigation is to prevent future aircraft accidents and incidents. It is not the purpose of this activity to apportion blame or liability.

The Air Accident Investigation Sector of the United Arab Emirates issued this Final Report in accordance with National and International Standards and best practice. Consultation with applicable stakeholders, and consideration of their comments, took place prior to the publication of this Report.

The Final Report is publicly available at:

<http://www.gcaa.gov.ae/en/epublication/pages/investigationReport.aspx>

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Occurrence Brief

Occurrence File Number	:	AIFN/0008/2016
Occurrence Category	:	Accident
Name of the Operator	:	Emirates
Manufacturer	:	The Boeing Company
Aircraft Model	:	777-31H
Engines	:	Two Rolls-Royce Trent 892
Nationality	:	The United Arab Emirates
Registration	:	A6-EMW
Aircraft Serial Number	:	32700
Date of Manufacture	:	27 March 2003
Flight Hours/Cycles	:	58,169/13,620
Type of Flight	:	Scheduled Passenger
Flight Number	:	UAE521
State of Occurrence	:	The United Arab Emirates
Place of Occurrence	:	Runway 12L, Dubai International Airport
Date and Time	:	3 August 2016, 0837:38 UTC
Total Crewmembers	:	18 (two flight and 16 cabin)
Total Passengers	:	282
Injuries to Passengers and Crew	:	32 (four serious, 28 minor)
Other injuries	:	One firefighter fatally injured
Damage	:	The Aircraft was destroyed

Investigation Process

The Air Accident Investigation Sector (AAIS) of the United Arab Emirates was notified of the Accident at 0840 UTC. The Occurrence was advised by Dubai air traffic control to the AAIS Duty Investigator (DI) hotline number +971506414667.

The occurrence was classified as an Accident according to the ICAO Annex 13 definition, and the AAIS assigned an Accident Investigation File Number, AIFN/0008/2016, to the case.

The AAIS formed an Investigation team led by an investigator-in-charge (IIC) and consisting of investigators from specialized areas of the AAIS. The National Transportation Safety Board (NTSB) of the United States, being the State of Manufacture and Design of the Aircraft, and the Air Accidents Investigation Branch (AAIB) of the United Kingdom, being the State of Manufacture of the engines, were notified of the Accident and both States assigned Accredited Representatives who were assisted by Advisers from the Boeing Company and Rolls-Royce. In addition, the Operator assigned an Adviser to the IIC. Dubai Civil Aviation Authority supported the Investigation team and provided the initial Aircraft wreckage mapping.



Notes:

1. Whenever the following words are mentioned in this Report with the first letter capitalized, they shall mean the following:
 - (Accident). This investigated accident
 - (Aircraft). The aircraft involved in this accident
 - (Airport). The aerodrome Dubai International Airport (OMDB)
 - (Commander). The Commander of the accident Aircraft
 - (Copilot). The Copilot of the accident Aircraft
 - (Investigation). The investigation into the circumstances of this accident
 - (Report). This accident investigation Final Report.
2. For the purpose of this Report, the Boeing 777-31H aircraft is described as a B777.
3. The Aircraft Operator's name used in this Report is Emirates. The air operator certificate (AOC) No. AC-0001 dated 22 February 2016 was issued to the Operator under the title of Emirates. The trading name stated in the AOC is Emirates Airline.
4. Unless otherwise mentioned, all times in this Report are UTC time. Local time of the United Arab Emirates is UTC plus 4 hours.
5. Photos and figures used in this Report are taken from different sources and adjusted from the original for the sole purpose of improving the clarity of the Report.



Abbreviations

AAIB	The Air Accidents Investigation Branch of the United Kingdom
AAIS	The Air Accident Investigation Sector of the United Arab Emirates
ADF	Automatic direction finders
ADIRS	Air data inertial reference system
AEP	Airport emergency plan
AFDS	Autopilot flight director system
AFS	Airport fire service (Service provider at Dubai International Airport)
AGL	Above ground level
AGS	Air/ground system
AIC	Air India (ICAO call sign)
AMM	Aircraft maintenance manual
AOC	Air operator certificate
ARFFS	Airport rescue and firefighting service
A/T	Autothrottle
ATC	Air traffic control
ATIS	Automatic terminal information service
ATSP	Air traffic service provider
CAR	The <i>Civil Aviation Regulations</i> of the United Arab Emirates
CBT	Computer-based training
cm	Centimeters
CRM	Crew resource management
CVR	Cockpit voice recorder
‘dans’	Dubai Air Navigation Services
DCD	Dubai Civil Defense
DMATS	Dubai manual of air traffic service
DME	Distance-measuring equipment
DISC	Disconnect
DXB	Dubai
EASA	European Union Aviation Safety Agency
EEC	Engine electronic control
EGPWS	Enhanced ground proximity warning system
EGT	Exhaust gas temperature
EICAS	Engine indication and crew alerting system
EPR	Engine pressure ratio
FAA	Federal Aviation Administration of the United States



FADEC	Full authority digital engine control
FAR	<i>Federal Aviation Regulations</i> of the United States
FCOM	Flight crew operations manual
FCTM	Flight crew training manual
F/D	Flight director
FDM	Flight data monitoring
FDR	Flight data recorder
FDRC	Flight Data Review Committee
FMA	Flight mode annunciations
FMS	Flight management system
FMC	Flight management computer
FOSB	Flight Operations Safety Board
ft	feet
GA	Go-around
GCAA	The General Civil Aviation Authority of the United Arab Emirates
GE	General Electric
GMC	Ground movement controller
GNSS	Global navigation satellite system
GPS	Global positioning system
GPWS	Ground proximity warning system
hPa	hectopascal
HPC	High-pressure compressor
HPT	High pressure turbine
HRET	High reach extendable turret
IAS	Indicated airspeed
IAW	Iraqi Airways (ICAO call sign)
ICAO	International Civil Aviation Organization
IIC	Investigator-in-charge
ILS	Instrument landing system
IPT	Intermediate pressure turbine
ISA	International standard atmosphere
JCR	Joint control room
kg	kilograms
kt	knots
LDA	Landing distance available
LNAV	Lateral navigation



m	meters
MCP	Mode control panel
METAR	Meteorological terminal air report
MFV	Major foam vehicle
MICC	Mobile incident command center
MoC	Maintenance of competency
MSRC	Management Safety Review Board
NCMS	The United Arab Emirates National Center of Meteorology and Seismology
ND	Navigation display
NTSB	National Transportation Safety Board of the United States
OFP	Operational flight plan
OGS	Online grading system
OM	Operations manual
OMDB	Dubai International Airport (ICAO Code)
OPC	Operator proficiency check
PAM	Pilot assessment marker
PBE	Protective breathing equipment
PEMS	Passenger evacuation management system
PF	Pilot flying
PFD	Primary flight display
PM	Pilot monitoring
PWS	Predictive windshear system
QAR	Quick access recorder
QNH	Barometric pressure adjusted to sea level
QRH	Quick reference handbook
RAAS	Runway awareness and advisory system
RNAV	Area navigation
RR	Rolls-Royce
RPL	Repetitive flight plan
rpm	Revolution per minute
SAG	Safety Action Group
SARPS	Standards and Recommended Practices
SMS	Safety management system
SOP	Standard operating procedure(s)
SPD	Speed
SPECI	Special significant weather reports (similar to METAR)



SRC	Survivor reception center
SSFDR	Solid-state flight data recorder
TAF	Terminal aerodrome forecast
TLA	Thrust lever angle
TO/GA	Takeoff/go-around
TRA	Thrust resolver angle
TSO	Technical standard order
UTC	Coordinated universal time
VNAV	Vertical navigation
VOR	Very high frequency omnidirectional range
VOTV	Trivandrum International Airport (ICAO Code)
V_{REF}	Reference speed
WOW	Weight-on-wheels



Synopsis

On 3 August 2016, an Emirates Boeing 777-31H Aircraft, registration A6-EMW, operating a scheduled passenger flight UAE521, departed Trivandrum International Airport (VOTV), India, at 0506 UTC for a 3 hour 30 minute flight to Dubai International Airport (OMDB), the United Arab Emirates, with 282 passengers, 2 flight crew and 16 cabin crewmembers on board.

The Commander attempted to perform a tailwind manual landing during an automatic terminal information service (ATIS) forecasted moderate windshear warning affecting all runways at OMDB. The tailwind was within the operational limitations of the Aircraft. During the landing on runway 12L at OMDB the Commander, who was the pilot flying, decided to fly a go-around, as he was unable to land the Aircraft within the runway touchdown zone. The go-around decision was based on the perception that the Aircraft would not land due to thermals and not due to a windshear encounter. For this reason, the Commander elected to fly a normal go-around and not the windshear escape maneuver.

The flight crew initiated the *flight crew operations manual (FCOM) Go-around and Missed Approach Procedure* and the Commander pushed the TO/GA switch. As designed, because the Aircraft had touched down, the TO/GA switches became inhibited and had no effect on the autothrottle (A/T). The flight crew stated that they were not aware of the touch down that lasted for six seconds.

After becoming airborne during the go-around attempt, the Aircraft climbed to a height of 85 ft radio altitude above the runway surface. The flight crew did not observe that both thrust levers had remained at the idle position and that the engine thrust remained at idle. The Aircraft quickly sank towards the runway as the airspeed was insufficient to support the climb. As the Aircraft lost height and speed, the Commander initiated the *windshear escape maneuver* procedure and rapidly advanced both thrust levers. This action was too late to avoid the impact with runway 12L.

Eighteen seconds after the initiation of the go-around the Aircraft impacted the runway at 0837:38 UTC and slid on its lower fuselage along the runway surface for approximately 32 seconds covering a distance of approximately 800 meters before coming to rest adjacent to taxiway Mike 13. The Aircraft remained intact during its movement along the runway protecting the occupants however, several fuselage mounted components and the No.2 engine/pylon assembly separated from the Aircraft.

During the evacuation, several passenger door escape slides became unusable. Many passengers evacuated the Aircraft taking their carry-on baggage with them. Except for the Commander and the senior cabin crewmember who evacuated after the center wing tank explosion, all of the other occupants evacuated via the operational escape slides in approximately 6 minutes and 40 seconds. Twenty-one passengers, one flight crewmember, and six cabin crewmembers sustained minor injuries. Four cabin crewmembers sustained serious injuries.

Approximately 9 minutes and 40 seconds after the Aircraft came to rest, the center wing tank exploded which caused a large section of the right wing upper skin to be liberated. As the panel fell to the ground, it struck and fatally injured a firefighter. The Aircraft was eventually destroyed due to the subsequent fire.

Following the Accident, the Operator (Emirates), the General Civil Aviation Authority (GCAA), Dubai Airports and Dubai Air Navigation Services ('dans') implemented several safety actions. In this Final Report, the AAIS issues safety recommendations addressed to the Operator, the GCAA, The Boeing Company, the Federal Aviation Administration (FAA), Dubai Airports, 'dans', and the International Civil Aviation Organization (ICAO).



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1. Factual Information

1.1 History of the Flight

On 3 August 2016, at 0837:38 UTC, an Emirates Boeing 777-31H Aircraft, registration A6-EMW, operating a scheduled passenger flight UAE521, impacted runway 12L at Dubai International Airport (OMDB) during an attempted go-around, and slid on its lower fuselage along the runway surface for approximately 32 seconds before coming to rest.

The Aircraft had departed Trivandrum International Airport (VOTV), India, at 0506 UTC for a 3 hour 30 minute flight to OMDB, the United Arab Emirates, with 282 passengers, 2 flight crew and 16 cabin crewmembers on board.

The flight crew had a rest period of approximately 30-hours, and the cabin crew were off-duty for periods of time varying between 53 hours and 72 hours prior to operating flight UAE521.

All of the crewmembers arrived at Trivandrum airport approximately two hours before departure time, where they were briefed for the flight. The operational flight plan briefing package was obtained by the Commander at 0110 UTC and it included the forecast weather for OMDB together with other en-route information and the B777-300 Aircraft variant assigned to the flight. The variant was a 777-31H equipped with Rolls-Royce Trent 892 engines.

The Aircraft takeoff weight was 257,789 kg, and the calculated landing weight was 229,682 kg.

The Commander, who was seated in the left pilot seat, was the pilot flying (PF) and the Copilot was the pilot monitoring (PM).

Approximately 60 minutes prior to landing, the Commander and the Copilot completed the approach briefings for OMDB runways 12L and 30L. The Commander briefed the Copilot that in case of a go-around, flaps 20 was to be selected and climb to 3,000 ft. This was in accordance with the missed approach *LIDO* plate 7-50 (Appendix C of this Report).

At 0735, the United Arab Emirates National Center of Meteorology and Seismology (NCMS) issued a moderate windshear warning affecting all OMDB runways, with a validity from 0740 to 0900. The OMDB Arrival automatic terminal information service (ATIS) commenced broadcasting the windshear warning at 0800 with information ZULU.

At 0806, as recorded in the cockpit voice recorder (CVR), the Commander briefed for the possibility of windshear and stated to the Copilot that “in case of a windshear, windshear TOGA, no configuration change”. They then discussed their previous go-around experiences. The Copilot stated that he experienced a windshear during descent “like three months ago”. The Commander stated that “I had one into Dubai but it was more like wind shift. The speed went ten knots more so we went around”. This conversation lasted approximately 60 seconds.

At 0817, as the Aircraft descended through 16,000 ft pressure altitude, the crew communicated with OMDB air traffic control (ATC) Approach and confirmed that they had received ATIS information Zulu.

The Commander stated to the Investigation that prior to the UAE521 flight, he had experienced similar windshear warnings on ATIS at OMDB. For UAE521, because there was no additional information from ATC regarding the windshear warning, he did not believe that the landing would be affected. The calculated reference landing speed (V_{REF30}) was 147 kt. An approach speed of 152 kt ($V_{REF30} + 5$) was selected on the mode control panel (MCP) for a normal landing configuration.



ATC vectored the Aircraft for RNAV (GNSS)¹ approach to runway 12L.

At 0829, and at 0831, two preceding aircraft performed go-arounds. The go-arounds were followed by two Emirates B777 aircraft that landed on runway 12L at 0833 and 0835. The UAE521 flight crew were not informed by ATC of the two go-arounds.

At 0834, the flight crew selected the landing gear to the down position, armed the speedbrake lever, selected flaps 30 and completed the landing checklist.

At 0836 the flight crew received and acknowledged the landing clearance for runway 12L from the Tower which gave the wind speed and direction as 11 kt from 340 degrees.

The approach was stabilized before 1,000 ft radio altitude. As the Aircraft descended through 930 ft radio altitude at 0836:10, the Commander disengaged the autopilot and continued the approach, with the autothrottle (A/T) engaged, in accordance with the Operator's policy. The A/T was in 'SPEED' mode. The flight directors remained in the 'on' position.

At 0836:22, as the Aircraft passed 750 ft radio altitude, at 153 kt indicated airspeed (IAS) the flight data recorder (FDR) recorded that the wind direction changed from a headwind to a tailwind component.

At 0836:40, at 450 ft radio altitude, and 156 kt IAS, an automated 'minimums' callout was annunciated, and the Commander announced "Landing". The Copilot provided feedback indicating that he had heard and understood the Commander's decision. The wind speed² component was now 10 kt from 317 degrees.

At 0836:56, passing 190 ft radio altitude at 152 kt IAS, the Copilot announced "Sixteen knots tailwind", which was acknowledged by the Commander. During this time, the Commander was maintaining the Aircraft on the nominal glidepath, at an average pitch of 0.7 degrees.

At 115 ft radio altitude and 157 kt IAS, the Copilot announced "Reducing to thirteen knots", with reference to the tailwind. This was acknowledged by the Commander who replied "Checked". The rate of descent was decreasing from 800 to 700 ft per minute, with an average pitch angle of 0.5 degrees. This was followed by a cockpit automated callout of "One hundred". The wind speed was now 13.5 kt from 308 degrees. Because of the reduction in the tailwind component, the airspeed started to increase which resulted in the A/T retarding both thrust levers.

At 0837:05, the Aircraft passed over the threshold of runway 12L (figure 1) at about 54 ft radio altitude and 159 kt IAS. Over the next four seconds automated callouts of 'fifty', 'forty', 'thirty', 'twenty' and 'ten' were annunciated.

At 0837:06, after the Aircraft had flown approximately 100 m beyond the threshold, as recorded by the FDR, the Commander initiated the flare at approximately 40 ft radio altitude with a pull on the control column.

At the start of the flare, the pitch angle changed from 0.0 to 0.4 degrees. Over the next 5 seconds, until the Aircraft reached 7 ft radio altitude, there was a steady increase in the Aircraft pitch angle from 0.4 to 2.6 degrees, with a corresponding decrease in the sink rate from 692 towards 350 ft per minute

At 0837:08, as the Aircraft passed 25 ft radio altitude, 158 kt IAS, approximately 300 m beyond the threshold, the A/T mode changed on the cockpit primary flight display (PFD)

¹ RNAV (GNSS) is the area navigation (RNAV) approach with global navigation satellite system (GNSS).

² Whenever wind speed is stated, in the 'History of the Flight' section, it is the wind speed component.



flight mode annunciations (FMA) from 'SPEED' to 'IDLE'. As designed, from 25 ft radio altitude, the A/T transitioned both thrust levers towards the idle position, and the engine pressure ratio (EPR) steadily decreased from 1.074 to 0.98.

Approximately two seconds later, the airspeed decreased to 153 kt as the Aircraft descended below 13 ft radio altitude.

From 0837:12 at 5 ft radio altitude several pulls and pushes on the control column along with control wheel roll and rudder inputs were recorded by the Aircraft FDR. The Commander made a left roll input to the control wheel, and at about this time, the Commander said "Oops". The IAS had increased to 160 kt, and the ground speed was 176 kt and decreasing.

Two seconds later, with the Aircraft at 2 ft radio altitude, the IAS had increased to 165 kt, the ground speed had reduced to 172 kt, and the sink rate had reduced to 80 ft per minute. The Commander uttered an exclamation and stated "Thermals", and the Copilot replied with "Check". Neither flight crewmember was aware of the increase in airspeed because their focus was on external scanning of the runway.

The Commander stated that in an attempt to have the Aircraft touch down, he had momentarily pushed the control column three times to lower the nose. This action was confirmed by the data recorded on the FDR.

At 0837:16, the Aircraft rolled 3 degrees to the left due to the wind effect and the Commander corrected with right control wheel input of 30 degrees. In response to this input, the resulting right bank of 7.4 degrees caused the right main landing gear to contact the runway approximately 1,090 m beyond the threshold.

The right main gear contact with the runway caused it to 'untilt' as indicated by the main landing gear 'tilt' and 'untilt' switch position recorded by the Aircraft FDR. Runway contact was made at an airspeed of 161 kt IAS, 14 kt above the landing reference speed of 147 kt.

From 0837:16 to 0837:22, as recorded by the Aircraft FDR, both main landing gear experienced a series of 'tilt/untilt' cycles. During this six-second period, there were two automatic partial movements of the speedbrake lever recorded by the FDR.

The Commander stated during his interview "Below 2,000 ft started having tailwind and getting close to the runway, like 50 feet flare height, we had thermals updraft coming from the ground because of the heat so it was pushing the aircraft up so it caused a long flare. It [the Aircraft] was going towards the end of the touchdown zone, so after that we decided to go around."

The Copilot stated during his interview "The flare felt like it just wouldn't land it was bumpy." The Copilot also stated, "I would say we were definitely less than 50 feet at the initiation of the go around."

The Commander stated that he pushed the left takeoff/go-around (TO/GA) switch and then called "Go-around". The push on the TO/GA switch did not have any effect on the A/T and the thrust levers remained at the idle position.

The Commanders' declaration of a go-around was immediately followed by a 'long landing' automated cockpit annunciation. The Commander pulled the control column back and the Aircraft pitch-up angle started to increase. One second after the Commander's 'go-around' declaration the Copilot responded by saying "Okay". This was followed by a second 'long landing' cockpit annunciation.

During his interview, the Commander stated he had his right hand on the thrust levers when he pushed the TO/GA switch. He stated that the initiation of the go-around was before touchdown. He could not remember any changes in the flight director and the FMA



after pushing the TO/GA switch. He also stated that during the go around, he pitched the Aircraft to an approximate pitch attitude of 7.5 degrees and had positive climb.

The FDR indicated that the Aircraft had touched down for a duration of six seconds. During this time, both main landing gear were simultaneously in 'ground' mode for a period of less than two seconds. The nose landing gear remained in the air throughout this time.

At 0837:22 the Commander called "flaps 20".

Just before 0837:23, the main landing gear transitioned back to 'air' mode, and the Aircraft became airborne at 153 kt IAS ($V_{REF} + 6.5$ kt), with the flaps in the 30 position (landing configuration). As the Aircraft climbed, the wind direction was from 102 degrees at 8 kt. The Copilot moved the flap lever to the flaps 20 position and verbally confirmed this action. The Aircraft continued gaining height and when it reached approximately 47 ft radio altitude, the Copilot announced "Positive climb." In his interview, the Copilot stated that he could not recall information in changes in the FMA and had referred to the PFD vertical speed indicator to confirm that the Aircraft was in a positive climb.

The Commander called "Gear-up" as the Aircraft was passing 58 ft radio altitude, at a rate of climb of 608 ft per minute, and 145 kt IAS. Thereafter, the rate of climb started to decrease. Shortly after the "Gear-up" call by the Commander, the Tower transmitted a modified missed approach instruction to UAE521 to continue straight ahead and climb to 4,000 ft.

At 0837:29, the Copilot stated "Gear-up" while the Aircraft was climbing pass 77 ft radio altitude and 135 kt IAS. The Copilot then read back the Tower instructions and changed the preselected missed approach altitude from 3,000 ft to 4,000 ft in the MCP.

Two seconds later, at 0837:31, the Aircraft started to lose height after reaching a maximum of 85 ft radio altitude at 131 kt IAS.

Three seconds after the Aircraft started to lose height, the Commander called "Windshear TOGA" as the Aircraft was sinking below 67 ft radio altitude. The A/T mode on the FMA changed from 'IDLE' to 'THR' ('thrust' mode).

One second later (0837:35), the Commander advanced both thrust levers manually to maximum at the same time as an automated 'don't sink' cockpit aural warning was annunciated. The Copilot called out "Check speed" followed by a cockpit AIRSPEED LOW caution at 128 kt IAS, and a 'don't sink' cockpit aural warning annunciation for the second time. Following these warnings, the Aircraft was losing height at a rate of 800 ft per minute. The Commander increased the Aircraft pitch to 9.2 degrees in an unsuccessful attempt to regain height.

At 0837:38, the Aircraft aft fuselage impacted the runway, at a speed of 124 kt IAS, which was above the Aircraft stall speed. The impact with the runway occurred 18 seconds after the initiation of the go-around, and 7 seconds after the Aircraft started to sink from 85 ft radio altitude.

The FDR data indicated that the EPR for both engines had started to respond to the manual thrust lever movement, but the height remaining did not provide enough time for the engine thrust to increase sufficiently to prevent the Aircraft from sinking onto the runway.

The Commander stated during his interview "we noticed the aircraft speed dropping so I applied maximum power because TO/GA power sometimes limits the thrust so I pushed the thrust lever forward. However, the aircraft continued to lose airspeed because of the shifting wind and windshear. At that time, I called windshear TOGA". The Commander stated that after gear up "the speed started reducing until the aircraft lost speed and then it started going down". He further clarified that "It didn't climb much just a few feet once we started positive climb and then I felt the aircraft just sinking".



The initial impact point of the Aircraft on runway 12L was abeam the intersection with taxiway November 7, with the landing gear in transition to the 'up' position. The right (No.2) engine contacted the runway and the engine/pylon assembly separated from the wing as the Aircraft slid along the runway.

Fire was observed on the right engine and pylon and another fire started to emanate from the bottom of the left (No.1) engine. After the Aircraft came to rest adjacent to taxiway Mike 13, on a magnetic heading of approximately 250 degrees, and 70 m to the right of the runway centerline, dense grey smoke was observed coming from the right side of the fuselage in the vicinity of the right main landing gear bay.

At 0839:04, the Commander transmitted a 'mayday' call and informed ATC that the Aircraft was being evacuated. The flight crew completed the evacuation checklist in about one minute from the time that the distress call was transmitted and instructed the cabin crew to commence the evacuation.

The fire commander and the first two Airport rescue and firefighting service (ARFFS) vehicles arrived at the Accident site within 90 seconds of the Aircraft coming to rest and immediately started to apply fire extinguishing agent. Additional firefighting vehicles arrived shortly after.

Apart from the Commander and the senior cabin crewmember, who both jumped from the L1 door onto the detached escape slide, crewmembers and passengers evacuated the Aircraft using the available passenger door escape slides.

Twenty-one passengers, one flight crewmember, and six cabin crewmembers sustained minor injuries. Four cabin crewmembers sustained serious injuries.

Approximately 9 minutes and 40 seconds after the Aircraft came to rest, the center wing tank exploded which caused a large section of the right wing upper skin to be liberated. As the panel fell to the ground, it struck and fatally injured a firefighter.

The Aircraft sustained substantial structural damage as a result of the impact and its movement along the runway and it was eventually destroyed by fire.

Refer to figure 1 which illustrates the final flightpath of the Aircraft from before the runway threshold until the impact. Appendix A to this Report illustrates the FDR and CVR data recorded along the flightpath over runway 12L.



Figure 1. UAE521 flightpath and impact along runway 12L



1.2 Injuries to Persons

Table 1 shows the number of injuries.

Table 1. Injuries to persons					
Injuries	Flight Crew	Cabin crew	Passengers	Total on board	'Others' ³
Fatal	0	0	0	0	1
Serious	0	4	0	4	0
Minor	1	6	21	28	7
None	1	6	261	268	0
TOTAL	2	16	282	300	8

1.2.1 Crewmembers

The impact of the Aircraft on the runway caused high loads to be imparted to the Aircraft, particularly to the forward section. The senior cabin crewmember and two cabin crewmembers seated next to the forward passenger doors, sustained serious back injuries that required hospitalization. Another cabin crewmember seated at door R5 sustained a spinal injury.

Six cabin crewmembers sustained minor injuries caused by the impact and the subsequent evacuation.

All crewmembers received post-traumatic stress assessment, which was provided by the Operator's medical team.

1.2.2 Passengers

Twenty-one passengers were transported to hospital and treated for minor injuries.

1.2.3 'Others'

A member of the airport rescue and fire-fighting services sustained fatal injuries during the fire-fighting activity. Seven members of the airport rescue and fire-fighting services were transported to hospital for treatment of minor injuries.

1.3 Damage to Aircraft

The Aircraft was severely damaged due to the impact and was destroyed by the subsequent fire.

1.4 Other Damage

The impact and movement of the Aircraft along the runway caused damage to the runway surface from abeam taxiway November 7 to the final resting point of the Aircraft.

When the Aircraft veered to the right of the centerline, it impacted several runway and taxiway lights and signs.

The Accident site was contaminated by ash, firefighting fluids (foam solution and water), and spillage of Aircraft fuel and hydraulic fluid.

³ 'Others' refer to injuries during the post-Accident firefighting activities.



1.5 Personnel Information

1.5.1 Flight and cabin crew

Table 2 illustrates the flight crew data.

Table 2. Flight crew data		
	Commander	Copilot
Age	34	37
Type of license	ATPL ⁴	ATPL
Valid to	21 April 2023	4 March 2023
Rating	M/E LAND, A330 (P2), A340 (P2), BOEING 777/787	M/E LAND, BOEING 777/787 (P2)
Total flying time (hours)	7,457.16	7,957.56
Total on B777 (hours)	5,123.41	1,292
Total last 90 days (hours)	194.4	233.22
Total on last 7 days (hours)	13.56	19.30
Total last 24 hours (hours)	3.59	3.59
Last recurrent SEP ⁵ training	30 May 2016	11 January 2016
Last proficiency check	17 March 2016	24 February 2016
Last line check	8 May 2016	10 March 2016
Medical class, validity	Class 1, 31 October 2016	Class 1, 16 July 2017
Medical limitation	VDL/VNL ⁶	Nil

1.5.1.1 The Commander

The Commander joined the Operator's cadet program in March 2001 and on receiving his license, commenced his operational flying career in 2004 as a copilot on the Airbus A330 aircraft. In 2008 he became a copilot on the Airbus A340. He had logged 1,965 flying hours on the A330 and 367 flying hours on the A340, prior to commencing training on the B777 in 2009. He accumulated 3,950 flying hours as a copilot on the B777 aircraft.

After completing a total of 6,283 flying hours, and satisfying the Operator's selection process, he began his two-month upgrade training to become a commander on the B777 in March 2015. At the time of the Accident, he had flown 1,173 hours as a commander on the B777 and his total flying time was 7,457 hours.

Of the 135 flights that the Commander had operated in the 12-month period prior to the Accident flight, he had completed 66 landings, as pilot flying, on B777 aircraft powered by Rolls-Royce (RR) and General Electric (GE) engines. Nine of the landings were performed at OMDB. His most recent landing prior to the Accident was on 21 July 2016. His most recent

⁴ ATPL: Air transport pilot license.

⁵ SEP: Safety and emergency procedures.

⁶ VDL: Wear corrective lenses and carry a spare set of spectacles.

VNL: Wear multifocal spectacles and carry a spare set of spectacles.



flight to OMDB prior to the Accident was on 29 July 2016, which he operated as pilot monitoring.

The Operator stated that after completing the B777 conversion course, the Commander conducted 127 monitored landings in the simulator and in line operations.

The Commander performed 54 go-around maneuvers in the simulator with no adverse comments relating to his handling. This training involved execution of go-arounds and missed approaches employing both two engine and single engine scenarios. All normal missed approaches were commenced during the approach and at a height of above 50 ft radio altitude. The trained normal go-around and missed approach training was based on the procedure in the *flight crew operations manual (FCOM)* and *flight crew training manual (FCTM)* which required pushing the TO/GA switch to automatically increase engine thrust.

In March 2015 during his upgrade to commander training, the Commander practiced rejected landings from heights below 50 ft, but before the aircraft had touched down. His most recent bounced landing recovery training, and his last windshear recovery training were carried out in March 2015. The Commander stated that he had never practiced normal go-arounds after touchdown with the autothrottle armed and active.

According to the Operator's training program, the Commander practiced a go-around initiated after touchdown during his *manual handling phase 2* training⁷ session. The Commander's last phase 2 session, before the Accident, was completed as a copilot, in August 2014. However, the scenarios were different from the circumstances of the Accident flight because the training was accomplished with the autothrottle, flight directors and autopilot switched off. The Commander's performance was assessed as satisfactory.

During two of the Commander's upgrade training sessions, between March and May of 2015, the evaluator had commented on landing technique related to flare and that the landing was towards the end of the touchdown zone. The Operator stated that provided a pilot lands within the touchdown zone, it is considered safe and satisfactory.

In September 2015, the Commander had his Operator proficiency check (OPC). During the simulator session, the evaluator commented that the Commander became somewhat "tunnel visioned" during the approach with the simulated condition of reserve brakes and steering unavailable. The evaluator stated that the first officer had suggested that the flaps would run slowly and landing distance might be a problem. After the first officer made the call 'uncomfortable', the tunnel vision stopped and the Commander initiated a go-around. All sessions were graded as acceptable.

During the October 2015 line continuation training performed during two flight sectors, the evaluator commented that the Commander had settled well in the left hand seat, and took his time to communicate and slowed down the pace appropriately when the situation dictated it.

In the May 2016 line check, the comments of the evaluator stated "The Commander was well prepared for his flight; has a great attitude; sets a nice tone on the flight deck, and could be more assertive with brand new first officer as some direction was needed during approach". Under the handling competency, the evaluator's comment stated that the

⁷ Manual handling phase training consist of six phases and is part of the Operator's recency and refresher training program to refresh and develop pilot manual handling skills. Pilots were rostered for two manual handling simulator sessions per year. Of the six manual phases, phase 2 training was the only session that included go-around after touchdown training. See description in section 1.17.1.8 of this Report.



Commander had accurate taxi; proper rotation rate V_2+20 ; and smooth hand flying on short final to a nice touch down in the zone and on centerline.

The Commander's 3-year average rating, 2014 to 2016, based on the Operator's pilot assessment marker (PAM) system⁸, was within the range of 3.7 to 4.0. The Operator considered that he was trained to competency and achieved the required acceptable standard.

Flight data monitoring (FDM) data records for the Commander indicated that all landings were performed within the requirements of the Operator and within the runway touchdown zone.

The Operator's FDM data recorded that, on 13 April 2016 at OMDB, the Commander as the pilot flying had performed a normal procedural go-around following an approach that became unstable due to wind shift resulting in a rapid speed increase.

The Commander had no known medical problem and his records held by the Operator did not contain any incidents or accidents prior to the Accident flight.

The Commander stated at the post-accident interview that upon hearing the ATIS, he briefed for a windshear escape maneuver but did not believe that there was need to change the approach speed. He confirmed that he had performed landings at OMDB when windshear was reported at the aerodrome on ATIS as well as landings during the peak of summer months.

After the Aircraft passed the runway threshold, the Commander stated that his attention was outside the cockpit, focused on the far end of the runway. He stated that his practise, in accordance with his training, was not to look at the cockpit instrumentation after the flare was started. In addition, he stated that during the attempted go-around, he was focused on the Aircraft attitude during the rotation and described his state of mind at that stage of the go-around as being "tunnel visioned". He could not recall if there was movement of the thrust levers from idle position after initiating the go around when he pushed the left thrust lever TO/GA switch.

During his interview, the Commander stated that his seat was in the optimum position and he had his right hand on the thrust levers during the entire landing phase including the attempted go-around.

1.5.1.2 The Copilot

The Copilot joined the Operator in 2014, and was enrolled in B777 initial and conversion courses. He was released as a line pilot after successful completion of training on 26 March 2015. Until the Accident, he had accumulated 1,292 hours as a B777 copilot. Prior to joining the Operator, the Copilot's flying hours were 6,665.

Of his 130 flights during the 12-month period prior to the Accident flight, the Copilot as the pilot flying, had completed 58 landings on B777 aircraft powered either by Rolls-Royce (RR) or by General Electric (GE) engines. Twenty-nine of these landings were performed at OMDB. His most recent landing prior to the Accident was on 28 July 2016.

During his B777 type training, the Copilot carried out go-around and missed approach exercises employing both two engine and single-engine scenarios. He also practiced windshear recovery. His only rejected landing exercise, for heights below 50 ft, but before touchdown, was carried out during his initial B777 training. During his recurrent and checking training, the Copilot did not perform any sessions that involved automatic or manual go-arounds flown from below 50 ft above-ground-level, after touchdown, or for a bounced landing recovery. The Copilot had not attended a *manual handling phase 2* training session.

⁸ The pilot assessment marker (PAM) system is described in section 1.17.1.3 of this Report.



The Operator's cycle for the *manual handling phase 2* training coincided during his B777 conversion course. Upon the Copilot's release to line operations as a B777 pilot, he attended the Operator's schedule of manual handling phase training which were phase 3 and phase 4.

All of the Copilot's OPCs were graded as satisfactory, and he had a PAM⁹ acceptable average of 3.9. His most recent check was performed on 10 March 2016. The evaluator's comments indicated satisfactory performance. There were no significant evaluator comments recorded in the Copilot's training file.

The Operator's FDM data records showed that the Copilot had performed a normal procedural windshear go-around as the pilot flying during an approach to Istanbul on 8 April 2016. The FDM data records for the Copilot indicated that he had no operational issues.

The Copilot had no known medical problem and his records at the Operator did not contain any incidents or accidents prior to the Accident flight.

During the post-accident interview, the Copilot recalled that as the Aircraft crossed the runway 12L threshold, he felt some turbulence and that the Aircraft was affected by updrafts. He said that the Aircraft was not settling to land and was floating over the runway, and it looked that the Aircraft was going to land a bit long just before the Commander called for go around. He could not recall looking at the Aircraft instruments after passing the threshold as his scanning was outside the cockpit.

The Copilot could not recall what was on the FMA during the go around phase. He stated that for a go around, he would normally verify FMA changes after selecting landing gear lever to 'up' position.

1.5.2 Flight crew fatigue

On 1 August 2016, the Commander positioned from Dubai to Trivandrum. He departed OMDB at 2125 United Arab Emirates local time and was accompanied by the Copilot for a 30-hour layover. This was the first time that the Commander and Copilot had met.

After hotel check-in at about 0300 Trivandrum LT (2130 UTC), the Commander went to bed. He stated that he woke up after about six hours of good quality sleep. He had breakfast, and went to the gym two hours later.

The Copilot went to bed soon after check-in at the hotel and he woke up at noon. After engaging in some light activities for the rest of the day.

Both flight crewmembers stated that they had slept for approximately six hours the night before the flight to Dubai.

The flight crew began their duty on the morning of 3 August 2016 at 0905 Trivandrum LT (0335 UTC).

The Commander had been off-duty for about 62.5 hours before the flight to Trivandrum, and the Copilot had been off-duty for about 80 hours.

Both flight crewmembers stated during the post-accident interview that they were well rested when they commenced their duty and that they were generally physically fit through regular exercise. They considered that they were mentally prepared for the flight.

Recordings from the CVR were evaluated by the Investigation and no tone of voice was noticed to indicate crew fatigue.

⁹ The PAM system is described in section 1.17.1.3 of this Report.

Both flight crewmembers' duty and flight hours for the three months prior to the Accident were within the regulatory requirements of the *Civil Aviation Regulations CAR – OPS 1 Commercial & Private Air Transportation (Aeroplanes)* subpart Q. Analysis of their fatigue level for the Accident flight was considered 'okay, somewhat fresh' based on the Samn-Perelli¹⁰ seven-point fatigue scale.

1.5.3 Cabin crew information

Each of the sixteen cabin crewmembers held a valid cabin crew license issued by the General Civil Aviation Authority of the United Arab Emirates (GCAA). The crew were qualified on the Aircraft type, including medical and emergency procedures training.

Twelve of the cabin crewmembers had been off-duty for 72 hours prior to the Accident flight, and four had been off-duty for 53 hours.

The cabin crewmembers were between 22 and 36 years old, 14 of them were female. The experience level of the crewmembers ranged from 5 months to 11 years.

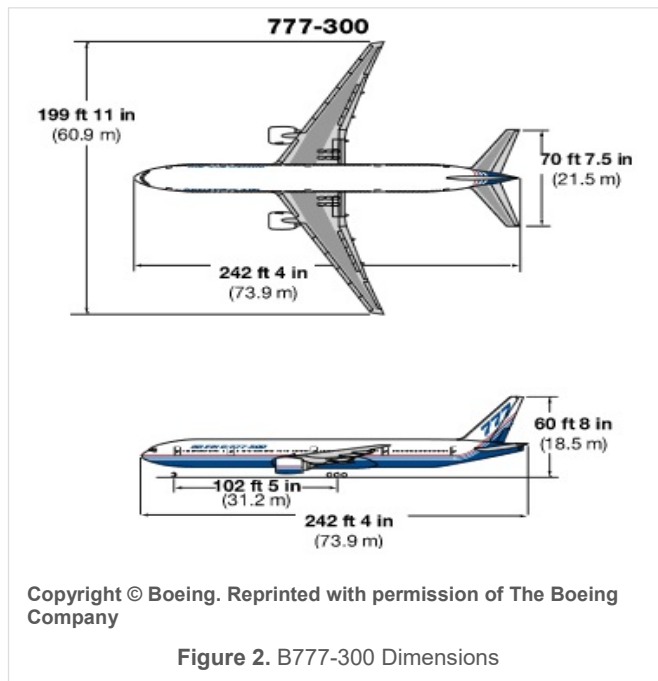
1.6 Aircraft Information

1.6.1 General data

The Aircraft was certificated under the Boeing 777 - 300 type according to the certification specifications in the *Federal Aviation Regulations (FAR)* of the United States.

The Boeing manufactured wide body Aircraft variant was 777-31H equipped with two Rolls-Royce Trent 892 engines.

The Aircraft was manufactured in 2003 and was delivered to the Operator on 28 March 2003. At the time of the Accident, it had accumulated 58,169 hours and 13,620 landings since delivery, and 888 hours and 281 landings since its last major check on 6 May 2016.



The Aircraft was configured in three zones: 12 first class, 42 business class, and 310 economy class seats. There were three cargo compartments located in the lower fuselage below the passenger cabin.

The Aircraft performance data showed that the maximum allowable tailwind speed for landing was 15 kt. The crosswind speed limit was 40 kt under normal operations, on a dry runway with a width of at least 45 meters.

The Investigation reviewed the Aircraft and engine maintenance records and no significant defects were found.

¹⁰ Samn-Perelli was part of the fatigue risk management system used by the Operator.



For the flight to OMD, the Aircraft take-off weight was 257,789 kg, and the calculated landing weight was 229,789 kg, including 8,200 kg of fuel.

1.6.1.1 Aircraft and engine data

Table 3 illustrates the general Aircraft and engine data.

Table 3. Aircraft data		
Manufacturer:	The Boeing Company	
Model:	Boeing 777-31H	
Manufacture serial number:	32700	
Date of delivery:	28 March 2003	
Nationality and registration mark:	United Arab Emirates, A6-EMW	
Name of the owner:	Wilmington Trust SP Services Dublin, Ireland	
Name of the Operator:	Emirates	
Certificate of registration		
Number:	05/03	
Issuing Authority:	GCAA	
Issue date:	28 March 2003. Reissued on 10 July 2014.	
Certificate of Airworthiness		
Number:	EAL/66	
Issuing Authority:	GCAA	
Issue date:	28 March 2003. Reissued on 13 March 2013	
Valid to:	ARC issued on 10 March 2016	
Total hours since new:	58,169:22	
Total cycles since new:	13,620	
Last major check:	5C, on 28 May 2015, at 53,900 hours/12,201 cycles	
Last inspection	Daily check on 2 August 2016	
Maximum take-off weight:	276,000 kg	
Maximum landing weight:	237,682 kg	
Maximum zero fuel weight:	224,528 kg	
Zero weight	221,489 kg	
Engine data:		
Manufacturer	Rolls-Royce	
	No.1 engine	No.2 engine
Model	TRENT 892	TRENT 892
Serial number	51208	51406
Date installed	7 September 2015	23 February 2016
Total hours since new:	51,529:34	50,682:11
Total cycles since new:	14,071	12,185
Cycles since last shop visit:	4,083	517

The Rolls-Royce Trent 800 engine is a three-shaft, axial flow, high by-pass ratio, turbo-fan engine. The engine comprises a single-stage low pressure compressor (fan assembly [N1]) which is driven by a five-stage low pressure turbine (LPT). An eight-stage intermediate pressure compressor (IPC [N2]) is driven by a single-stage intermediate pressure

turbine (IPT) and a six-stage high pressure compressor (HPC [N3]) is driven by a single-stage high pressure turbine (HPT). The engine features a full authority digital engine control (FADEC) system with a dual channel engine electronic control (EEC) that is mounted in a housing located on the upper, left-hand side of the engine rear fan case.

The installed engines on the Aircraft were both configured as the Trent 892-17 mark, each with an international standard atmosphere (ISA) sea-level static take-off thrust rating of 91,450 lbs.

1.6.1.2 Aircraft cockpit layout

The Aircraft cockpit is configured with four seats, including two for observers.

The forward panel contains the flight display system, indicators, and some systems controls. The landing gear lever is located on the forward panel.

Above the display units is the glareshield, where the MCP and red master warning and amber caution lights are located. The MCP includes two A/T 'arm' switches and one A/T activation pushbutton switch.

The control columns are located forward of the pilot seats. Each control column wheel includes the pitch trim switches, autopilot disconnect switch, and a boom microphone push-to-talk switch. The control column design permits a clear view of all the flight instruments when the pilots adjust their seats to the eye reference point.

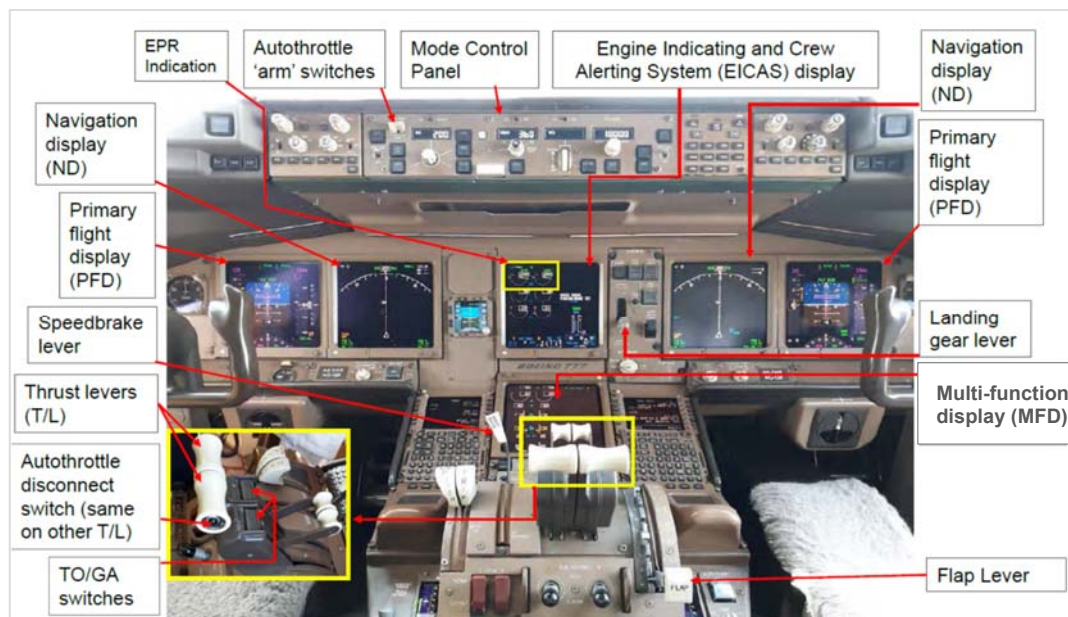


Figure 3. Boeing 777-31H cockpit

The control stand located at the center of the cockpit has provisions for easily reachable controls. Among these controls are the thrust levers, flap lever and speedbrake lever.

Both thrust levers can be manually moved by the pilots in addition to being automatically controlled by the A/T. There are no gates between the idle and maximum thrust lever positions. A TO/GA switch is located on the forward side of each thrust lever and an A/T disconnect switch is located on the side of each thrust lever (figure 3 insert).

The flap lever positions the slats and flaps and is located on the center control stand adjacent to the right thrust lever. There are seven selectable positions for the flap lever from

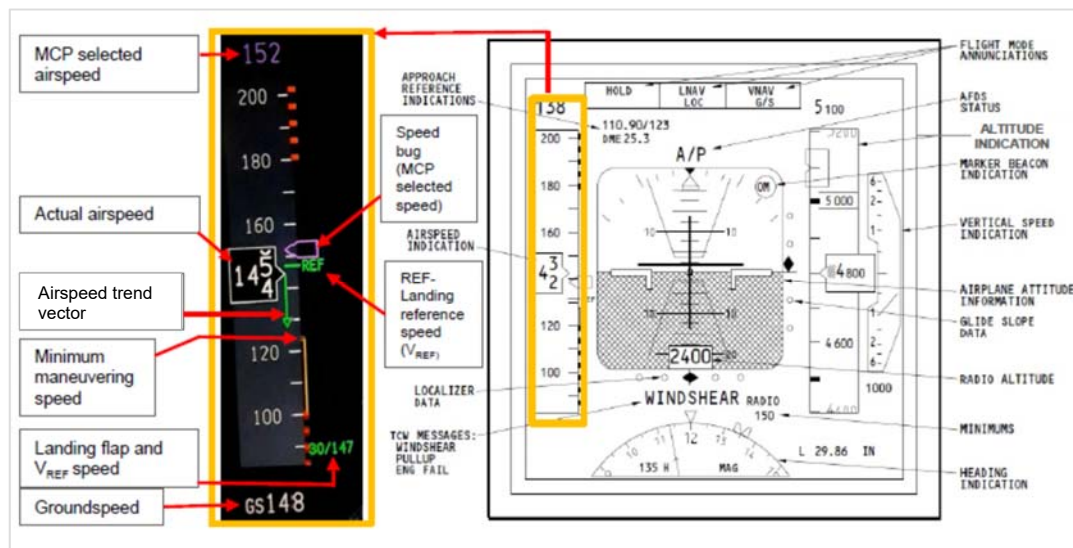
'up' to '30', with gated slots at positions '20' and '1'. The mechanical gate at the flaps 20 detent prevents inadvertent retraction of the flaps past the go-around flap setting. The mechanical gate at flaps 1 prevents inadvertent retraction of the slats past the midrange position.

The speedbrake lever has three positions: 'down' when it is stowed, 'arm' for landing, and 'up' when fully deployed. Automatic movement of the speedbrake lever can be observed by both pilots.

1.6.2 Aircraft systems

1.6.2.1 Primary display system (PDS)

The PDS provides information for all flight phases and includes aircraft warnings and the status of aircraft systems, navigation data, flight plan data, the engine-indicating and crew alerting system (EICAS), and communication data, which is shown on six displays: two PFDs, two navigational displays, (ND), one EICAS display, and one multi-function display (MFD).



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Figure 4. Illustration of primary flight display (PFD) [source: FCOM/AMM/Simulator]

The PFD provides the flight crew with flight information including aircraft attitude, flight modes, airspeed, altitude, vertical speed, and other information.

The flight mode annunciations (FMA) are displayed just above the PFD autopilot flight director system (AFDS) status annunciations. The mode annunciations, from left to right, are autothrottle, roll and pitch.

Aircraft speed information is indicated on the left side of the PFD. The MCP selected airspeed is displayed at the top of the PFD speed tape. The indicated airspeed (IAS) is indicated in a white box inserted in the movable speed tape. An airspeed trend vector (green arrow) indicates a 10-second airspeed prediction by the length of the arrow and its direction. Additional information is provided on the speed tape: a yellow bar indicating the minimum cg speed; green 'REF' indicating V_{REF} ; a speed bug indicating the MCP selected speed; groundspeed; landing flaps/ V_{REF} indication at the bottom of speed tape; and other information.

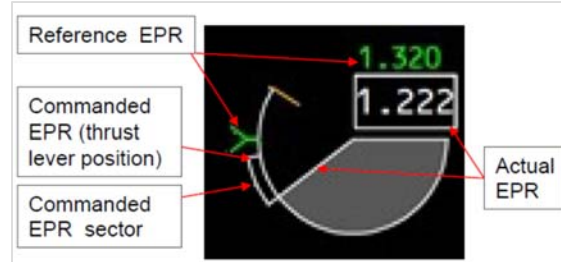
When the airspeed decreases below the minimum maneuvering speed, the flight crew will be alerted by an EICAS caution amber message AIRSPEED LOW, an aural quadruple beeper sound, both master caution lights and the box around the current airspeed indication on the PFD will be highlighted in amber. The Aircraft manufacturer stated that the AIRSPEED

LOW message will be illuminated when the airspeed has decreased 30% into the lower amber band.

The EICAS provides information to the flight crew about the primary engine parameters, flaps and flap lever position, landing gear status, and other messages.

The primary engine indications on EICAS are EPR, low pressure compressor speed (N1 % rpm) and exhaust gas turbine (EGT) temperature. The secondary engine indications on the MFD display include the IPC (N2 % rpm) and HPC (N3 % rpm).

Movement of the thrust levers will be indicated on the EICAS with a corresponding change in the engine indications. For the RR engine, EPR is the main parameter used to indicate and verify thrust changes (figure 5). A change in thrust lever position is indicated by a commanded EPR sector white arc on the EICAS which disappears after the commanded EPR value reaches the corresponding new lever position.



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Figure 5. Rolls-Royce EPR display on EICAS

When the flap lever is out of the 'up' position, the combined flap and slat positions are indicated on the EICAS when all surfaces are operating normally and control is in the primary (hydraulic) mode. The indicator shows continuous motion. The indication is no longer displayed 10 seconds after slat retraction.

Unlike the flap and slat indicator, the movement of the speedbrake lever is not indicated on the EICAS. However, the following EICAS messages are illuminated which are associated with the speedbrake lever position:

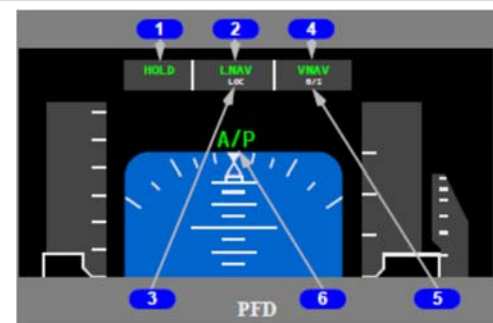
- SPEEDBRAKE ARMED white memo message indicates that the speedbrake lever is armed for landing.
- SPEEDBRAKE EXTENDED caution message indicates that the speedbrake lever is extended and radio altitude is between 15 and 800 ft, or when the flap lever is in a landing position, or when either thrust lever is more than 5 degrees above the idle stop.
- CONFIG SPOILERS warning message is illuminated on the ground and indicates that the speedbrake lever is not in its down detent when either the left or right engine exceeds takeoff thrust.

The ND shows the wind speed and direction. Information is also available for the aircraft groundspeed, and the weather radar information. An amber 'long landing' message appears in the center of the ND when a long landing is annunciated by the runway awareness advisory system (RAAS).

1.6.2.2 The flight mode annunciations (FMA)

The FMA announces (figure 6):

- The A/T modes (1). One of five active modes is displayed in green: THR; THR REF; IDLE; HOLD; SPD
- Roll modes (2). One of nine engaged modes is displayed in green: LNAV; HDG HOLD; HDG SEL; TRK SEL; TRK HOLD; ATT; LOC; TO/GA; ROLLOUT.
- Roll modes (3). One of three armed roll modes is displayed in white: LOC; LNAV; and ROLLOUT.
- Pitch modes (4). One of ten engaged modes displayed in green: TO/GA; ALT; V/S; VNAV PTH; VNAV SPD; VNAV ALT; G/S; FLARE; FLCH SPD; FPA.
- Pitch Mode (5). One of three armed modes is displayed in white: G/S; FLARE; and VNAV.
- Autopilot flight director system (AFDS) status (6). This will annunciate 'A/P' to indicate that the autopilot is engaged; or 'FLT DIR' when the flight director is selected 'on'; or the autoland¹¹ status.



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Figure 6. PFD Flight Mode Annunciations (FMA)

In an automatic landing, with the auto-pilot and A/T engaged, 'ROLLOUT' will replace the 'LOC' mode annunciation when the radio altitude is less than two feet. At touchdown, the 'FLARE' annunciation is no longer displayed. These features are not available for a manual landing.

1.6.2.3 Autothrottle (A/T)

The A/T provides thrust control from takeoff to landing. The selective positions of the A/T are: 'off' and 'arm'. When the A/T is armed and activated (by the pushbutton switch), it will move the thrust levers to achieve either 'speed' or 'thrust' control, depending on the selected mode.

Either pilot can move the thrust levers manually at any time to override the A/T. After manual positioning, the A/T will return the thrust levers to the position corresponding to the previously active mode. With the A/T active, during landing and below 25 ft radio altitude, the thrust levers will move towards the idle position and the A/T mode on the FMA will change to 'IDLE'.

After touchdown, in manual or automatic flight, until the thrust reversers are selected, the A/T mode stays at 'IDLE'. By design, because the TO/GA switches are now inhibited, either because the weight-on-wheels is valid, or the aircraft radio altitude is less than two feet for more than three seconds, pushing the TO/GA switch does not affect the mode and the A/T will stay at 'IDLE'.

In the landing configuration, the A/T will automatically arm the go-around mode. The green letters 'GA' appear at the top of and between the EPR indicators reflecting the change

¹¹ Depending on the autoland status, the annunciation on the PFD will display one of the following: 'LAND 3', 'LAND 2', or 'NO AUTOLAND'. [source: FCOM].



in the reference limit. The reference EPR indicated on the EICAS changes to the go-around 'GA' reference thrust limit. In this situation, pushing either TO/GA switch once, will activate the A/T in 'THR' mode with the 'GA' reference thrust limit displayed and automatically advance the thrust levers to a go-around thrust setting that provides a climb rate towards 2,000 feet per minute. A second push of a TO/GA switch activates the A/T in 'THR REF' mode using the 'GA' thrust reference.

In order to activate the A/T for a go-around, all of the following conditions must be fulfilled:

- A/T arm switch is in the 'arm' position;
- aircraft is in 'air' mode;
- glideslope is engaged or the flap lever is not in the 'up' position;
- thrust limit mode is not at 'takeoff'; and
- either TO/GA switch is pushed.

For manual flight, the following occurs after the TO/GA switch is pushed when the aircraft is in 'air' mode:

- The A/T mode commands go-around thrust and 'THR' is annunciated on the FMA;
- Roll and Pitch mode changes to 'TO/GA' which is annunciated on the FMA;
- The A/T moves the thrust levers to the takeoff/go-around thrust position for a rate of climb towards 2,000 ft per minute;
- AFDS commands an airspeed towards the selected speed on the MCP, or maintains the current airspeed, whichever is higher, to a maximum of 25 kt above the selected MCP speed;
- The flight director (F/D) will provide go-around guidance.

The Aircraft manufacturer provided the A/T operation logic to the Investigation for both the ground and air modes. See Table 4.

The logic was described as:

"A/T_on_ground" is met when either of the following conditions is fulfilled:

- the radio altitude is less than 2 ft and 3 seconds have elapsed;
- or
- the radio altitude is less than 2 ft, the weight-on-wheels (WOW) is valid, and WOW indicates On-Ground (either the left or right WOW indicates on ground.)

The A/T is enabled automatically when the A/T is no longer in 'A/T_on_ground' and when the radio altitude is more than 2 ft."

Pushing either TO/GA switch when the A/T is enabled will automatically advance the thrust levers to the go-around thrust setting. If the TO/GA switch is pushed during the inhibited period, the A/T will not automatically advance the thrust levers to the go-around thrust setting.

The flight director does not provide go-around guidance when the aircraft is on the ground. The flight director is enabled when the aircraft is in 'air' mode and upon pushing a TO/GA switch when glideslope mode is engaged or when the flaps are out of the 'UP' position.



Table 4. Boeing 777 A/T Inhibit and Enable Logic [source: Boeing]

State	Autothrottle go-around (GA) mode Enable/Inhibit logic	Autothrottle In Air logic
Inhibit	A/T_GA_inhibit = NOT (A/T_GA_enabled)	A/T_on_ground = Radio altitude < 2 ft <u>AND</u> 3 seconds have elapsed. <u>OR</u> Radio Altitude < 2 ft <u>AND</u> WOW valid <u>AND</u> WOW indicates On-Ground (either left or right WOW sensor).
Enable	A/T_GA_enabled = A/T_inair <u>OR</u> Autopilot (A/P) engaged	A/T_inair = NOT (A/T_on_ground) = Radio altitude > 2 ft.

The A/T can be disconnected manually by pressing either one of the two disconnect switches located on the sides of the thrust levers (figure 3), or when the A/T arm switch is set to 'off'. The A/T will disconnect automatically if the thrust levers are overridden during a manual landing after the autothrottle has begun to retard the thrust levers to idle.

When the A/T disconnects automatically or manually, an alert AUTOTHROTTLE DISC caution message is displayed on the EICAS together with illumination of the master caution lights and an aural quadruple beeper sound is annunciated in the cockpit. After the A/T is disconnected by pushing a disconnect switch, a second push on the disconnect switch will reset the master caution lights and the EICAS message.

The A/T also disconnects on the ground when the pilot applies reverse thrust. For this, there is no A/T disconnect message, caution or aural sound.

During takeoff, the pilot flying is required to push the TO/GA switch at a speed below 50 kt and with the flaps out of the up position and the A/T will activate in 'THR REF' mode and the thrust levers will automatically advance to takeoff thrust setting. If the TO/GA switch is not pushed below 50 kt the A/T operation is inhibited until reaching 400 ft altitude.

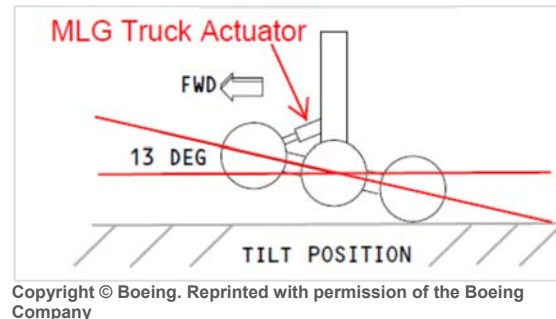
The *Aircraft maintenance manual (AMM)*¹² states that the A/T will move the thrust levers from idle to the takeoff/go-around thrust position in approximately five seconds. The Aircraft manufacturer stated that this is the highest rate that the A/T can move the thrust levers over the 50 degrees of thrust lever travel. During a normal go-around, with the thrust levers not at the idle position, when the TO/GA switch is pushed, the Aircraft manufacturer stated that the initial rate of thrust lever travel may be 10.5 degrees per second, but this will reduce as the partial thrust target is reached. Similar information for the time it takes to move the thrust levers by use of the A/T was neither stated in the *FCOM* nor the *FCTM*.

¹² *Aircraft maintenance manual (AMM)* describes the A/T servo loop functional check. During this check, the servo motor shall move the thrust levers in the forward command at a rate of 8 degrees per second for 5 seconds. For an accepted test, the average tach feedback must be between 6 and 10 degrees per second. When the thrust lever is at idle, the thrust resolver angle (TRA) is approximately 34 degrees and at full forward the TRA is 85 degrees. At the go-around thrust setting, the TRA for the thrust levers angle is 81 degrees. [source: 777 AMM 22-31-00 dated July 2016].

1.6.2.4 Main landing gear – Truck tilt/untilt

Each main landing gear consists of a six-wheel truck with a truck position actuator that tilts the truck up 13 degrees in preparation for landing and down 5 degrees for gear retraction.

When the main gear is extended for landing, the 'tilt' position of the truck allows the aft wheels to contact the runway first. The truck will then 'untilt' allowing the center and forward wheels to contact the runway surface.



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Figure 7. Main landing gear 'tilt' position

Truck tilt sensors are installed to sense the tilt position of the truck. From 13 to 10 degrees, the sensor transitions from the 'tilt' to the 'untilt' position.

1.6.2.5 Air/ground system (AGS)

The AGS transmits an 'air' or 'ground' mode signal to aircraft systems including the A/T, auto speedbrake, and autobrake systems.

Two variable reluctance strain load sensors are installed on each wing side landing gear beam. In 'ground' mode, the aircraft weight-on-wheels (WOW) will load the landing gear beam causing it to elastically bend. The load sensor will detect the load bending and transmit an analog signal to the AGS.

1.6.2.6 B777 radio altitude and main gear altitude

The radio altimeter system measures the distance between the aircraft forward lower fuselage and terrain (figure 8). Three transceivers and three antennas are installed on the lower fuselage, aft of the nose landing gear.

The system provides the enhanced ground proximity warning system (EGPWS) with data about the measured distance which will be announced at certain predetermined radio altitudes. Radio altitudes are also used by the A/T system. Additionally, radio altitude is displayed on the bottom center of the PFD for altitudes between minus 20 ft and 2,500 ft. During landing, and when the aircraft reaches 50 ft radio altitude, the frequency of the callouts increases to 10 ft increments. The last callout is 'ten'.

The main gear altitude (figure 8) is the distance between the aft wheels of the main landing gear and the runway. The gear altitude is computed by the primary flight control computer which uses the aircraft radio altitude and pitch attitude to calculate the gear altitude and provides data for the auto speedbrake system.

Gear altitude is used in the logic of the speedbrake lever movement. Among other conditions, for landing, the speedbrake lever will automatically deploy when it is in the 'arm' position, the gear altitude is less than 5 ft, both WOW senses are on-ground or both main landing gear are in 'untilt', and the thrust levers are at the 'idle' position. Provided these conditions are maintained, the auto speedbrake lever will fully extend to 60 degrees from the 'arm' position to the 'up' position in 1.5 seconds on landing. The speedbrake handle retracts automatically if any of the above conditions are no longer valid.

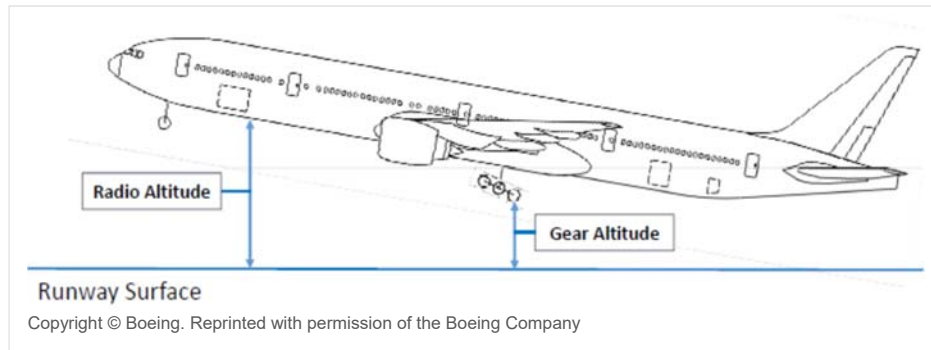


Figure 8. B777 Radio altitude and main gear altitude

1.6.2.7 Windshear detection system

The Aircraft was equipped with two windshear detection and alerting systems. A predictive windshear system (PWS) alert is provided when an excessive windshear condition is detected ahead of the aircraft by the weather radar. The enhanced ground proximity warning system (EGPWS) is capable of providing an immediate windshear alert when an excessive downdraft or tailwind occurs.

The weather radar transmits radio frequency pulses in a 180 degrees' sector forward of the aircraft path. Precipitation reflects the pulses back to the aircraft. The radar cannot predict windshear in situations where reflectivity is nonexistent, for example in very dry conditions where there is no moisture in the air.

Predictive windshear alerts are enabled when the aircraft is below 1,200 ft radio altitude. For PWS alerts not already generated, the alerts are inhibited once the aircraft descends through 50 ft radio altitude. This inhibit is removed after the aircraft climbs through 50 ft radio altitude.

The PWS cockpit voice annunciation and cockpit effect depends on the distance ahead of the predicted windshear. A windshear predicted close to and directly ahead of the aircraft will trigger a WINDSHEAR AHEAD, WINDSHEAR AHEAD audio annunciation. A windshear predicted within 1.5 nautical miles of the aircraft, will trigger a GO AROUND, WINDSHEAR AHEAD audio annunciation. In addition, both of these predicted windshears will also generate a red WINDSHEAR message on both PFDs and NDs, a red windshear symbol on both NDs, together with illumination of the master warning lights.

A predicted windshear within three nautical miles and ahead of the aircraft, will trigger a MONITOR RADAR DISPLAY audio annunciation together with an amber WINDSHEAR message and a red windshear symbol on both NDs.

The Aircraft was equipped with a EGPWS computer updated to modification status 11 with seven modes of operation. Mode 7 provided warning for windshear conditions.

The EGPWS windshear detection is active between 10 ft and 1,500 ft above ground level (AGL) during the initial takeoff and final approach phases of flight. The system provides a windshear warning if an excessive downdraft or tailwind condition is detected as a result of vertical winds and rapidly changing horizontal winds.

The Aircraft manufacturer stated that several aircraft flight data elements are used in the EGPWS algorithm computation to determine exceedance of the threshold values. The threshold requirements are in accordance with Federal Aviation Administration of the United States (FAA) Technical Standard Order (TSO) *TSO-C117a – Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes*. The alert does not respond to vertical



winds below 50 feet AGL. The Aircraft manufacturer stated that these thresholds were not exceeded during the attempted landing of UAE521.

The EGPWS windshear warning alerts are given for aircraft decreasing performance due to decreasing headwind (or increasing tailwind) and severe vertical down drafts. The EGPWS windshear alert consists of a two-tone siren followed by the words "WINDSHEAR" repeated three times and a red WINDSHEAR message appearing on both PFDs, associated with illumination of the master warning lights.

The EGPWS Mode 7 (Windshear Alerting¹³) was capable of providing a windshear caution alert for aircraft performance increasing due to increasing headwind (or decreasing tailwind) and severe updrafts. However, this feature was not enabled on the Aircraft. The manufacturer of the EGPWS in the *Product Specification – Mode 7 – Windshear Alerting*, it was stated:

"Windshear warning alerts are given for decreasing head wind (or increasing tail wind) and severe vertical down drafts.

Windshear caution alerts are given for increasing head wind (or decreasing tail wind) and severe up drafts."

If a fault occurs in the EGPWS immediate windshear system or in the PWS system, an EICAS advisory message WINDSHEAR SYS is displayed and the aural WINDSHEAR alert and the PFD WINDSHEAR alert is inhibited.

1.6.3 Crew alerting and configuration warnings

The B777 cockpit warnings are conveyed to the flight crew by visual and aural alerts. The warnings include take-off and landing configuration warnings, and 'long-landing' alerting, which was programmed by the Operator to issue alerts based on runway landing distance remaining.

The take-off configuration warning system warns the flight crew when the aircraft configuration is inconsistent with takeoff requirements. A CONFIG message is displayed in the EICAS, together with a 'master warning' (visual and aural). This occurs when the aircraft is in 'ground' mode and the engine fuel control switches are in the 'run' position, either engine thrust lever is in the take-off range, thrust reversers are not unlocked, and airspeed is less than V_1 .

A CONFIG FLAPS message will be displayed in the EICAS together with a 'master warning' (visual and aural) during a normal go-around after touchdown when the flap lever remains in the landing configuration (flaps 30) and the thrust levers are advanced to TO/GA thrust.

During landing, a CONFIG GEAR message will be displayed in the EICAS, together with a 'master warning' (visual and aural) if the landing gear is not extended, and either thrust lever is at idle and the radio altitude is less than 800 ft, or the flap lever is in the landing configuration (flaps 30).

An aural 'long landing' message is generated by the EGPWS when the aircraft has not touched down within a nominal pre-defined distance. If the aircraft is still airborne, after passing the pre-defined touchdown distance, then a 'long landing' call will occur followed by the distance remaining annunciation (example 'long landing one-thousand-two-hundred-remaining'). In addition to the aural annunciations, a visual amber 'long landing' message will be displayed on the ND. The system had been programmed by the Operator to alert the flight crew if the Aircraft was airborne over the runway at a height of less than 100 ft, with 67 percent

¹³ Description is taken from the manufacturer of the EGPWS, Honeywell International Inc., *Product Specification for the Enhanced Ground Proximity Warning System*.



of the landing distance available (LDA) remaining. For OMDB runway 12L, with 3,600 m LDA, the programmed 'long landing' annunciation should have occurred at approximately 1,188 m beyond the threshold.

A 'don't sink' cockpit alert is generated by the EGPWS system when there is an altitude loss after take-off or during a go-around. The alert is a function of the height of the aircraft above the terrain. It is enabled after takeoff or go-around when the landing gear or flaps are not in landing configuration, and stays enabled until the EGPWS computer detects that the aircraft has gained sufficient altitude. The visual and aural alert annunciators remain active until a positive rate of climb is re-established.

The B777 crew alerting and configuration warning systems do not provide an indication to the flight crew as to when the TO/GA switches are inhibited. In addition, the crew alerting system does not provide a warning for thrust levers at the idle position during a go-around.

1.6.4 The Aircraft emergency configuration

The Aircraft was fitted with emergency equipment as required by the *Civil Aviation Regulations*. The equipment locations were illustrated in the Operator's *emergency equipment locations* diagram.

1.6.4.1 Emergency exits

The Aircraft had 12 emergency exits comprising two cockpit evacuation windows, eight Type A¹⁴ cabin door exits, and two Type A over-wing exits.

The cabin exits were labeled by their respective sides (R and L) and were numbered from 1 to 5, from forward to aft. Each exit door was fitted with a viewing window. All doors, except L3 and R3, were fitted with an automatically inflating escape slide raft. Opening the L3 and R3 doors automatically activates the deployment of slide ramps, which are designed to facilitate an over-wing evacuation.

Additionally, the left and right No. 2 cockpit windows are designed as sliding windows which are designated as secondary emergency exits for the flight crew. Emergency escape ropes are stowed above these windows. The primary emergency exits for the flight crew are the L1 and R1 doors.

1.6.4.2 Escape slide rafts and slide ramps

Eight of the emergency exits (figure 9) were fitted with escape slide rafts that deploy automatically when the door has been placed in the armed position and is then opened. They function as slides when the Aircraft is on the ground and as rafts in the case of a water ditching, when they can be detached from the Aircraft.

Opening the armed L3 and R3 doors automatically deploys slide ramps, which are stowed behind a panel in the fuselage above the wing trailing edge. These are designed to assist occupants to evacuate over the wing by deploying towards the emergency exit door and down the trailing edge of the wing. Flap position does not affect the deployment and use of the slide ramps.

The slide rafts and slide ramps were manufactured in accordance with *Technical Standard Order (TSO) TSO-C69b* issued by the FAA.

¹⁴ Type A exit is a floor-level exit with a rectangular opening of not less than 42 inches (1.06 meters) wide by 72 inches (1.83 meters) high.

The slide rafts were manufactured by Air Cruisers Co., while the slide ramps were manufactured by BF Goodrich. Available records show that the slides were serviceable and within overhaul limits at the time of the Accident.

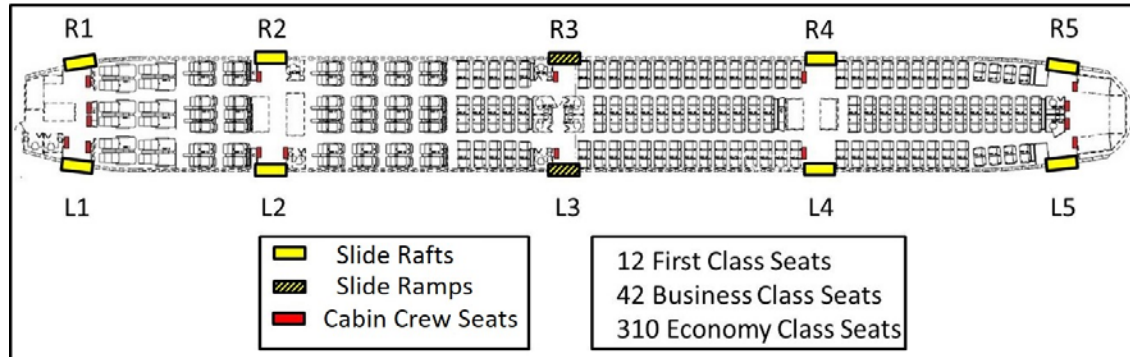


Figure 9. Cabin layout with cabin crew seats, emergency exits, slide rafts and slide ramps

Cabin exits L1, R1, L2, R2, L4, R4, L5 and R5 were fitted with escape slide packs, which were mounted on the inside of the door and contained a folded slide raft. A lower liner was attached to the door and provided a cover for the slide pack. A girt bar is latched onto a floor fitting in the door sill when the door is armed.

When the door is opened in the armed position, the tension on the slide girt bar pulls on the bottom of the escape slide pack, releasing the folded slide from the packboard, with the result that the slide falls away from the door. This fall applies tension to the inflation cable, which opens the inflation valve of the pressure cylinder. According to the Aircraft manufacturer, the average time between door opening and slide inflation is 7 seconds.

A handle can be operated to manually release the pressure from the cylinder and inflate the slide, should automatic deployment fail due to insufficient fall-height of the slide pack or during a water landing.

Due to the over-wing location of the L3 and R3 emergency exits, slide ramp packs are stowed behind a hinged panel in the wing-to-body fairing above the wing trailing edge.

In the armed condition, rotating the door handle will electrically activate the release valve squib of the pressure regulator, which pneumatically opens the stowage panel, enabling the slide ramp to inflate out of its pack. The released slide ramp will deploy over the wing towards the exit, creating a guide barrier and slide for the evacuation over the wing trailing edge.

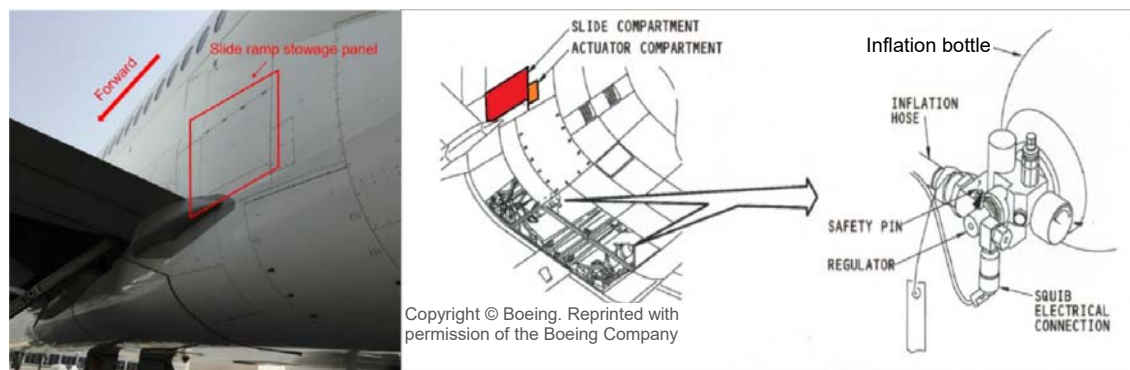


Figure 10. L3 slide ramp stowage and pressure cylinder locations

The slide ramp pressure cylinders (figure 10) were located in the wing-to-body fairing, below the slide stowage panels.

1.6.4.3 Protective breathing equipment (PBE)

The Aircraft was fitted with PBE for the flight and cabin crew, which was manufactured by Essex under FAA TSO-C116a and TSO-C99a.

The PBE was stored in a plastic pouch inside a metal container with a lid secured by a metal latch (figure 11). The lid is fitted with tamper indicators and a sight glass for a humidity indicator which is inside the container. The TSOs require that the PBE must be easily donned and activated within 15 seconds. This time limit includes the opening of the plastic pouch, but does not include access or opening of the storage container.

The PBE plastic pouch is opened by pulling a red tear strip in a direction indicated by arrows. Once the PBE is removed from the pouch, the flow of oxygen is initiated by pulling two oxygen cylinders away from each other. Immediately after the oxygen flow is initiated, the hood is ready for use. The hood will fully inflate after two to three minutes and provide oxygen for 15 minutes.



Figure 11. PBE stowage and pouch

1.7 Meteorological Information

1.7.1 Weather forecast at the Airport

On the Accident day, the United Arab Emirates National Center of Meteorology and Seismology (NCMS) issued one windshear warning before the Accident for OMDB:

OMDB WS WRNG1 030735 VALID 030740/030900 MOD WS ALL RWY FCST.

The windshear warning issued at 0735 was valid from 0740 to 0900 and forecast moderate windshear affecting all runways. This warning was broadcast in information Zulu of OMDB Arrival ATIS at 0800.

The NCMS standard operating procedures (SOP) state that 'moderate' windshear is between 5 to 11 kt per 100 ft vertically and 'severe' windshear is 12 kt or more per 100 ft vertically.

After the Accident, three additional windshear warnings were issued at 0859, 0958 and 1253. The warning issued at 0958 classified the windshear as 'severe' for all runways.

In addition, the meteorological terminal air report (METAR) issued by NCMS on 3 August 2016 described the weather conditions for 0830 as follows:

OMDB 030830Z 11015KT 060V150 6000 NSC 48/06 Q0993 WS ALL RWY
TEMPO 35015KT 4000 DU.

The METAR indicated that the wind speed was 15 kt from 110 degrees, variable between 60 and 150 degrees, visibility was 6,000 m with nil significant cloud. The temperature was 48 degrees centigrade, dew point 6 degrees centigrade and the barometric pressure adjusted to sea level (QNH) was 993 hectopascal (hPa). Windshear on all runways with a temporary wind from 350 degrees at 15 kt and visibility was 4,000 meters in widespread dust.



The terminal aerodrome forecast weather (TAF) issued on 3 August 2016 at 0505, and valid from 0600 on 3 August to 1200 on 4 August, showed the following forecast information:

TAF OMDB 030505Z 0306/0412 08008KT 7000 NSC BECMG¹⁵ 0308/0310
36012KT BECMG 0314/0316 09008KT PROB30 0404/0411 09016G26KT 3000 DU
PROB30 0410/0412 01012KT

The report indicated that the wind would be from 080 degrees at 8 knots, visibility 7,000 meters, nil significant cloud, a gradual change in wind conditions becoming 360 degrees at 12 knots beginning 0800 and ending 1000. The gradual change was expected to occur at an unspecified time within this time period.

The TAF continued with a change, which was forecast to commence on the 3 August at 1400 and be completed by 3 August at 1600. Wind direction was anticipated to be from 090 degrees at 8 knots, with a 30 percent probability that during the period between 0400 and 1100 on 4 August the wind direction would be from 090 degrees at a speed of 16 knots gusting up to 26 knots and a prevailing visibility of 3,000 meters in dust. In addition, there was a 30 percent probability that during the period between 1000 and 1200 on 4 August the wind direction would be from 10 degrees at a speed of 12 knots.

At 0848, the NCMS issued an Aerodrome Warning which was valid from 0848 to 1200. This stated that the observed and forecast for surface wind speed was 20 kt to a maximum of 30 kt with visibility 3,000 m.

1.7.2 Environmental conditions

The environmental conditions at the Airport were affected by an area of low pressure of 989 hPa, centered 300 kilometers south of the airport. Very hot conditions with a recorded temperature of 48.9 degrees centigrade existed across the Airport at the time of arrival of UAE521.

As a result of the hot conditions, a secondary low pressure center formed along the coast approximately 55 kilometers southwest of the airport, having a central pressure of 992 hPa.

The combined effect of these two low pressure areas delayed the onset of the regular sea breeze at the Airport. It also caused the sea breeze to cross the aerodrome unusually slowly from north to south. This movement of the sea breeze led to an extended period of windshear conditions across the runways.

After the Accident, the NCMS provided the Investigation with a 2-minute interval surface wind report for runway 12L. The wind data recorded for the runway 12L threshold indicated that the wind direction started to change from a headwind at 0825 of 121 degrees to a tailwind component at 0830 of 278 degrees. From 0830 until the Accident, the threshold surface wind speed varied between 4.1 kt and 13.8 kt. A wind gust¹⁶ of 24.5 kt was recorded at 0837 and a gust of 29.2 kt was recorded at 0838.

Table 5 illustrates the 2-minute average winds recorded at various locations at the Airport, at the time of the Accident. The 2-minute interval average wind speed and direction is available to the air traffic controller on his/her monitor.

¹⁵ As per ICAO Annex 3, Appendix 5, BECMG is defined as "The change indicator "BECMG" shall be used to describe forecast changes where the meteorological conditions are expected to reach or pass through specified values at a regular or irregular rate."

¹⁶ A gust can be defined as the difference between the extreme value and the average value of the wind speed in a given time interval. A gusty wind is characterized by rapid fluctuations in wind direction and speed. At airports, gustiness is specified by the extreme values of wind direction and speed between which the wind has varied during the last 10 minutes. [source: World Meteorological Organization WHO-No. 731].



Table 5. OMDB wind conditions at 0838 UTC

Site	Wind		
	Direction (degrees)	Speed (kt)	Gust (kt)
12L	315	9.1	29.2
30R	118	15.6	21.4
12R	131	13	22.2
30L	117	17.5	23.5
South	115	21.2	22

During the approach, the Aircraft FDR data indicated that from approximately 200 ft radio altitude, a 16 kt tailwind diminished and shifted to a headwind of less than 8 kt just prior to touchdown.

During the attempted go-around, the Aircraft FDR data indicated a headwind component of 8.5 kt as the Aircraft became airborne which increased to 14.5 kt at 78 ft radio altitude.

1.8 Aids to Navigation

The Airport was equipped with a CAT IIIB instrument landing system (ILS), distance-measuring equipment (DME), and global navigation satellite system (GNSS).

The Aircraft was equipped with the required navigational equipment which consisted of global positioning system (GPS), air data inertial reference system (ADIRS), very high frequency omnidirectional range (VOR) receivers, DME receivers, ILS receivers, transponder, weather radar, and flight management system (FMS) with two flight management computers (FMC) and two automatic direction finders (ADF).

All ground and onboard navigation equipment was serviceable.

1.9 Communications

All communications between air traffic control and the flight crew were recorded by the ground based voice recording equipment for the duration of the Accident flight and were made available to the Investigation.

1.9.1 Air traffic control communication

UAE521 was in communication with OMDB ATC during the approach. Until 0827, communication was with the Arrivals and with the Director for the following eight minutes and then with the Tower until the Accident.

During the period from 0800 to 0823, 12 aircraft landed uneventful on runway 12L following a single approach. During this period, the surface wind at the threshold had a headwind component.

At 0824, a Boeing 737, flight number IAW123, landed on runway 12L and the flight crew advised the Tower that there was an indication of light to moderate windshear on short final. The Tower acknowledged receipt of the information.

At 0829 an Airbus A321, flight number AIC933, was cleared to land on runway 12L with a surface wind from 170 degrees at 12 kt and was advised by the Tower that a preceding aircraft had reported windshear on the approach, which was acknowledged by the flight crew. At that time, UAE521 was still on the Arrival frequency.

At 0830, AIC933 performed a go-around after passing the threshold of runway 12L. The Tower observed that the aircraft had started to climb, and within a few seconds, instructed AIC933 to continue straight ahead, climb and maintain four thousand feet. The flight crew



immediately read back the cleared height. After another 18 seconds, the Tower instructed AIC933 “upon passing one thousand feet turn left track zero niner zero”. The flight crew immediately read back the instructions.

At 0831, the Tower cleared flight UAE706 (a B777) to land on runway 12L with a surface wind from 240 degrees at 9 kt. No additional information was passed by the Tower to UAE706.

At 0832, UAE706 performed a go-around after passing the threshold of runway 12L. The Tower observed that the aircraft had started to climb, and within a few seconds, instructed UAE706 to continue straight ahead, climb and maintain four thousand feet. The flight crew immediately read back the cleared height. After another nine seconds, the Tower instructed UAE706 “upon passing one thousand feet turn left track zero niner zero”. The flight crew immediately read back the cleared height but stated a heading of “one zero nine”. The Tower corrected UAE706 which was immediately read back correctly by the flight crew.

The reason(s) for the go-arounds, AIC933 and UAE706, were neither reported to the Tower, nor requested by air traffic control. During this period, UAE521 was still on the Arrival frequency.

After the UAE706 go-around, the Tower and Approach watch managers discussed the wind conditions, the windshear warning on the ATIS, and the two go-arounds. Initially, Approach offered the Tower more time separation on the final approach. However, both agreed that increasing the separation on the approach would not resolve the issue, and the solution would come from OMDB Arrivals reducing the rate of entry to the OMDB control area.

At 0832, flight UAE409 (a B777), was cleared to land on runway 12L with a surface wind from 250 degrees at 8 kt. No additional information was passed to UAE409 by the Tower. UAE409 landed uneventful.

At 0834, flight UAE545 (a B777), was cleared to land on runway 12L with a surface wind from 190 degrees at 11 kt. No additional information was passed UAE545 by the Tower. The aircraft landed towards the end of the touchdown zone, missed its assigned taxiway Mike 9, and vacated the runway at taxiway Mike 12A.

The 2-minute average wind records provided to the Investigation by the NCMS indicated the wind at 0834 was from 352 degrees at 6.6 kt.

After the landings of UAE409 and UAE545, there were no pilot reports about the wind conditions during the approach and landing to the air traffic controller.

At 0835, UAE521 was transferred to the Tower frequency and was cleared to land on runway 12L with a request to vacate via taxiway Mike 9.

The Tower and Approach again discussed the prevailing wind conditions, as the threshold surface wind displayed on runway 12L indicated a 12 kt tailwind, and a 16 kt tailwind at the threshold of runway 30R (opposite end of runway 12L). Both expected that the sea breeze was approaching, however decided that a commencement of runway change was untimely.

At 0836, the Tower cleared UAE521 to land on runway 12L, and provided surface wind information of 11 kt, from 340 degrees.

At 0837:04 UAE521 crossed the threshold of runway 12L.

At 0837:26, the Tower observed UAE521 commencing a go-around and in a three seconds communication, instructed the flight crew to continue straight ahead and climb to 4,000 ft. Twelve seconds later, the Aircraft impacted the runway.



At 08:37:30, Approach and the Tower continued the discussion about the process of changing runways. This discussion was interrupted by the occurrence of the Accident.

Once the Accident occurred, ATC immediately closed both runways at OMDB and started radar vectoring traffic away from OMDB.

During the post-Accident interview, the Tower controller stated that “I saw UAE521 rear wheels touched the runway but he [the Aircraft] looked unstable and I could see him pulling up so I gave him go-around clearance of straight ahead 4,000 ft”.

Table 6 gives a summary of the recorded 2-minute average surface wind information for runway 12L between 0825 and 0838, the wind information passed to the flights by ATC, and comments with regards to approach/landing.

Table 6: Runway 12L surface wind reported and recorded wind information								
Time	Flight No.	Aircraft	ATC surface wind information passed to the flight crew		NCMS recorded surface (threshold) wind information			Comment
			Heading (degrees)	Speed (kt)	Heading (degrees)	Speed (kt)	Gust (kt)	
0824	IAW123	Boeing 737	(Aircraft landed at 0824)		121	10.1	25.3	Pilot reported to ATC “light to medium windshear” on short final
0829	AIC933	A321	170	12	161	12.8	15.7	Go-around performed
0830	NCMS recorded wind information				278	4.1	15.7	Wind shift
0831	UAE706	B777	240	9	265	12.2	15.7	Go-around performed
0832	UAE409	B777	250	8	251	8.6	15.6	Landed
0834	UAE545	B777	190	11	352	6.6	15.6	Deep landing
0836	UAE521	B777	340	11	328	13.8	24.5	Attempted go-around
0837 -0838	NCMS recorded wind information				326	9.8	26.9	Gust at 0838 was 29.2

1.10 Aerodrome Information

Dubai International Airport was certificated by the GCAA in accordance with *Part IX – Aerodromes*, of the *Civil Aviation Regulations*.

The Airport ICAO code is OMDB, its coordinates are 25°15'10"N 55°21'52"E, and it is located 4.6 kilometers east of Dubai city. The airport elevation is 62 ft.

The Airport is equipped with two asphalt runways: 30R/12L and 30L/12R. The runway 12L threshold is displaced by 450 m and the runway 12R threshold is displaced by 715 m. The runways 12R threshold is 1,880 m ahead of 12L threshold. From the centerlines, runways 12L and 12R is 385 m apart.

The Airport rescue and firefighting services (ARFFS) comply with Category 10 requirements of *Part XI- Aerodrome Emergency Services, Facilities and Equipment*, of the *Civil Aviation Regulations*, and are in conformity with *Annex 14 – Aerodromes*.

Table 7 illustrates the general data of the Airport.



Table 7. Airport general data

Aerodrome code (ICAO/IATA)	OMDB/DXB
Airport name	Dubai International Airport
Airport class	CAT IIIB
Airport authority	Dubai Airports Company
Airport service	ADC/APP
Type of traffic permitted	VFR/IFR
Coordinates	251510N/0552152E
Elevation/reference temperature	62 ft/41 degrees centigrade
12L total take-off run available (TORA)	4,050 m (Threshold displaced 450 m)
12L accelerate-stop distance available (ASDA)	4,176 m
12L take-off distance available (TODA)	4,110 m
12L landing distance available (LDA)	3,600 m
12L runway width	60 m
12L stopway	126 m
12L Runway end safety area	140x150 m
Azimuth	121 degrees
Category for rescue and firefighting service	10

1.10.1 Runway markings

The color, intensity, dimensions, lateral and longitudinal spacing, and photometric characteristics of the Airport lighting comply with the criteria of *Part IX – Aerodrome*, of the *Civil Aviation Regulations* of the United Arab Emirates, and conform with volume 1, appendix 2 to *Annex 14 – Aerodromes*, to the Convention on International Civil Aviation.

Runway 12L was equipped with an ICAO Category IIIB precision approach lighting system, and with a 3-degree precision approach path indicator (PAPI)¹⁷, placed at 270 m beyond the displaced threshold. Runway 12L was also fitted with threshold wing bar lighting, centerline lights, touchdown zone lights, edge lights and runway end lights.

The runway 12L markings (figure 12) consisted of a runway centerline, runway edge markings, threshold marking, and runway designation characters. Runway touchdown zone markers on each side of the centerline consisted of three stripes at 150 and 300 m beyond

¹⁷ The published United Arab Emirates AIP for OMDB gave 50 ft height at the threshold provided the aircraft glide path is 3 degrees.

the threshold, solid white stripe for aiming point at 400 m, two stripes at 600 m, and a single stripe at 750 and 900 m.

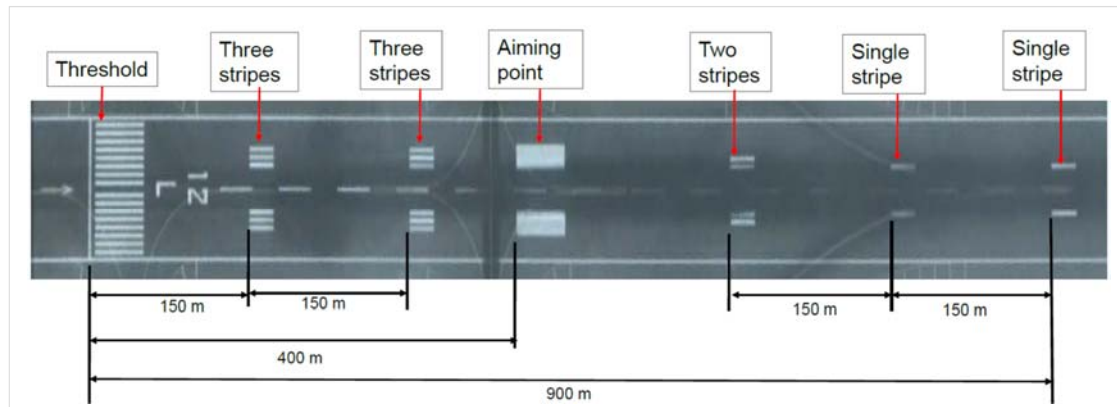


Figure 12. Runway 12L threshold and touchdown zone markings

1.10.2 The Airport rescue and firefighting capabilities

The Airport was fully equipped with rescue and firefighting services in accordance with *Part XI* of the *Civil Aviation Regulations* of the United Arab Emirates. This included 11 major foam vehicles (MFVs) (figure 13), three domestic fire vehicles (DOM), two incident command vehicles, and one rescue vehicle.

Six MFVs were equipped with forward looking infrared (FLIR) cameras and one was equipped with a video camera.

There were three fire stations at the Airport which consisted of a main fire station located north of runway 30R, and two satellite fire stations located south of runway 30L. The station manager (fire commander) was located at the main fire station.



Figure 13. Major foam vehicle (MFV)

The ARFFS resources had been determined through task and resource analysis carried out by the Airport and accepted by the GCAA. The minimum operational ARFFS staffing level for fire Category 10 was 24 personnel for the initial response. This encompassed a duty manager (operational incident commander), two station managers, three crew managers, two watchroom personnel, and 16 firefighters. In addition, 18 domestic fire crew were available to provide support for the ARFFS crew. The domestic crew operate from three fully equipped domestic vehicles.

During deployment, the incident command vehicle is required to be manned by the fire commander and a driver. The main fire vehicles and domestic vehicles were supervised by crew managers, with two or three firefighters.

The watchroom, located at the main fire station, was responsible for communications and raising alerts to the Airport fire service. The watchroom had an unobstructed view of the Airport movement areas. An alert system for ARFFS personnel was installed at the main fire station and was linked to all the satellite fire stations and to air traffic control.



The Airport had a number of fire hydrants at various locations, which were subject to continuous testing and examination according to paragraph 19 of Part XI of the *Civil Aviation Regulations – Supplementary Water Supply*. Additional water supplies and aerial rescue capabilities are provided by Dubai Civil Defense (DCD).

A mobile incident command center (MICC) is parked at the main fire station and is repositioned to be utilized as the communications and incident command hub at the accident site. As stated in the *Airport Emergency Plan (AEP)*, to ensure that emergency services work effectively together, an MICC is established at the incident site and all agency Incident Commanders report to the nominated Airport Incident Commander (AIC). This is normally the Senior Airport Fire and Rescue Service Officer on scene, who assumes responsibility for overall management of the emergency response and for organising and deploying all available resources in a safe and efficient manner. Dubai Airports designate this level of crash site command and control as 'Bronze Command'.

1.11 Flight Recorders

The Aircraft was equipped with a Honeywell solid-state flight data recorder (SSFDR) and an L-3 Communication cockpit voice recorder (CVR).

Both flight recorders were found mounted in their original locations on the Aircraft, with external signs of prolonged exposure to elevated temperatures. However, temperature indicators within each crash-survivable memory unit indicated that the memory components themselves had not been exposed to significantly elevated temperatures. The flight recorders were sent to the Air Accidents Investigation Branch (AAIB) facility in the United Kingdom for data retrieval in the presence of the Investigation Committee.

Both memory modules and cables were removed from the recorders and examined using optical microscopy. After the serviceability of the memory modules was established, they were attached to a new chassis allocated for each recorder in order to download the data. The data stored in both recorders was successfully downloaded and read out.

The examination excluded data that was recorded after the impact because the Investigation found that this data was invalid.

The quick access recorder (QAR), used by the Operator for the FDM program, was recovered but the Investigation could not use the downloaded data because it was corrupted. The QAR is not built to crash-proof standards.

1.11.1 The cockpit voice recorder

The Investigation Committee listened to the CVR recording with the objective of preparing a transcript, examining flight crew performance, flight crew status from a human factors perspective, and identifying sounds relevant to the Aircraft systems. As recorded by the CVR, both flight crewmembers verbal communications were normal, and had engaged in general open discussion about operational procedures. The crewmembers tone of voice did not indicate flight crew fatigue.

The Investigation identified a sudden change in the cockpit environment sound, recorded by the cockpit area microphone, after the Commander stated "Thermals". This sound lasted for approximately six seconds, ending when the Aircraft became airborne. The Investigation concluded that the change in sound occurred when the main landing gear wheels made contact with the runway.

A CVR transcript was prepared and synchronized with the flight data recorder (FDR) parameters by fixing the time of a reference event between both recorders.



1.11.1.1 TO/GA switch

The Commander stated that he had pushed the TO/GA switch just before calling 'go-around'. In an attempt to verify the Commander's statement, and because the operation of the TO/GA switch is not one of the parameters recorded by the FDR, the Investigation performed a detailed analysis of the CVR recordings, and confirmed that a click sound was recorded before the Commander called 'go-around'. The Investigation compared that click sound with a TO/GA switch sound recorded in the cockpit of a sister aircraft using a sound analysis and visual inspection of the waveform. Even though the methods used were not sufficiently reliable to determine the TO/GA sound signature, there was good similarity between both sounds. Ultimately, the Investigation concluded that the click sound recorded by the CVR was, most likely, the sound of the TO/GA switch being pushed.

1.11.2 The solid-state flight data recorder

1.11.2.1 Aircraft touchdown

As part of its analysis of the solid-state FDR data, the Investigation reviewed the Aircraft parameters relevant to the brief touchdown (figure 14) and the commencement of the go-around. The FDR recorded parameter for the main gear truck position of TILT / UNTILT is the truck tilt sensor. The main gear WOW sensor state is not a recorded FDR parameter.

For a period of six seconds, from 0837:16 to 0837:22, the main landing gear entered a series of 'tilt' ('air' mode) and 'untilt' ('ground' [GND] mode) cycles. Some cycles were in phase, or partially in phase, for both main gear, while for other cycles the main gear attitude changed for a single gear only.

During the initial cycle, the right main gear entered 'untilt' attitude. Because a left control wheel input was made, the Aircraft rolled left and then the left main landing gear became 'untilt' at 0837:19 and remained in that attitude for less than one second. With both main landing gear simultaneously in 'untilt' attitude the speedbrake lever moved partially from 7.5 to 20 degrees. At this point the left main gear 'tilted' causing the speedbrake lever to move towards the 'arm' position. Soon after this, the right main gear 'tilted'.

Both main landing gear remained 'tilted' for less than half a second. Following this, both main gear became 'untilt' for less than one second, and for a second time, the speedbrake lever partially moved from 7.5 to 38 degrees. Then the right main landing gear 'tilted' and the speedbrake lever returned to the 'arm' position. The speedbrake lever remained in this position until the impact. The left main gear remained 'untilt' for less than two seconds before it 'tilted' again at 0837:22.

During the time that both main landing gear were simultaneously 'untilt', the FDR data indicated that there was momentary application of brake hydraulic pressure of less than 200 psig. In addition, from 0837:21 there was an indication of approximately 400 psig autobrake hydraulic pressure being applied for two seconds.

At 0837:18, the FDR indicated the pitch-up angle increasing from 0.8 to 3 degrees. The increase in pitch angle occurred shortly before the Commander called for a go-around, at about 161 kt IAS. The pitch angle oscillated between 3 and 2.3 degrees over the next one second before it continued to increase at a positive rate towards 7.4 degrees, at about 153 kt IAS, with both main landing gear being 'untilt'. The landing gear lever was selected to 'up' at 0837:29 and the Aircraft then continued in 'air' mode with the landing gear being in transit to the up position until impact.

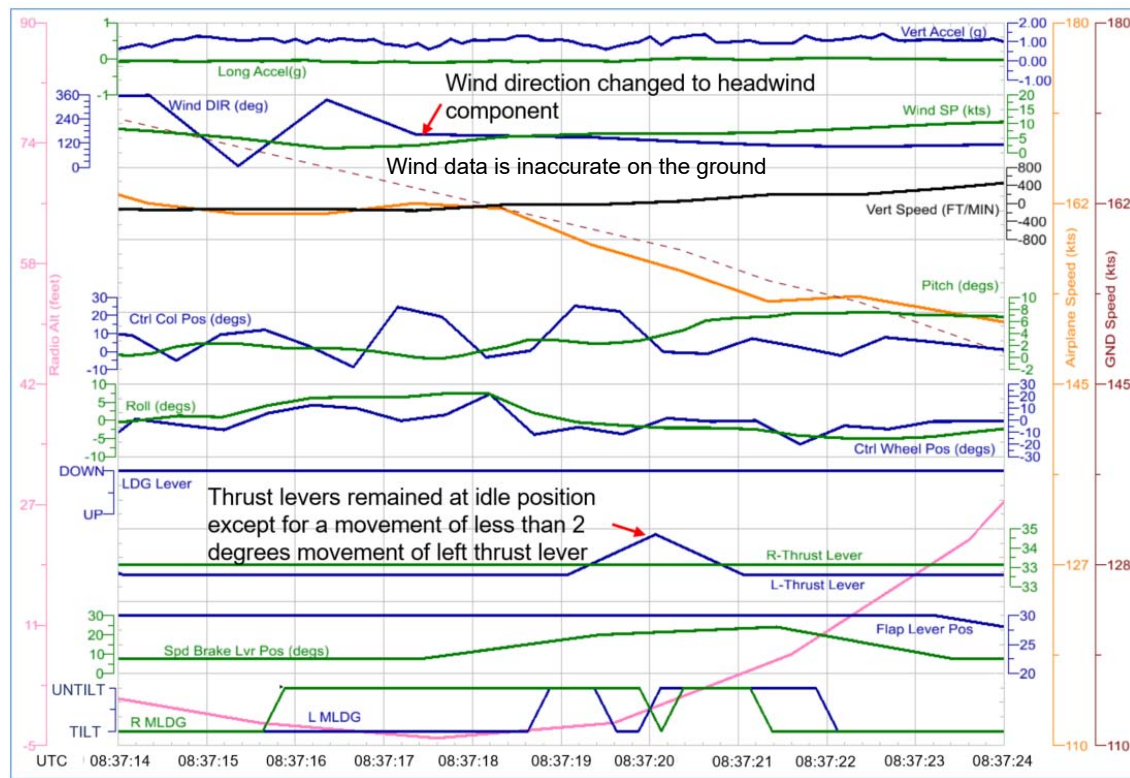


Figure 14. Main landing gear over six seconds of 'tilt' and 'untilt'

1.11.2.2 Engine performance

With the assistance of Rolls-Royce, the recorded data for both engines was reviewed to determine if the engine electronic control (EEC) was operating in accordance with design specifications. The engine data was also reviewed for the three engine idle speeds: high (approach), intermediate and low (ground) idle. The idle speeds are controlled in accordance with EEC logic in response to the Aircraft system inputs.

After the A/T had commanded the Aircraft engines to spool down towards idle thrust at 25 ft radio altitude, the data showed that with the flaps at the landing configuration, flaps 30, and with the radio altitude greater than 5 ft, the EEC maintained the engines at high idle. It was observed that the engines N3 speed varied during the latter part of the approach to runway 12L and the thrust levers retarded to the expected angular value for the idle position. This happened at a rate consistent with an automated command rather than a manual change. The high idle setting is scheduled during the approach such that the engine can spool up to take-off thrust quickly in the event of a decision to reject the landing and to perform a go-around.

As the Aircraft neared touchdown, with a radio altitude of 5 ft or less, the EEC commanded the engines to low idle in preparation for possible thrust reverser operation. However, before the engines had stabilized at low idle, the data showed that when the Aircraft started to climb and the radio altitude had increased above 5 ft, the EEC changed from ground to flight status and commanded the engines to high idle.

The data indicated that when the Aircraft flaps were retracted to flaps 20, the EEC, recognised that the Aircraft was no longer in a landing configuration although the landing gear was still in the down position. The EEC intermediate idle logic was now satisfied and both



engines were commanded to the intermediate idle setting. The data shows that the engines responded by spooling down to the target N3 intermediate idle speed.

As the engines began to stabilize at the intermediate idle speed, the landing gear lever position was set to the 'up' position. The EEC determined that the inputs to the logic for intermediate idle were no longer valid and it now scheduled the engines to low idle. The engines responded by spooling down to the target N3 speed for low idle.

Six seconds after the initiation of the landing gear lever to the 'up' position, the data indicated that both thrust levers were moved from idle to the maximum thrust positions within a two second period. The rate of change of the thrust lever angle (TLA) value indicated that the movement of the thrust levers was most probably a manual input. The engines began to respond by spooling up with N3 speed increasing by approximately 5% when the Aircraft impacted the runway.

Analysis of the data showed that both engines were behaving almost identically in respect of responses to EEC inputs, both automated and manual, as designed.

1.12 Wreckage and Impact Information

The Aircraft impacted runway 12L adjacent to taxiway November 7 (figure 15) approximately 2,530 m beyond the runway threshold. Marks on the runway indicated that the Aircraft slid for approximately 800 m with the nose and main landing gear partially retracted.

The Aircraft aft fuselage impacted first, followed by the engines, the lower section of the belly fairing, and then the forward fuselage.

The No.2 engine separated, moved laterally outboard along the right wing leading edge, and remained near the wingtip until the Aircraft came to rest with the engine on fire.

As the Aircraft slid along the runway, the right wing was on fire at the engine-pylon attachment point. Various parts detached from the Aircraft. These included portions of the engine cowlings, secondary support structure, parts of the wing to body fairings, access panel doors, and various systems components.

The Aircraft came to rest adjacent to taxiway Mike 13, having turned to the right onto a heading of about 250 degrees. The right wing was in contact with the pavement. Except for the parts that separated as the Aircraft slid along the runway, the Aircraft was intact protecting the occupants on board.

The Aircraft passenger cabin was intact except for some minor damages based on crew interviews and passenger statements.

At impact, the L1 cabin crewmember's seat base broke and folded downwards, the cockpit door opened, the first class cabin window blinds closed, a number of passenger oxygen masks deployed, and an air vent grill next to the R5 door detached and fell to the floor.

Passengers did not report any problems with the condition of the passenger seats or seatbelts.

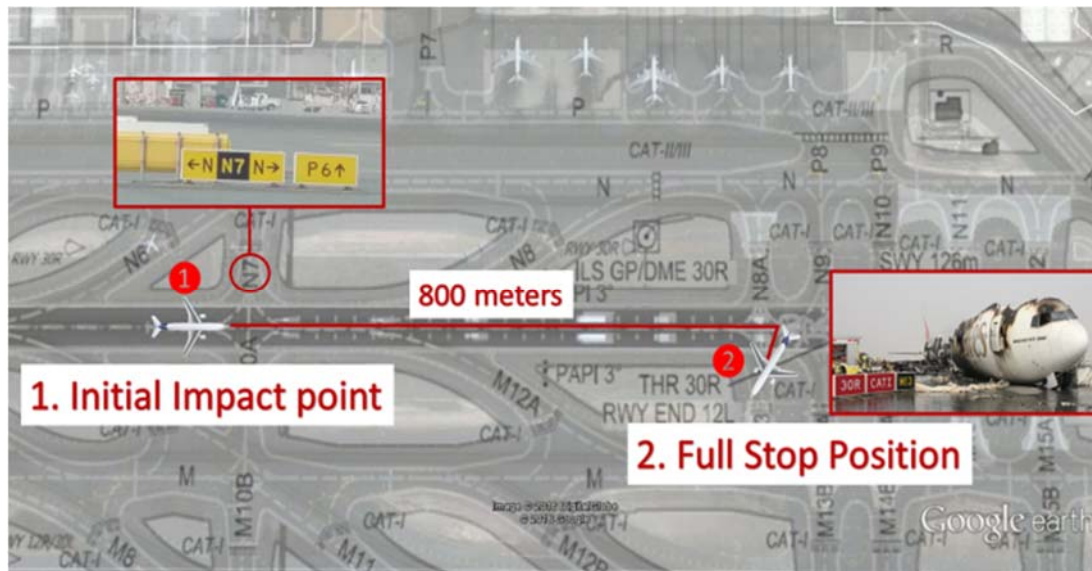


Figure 15. Aircraft Initial impact point and final position

1.13 Medical and Pathological Information

Post-Accident blood tests did not reveal any psychoactive materials that could have degraded the flight crew performance. There was no evidence that physiological factors or incapacitation had affected the performance of the flight crew.

1.14 Fire

After the Aircraft came to rest, the fire continued on the separated No.2 engine. Video footage recorded by a passenger showed the aft lower section of the No.1 engine, which was still attached to the left wing, was on fire.

In addition, a passenger video recording showed black smoke, without visible flames, issuing externally from the lower fuselage in the vicinity of the right wing root area and the right main landing gear bay. This smoke continued to increase in density after the Aircraft came to rest until the explosion of the center wing fuel tank.

There was discoloration and sooting on the external fuselage forward of the R4 door, which indicated a heat source with no visible flame.

From the statements of cabin crew and passengers, white smoke appeared in the cabin immediately after the Aircraft came to rest. This was confirmed by a passenger video which showed white smoke in the right center cabin before the evacuation was announced. The source of the smoke was not determined, however, the forward and aft cabins were not affected by smoke at this time. After the evacuation command, all passenger doors were opened except doors L3 and R3.

Inside the cabin, before the explosion, the white smoke changed color to grey and became very dense. Visibility throughout the cabin was dramatically reduced as the smoke spread. Cabin crewmembers at the aft galley (between the L5/R5 doors) searched the cabin for passengers but the smoke density prevented them searching beyond the L4/R4 exits.

In 9 minutes 40 seconds after the Aircraft came to rest, an explosion occurred in the center wing fuel tank. The explosion was caused by heat transfer from the burning right main

landing gear heating and causing the ignition of the approximately 100 kg of residual fuel in the center wing tank. The explosion caused the right wing upper skin panel of the center wing fuel tank to violently separate (figure 16).



Figure 16. Upper skin panel from right wing

The direction of the explosion pressure wave was from the center wing tank towards the right main wing tank. This resulted in a large section of the upper wing skin from the inboard right wing, approximately 15 m in length and the width of the upper wing surface, being separated with such force that it landed behind the right wing on the tarmac approximately 5 m from the wingtip. The wing skin panel separated from wing buttock line station (WB) 123.124 to wing station (WS) 732 (Rib 21). In addition, the explosion also caused the cabin floor over the center tank area to lift which provided a path for fire and smoke to enter into the passenger cabin.

During the explosion of the center wing tank, fuel in the right wing main tank was no longer contained beyond the rib that separated both fuel tanks. As a result, the fire dynamics changed and the fire became more intense which eventually spread into the Aircraft cabin and cargo compartments from the center wing fuel tank location.

This was consistent with a statement given by the senior cabin crewmember (who was at the forward end of the Aircraft at the time of the explosion) who described a sudden increase in the volume and density of the smoke coming from the center section of the passenger cabin immediately after the explosion.

Following the explosion, video evidence showed thick black smoke being emitted from all the Aircraft doors.

Figure 17 illustrates the sequence of events before and after the explosion.



Figure 17. Center wing fuel tank explosion



1.15 Survival Aspects

1.15.1 Emergency management at the Accident site

1.15.1.1 Airport emergency response

At 0837:59, the Tower activated the crash alarm and informed UAE521 flight crew that fire vehicles were being deployed.

The ARFFS watchroom attendant witnessed the Aircraft impacting the runway and activated the fire alarm. The Airport fire commander immediately responded to the site, and two MFVs were also deployed approximately 40 seconds after the impact. Following this, the Tower called the watchroom on the hotline declaring three times 'Crash'. After the Aircraft came to rest, the Aircraft Commander transmitted, at 0839:04, "Mayday, mayday, mayday, Emirates five two one evacuating" to the Tower.

The recording of the Airport ground movement radar and video showed that the fire commander arrived at the Accident site at 0839:38 and positioned the fire commander vehicle about 30 m from the Aircraft tail, to the left side.

Appendix D in this Report shows the location of the fire commander's vehicle and the other firefighting vehicles (referred to as Fire).

Several seconds after the fire commander's arrival, Fire 6 (Colet Jaguar) arrived and positioned behind the right wing, opposite to the R4 door, close to the base of the escape slide. The firefighters commenced to apply fire extinguishing agent from the main (roof) monitor against the fuselage forward of the R4 door. Video evidence showed this area of the fuselage had started to exhibit signs of sooting and paint discoloration which was an indication that a fire situation was present and was developing in intensity.

Fire 10 arrived at approximately 0840, and was positioned to the right and rear of Fire 6. The firefighters commenced applying fire extinguishing agent immediately towards the inboard surfaces of the right wing. Passenger evacuation was still in progress through the R4 door.

When the firefighters of Fire 10 perceived that the fire was suppressed, they offloaded the vehicle and started to use the sideline hoses for cooling the detached No.2 engine and the right wing leading edge. Fire 6 continued applying fire extinguishing agent from the roof monitor against the fuselage forward of the R4 door.

Based on video evidence, the R5 escape slide was disabled by wind effect for approximately 3 minutes 40 seconds after its deployment. This was observed by a firefighter, who was able to stabilize the lower end of the slide and allow it to be used for evacuation.

The fire commander was observed near his vehicle giving instructions. He was wearing a beige overall with no distinctive identification. There was no video evidence to suggest that the fire commander was practicing a dynamic risk assessment of the Accident site from different directions. The fire commander was moving between the fire commander vehicle and the L5 door to assist in evacuating the passengers.

At 0841, three additional firefighting vehicles (Fire 1, Fire 7, and Fire 11) arrived. Fire 7 was fitted with a high reach extendable turret (HRET). Fire 1 and Fire 7 were positioned on the left side of the Aircraft, whereas Fire 11 was positioned towards the rear of the Aircraft close to the fire commander's vehicle. Fire 1 extinguished a small fire under the No.1 engine.

Fire 16 arrived at 0842 and was positioned at the front left side of the Aircraft forward of Fire 1. Once in position, fire extinguishing agent was applied onto and over the left side fuselage, with agent also landing on the right side of the Aircraft.



There were five firefighters from Fire 6 and Fire 10 deploying sidelines and assisting passengers to exit using the R4 escape slide. Two firefighters were using a sideline from Fire 10 and applying water to the detached No.2 engine. A firefighter was using a sideline from Fire 6 to apply water to the fuselage and the right side wing root area.

Fire 5 arrived at 0843 and was positioned approximately 10 m from the right wingtip facing inboard. Firefighters from Fire 5 was observed using the front bumper monitor to apply fire extinguishing agent to the exhaust area of the detached engine, which was still on fire. After the No.2 engine fire was extinguished, Fire 5 remained in position.

Fire 9 arrived at 0844 and was positioned on the left side, behind the Aircraft.

Fire 6 and Fire 10 had exhausted their supply of water about 20 seconds before the center wing fuel tank explosion occurred. When the fuel tank exploded at 0847:50 (9 minutes 40 seconds from the time that the Aircraft came to rest), both of the Fire 6 and Fire 10 sideline firefighters were still in position. One of the firefighters was fatally injured when the liberated upper right wing skin panel struck him.

At the time of the explosion, the passengers and crew, with the exception of the Aircraft Commander and the senior cabin crewmember, had already evacuated the Aircraft, but some of them were still located at the Accident site.

Approximately four minutes after the explosion, four DCD firefighting vehicles and two incident command vehicles, were observed being escorted to the Accident site by Airport airside operations.

After the explosion, the fire dynamic changed, and fire spread to the Aircraft interior. Flames and heavy smoke were observed being emitted from the upper fuselage.

The ARFFS watchroom log stated that the Operator's network control was contacted at 0856 to obtain information on the occupants of the Aircraft. As recorded, the watchroom was informed by the Operator there were 275 passengers, 13 cabin crew and 2 pilots (total of 290). These numbers were passed to the fire commander.

At 0903, DCD water tankers had entered the Airport and proceeded to the Accident site. At approximately 0933, the DCD tankers had exhausted their supply of water and they departed the Accident site to be re-filled at the main ARFFS station. The fire commander requested more DCD tankers on several occasions.

At approximately 1022, the ARFFS reported low pressure at the Echo apron hydrants. Several minutes later, the manager of the water network advised that water was not available at that hydrant and recommended the use of three other hydrants at various locations. In the later stages of firefighting, Fire 6, Fire 10, and the two DCD tankers were being filled with water simultaneously from the hydrants located at the main station which caused a lowering of water pressure thus slowing the rate at which the vehicles were filled. Additional fire vehicles from both the ARFFS and DCD maintained a continuous supply of water at the Accident site.

At approximately 1032, the fire commander contacted the watchroom to check with the Operator as to whether there were dangerous goods on board the Aircraft and the watchroom was told by the Operator that there were none. This information was communicated to the fire commander.

With the change in the fire dynamics following the explosion, the fire continued to consume the Aircraft without any significant change in the firefighting tactics.

It was recorded in the ARFFS watchroom log that at 1116 the fire commander confirmed that the entire Aircraft was checked and that there were no passengers or crewmembers left in the Aircraft.



The high ambient temperature (close to 49 degrees centigrade) and a recorded runway surface temperature of 68 degrees centigrade resulted in a number of firefighters suffering heat stress¹⁸. According to a report received from the local ambulance services, in addition to the firefighter who sustained fatal injuries, five firefighters were transported to different medical centers and hospitals due complaints of various levels of body weakness, back pain, chest pain, smoke inhalation, and difficulty in breathing. Two police officers were also transported to hospitals for various complaints of dizziness, difficulty of breathing, and vomiting.

1.15.1.2 Incident command

The fire commander was the first member of the ARFFS to arrive at the Accident site, followed by Fire 6 and Fire 10. When he arrived at the site, the Aircraft doors had not yet been opened.

The fire commander stated during interview that the fire vehicles were positioned according to the vehicle's crew manager decisions, and that positioning was in conformity with the ARFFS training. He added that he divided the command sectors of the Accident site according to the existing circumstances with the aim of simultaneously saving the passengers and fighting the fire. For this purpose, he gave instructions to the ARFFS crew managers on 121.775 MHz to participate in the evacuation. From the interviews of the ARFFS personnel, the Investigation could not identify any clear firefighting tactics that were communicated by the fire commander to the crew managers.

The fire commander stated that there was no direct communication with the cockpit.

The fire commander's initial communication with agencies outside the Accident site was through the watchroom who then conveyed the message to the Airport Joint Control Room (JCR) where representatives of various emergency agencies were located. At the request of the fire commander, the Airport was closed at 0903.

The MICC, commanded by the AIC, arrived at the Accident site about 32 minutes after the crash alarm was activated. In their interviews with the Investigation, several personnel from ARFFS and airport airside operations stated that the MICC was not utilized.

Airport rescue and firefighting was restored to category 10 with single runway operation, 12R/30L, at 1415 after one MFV arrived from Al Maktoum Airport¹⁹, Dubai.

Several hours later, at about 1500, a meeting was conducted in the MICC to assess the site condition and discuss further action. At about 1600, DCD firefighting support ended at the request of the fire commander.

1.15.2 Aircraft evacuation

1.15.2.1 General

During a standard aircraft evacuation with the aircraft supported by its landing gear the distance from the bottom of the exit doors to ground level is between 184 inches (467 cm) for doors L1 and R1, 190 inches (483 cm) at L2 and R2, 205 inches (521 cm) at L4 and R4, and 212 inches (538 cm) for L5 and R5. This corresponds to escape slide slope angles ranging

¹⁸ Heat stress includes a series of conditions where the body is under stress from overheating. Heat-related illnesses include heat cramps, heat exhaustion, heat rash, each with its own symptoms and treatments. Symptoms can range from profuse sweating to dizziness, cessation of sweating, and collapse.

¹⁹ Al Maktoum Airport is located in Dubai at a road distance of approximately 60 kilometers south-west of Dubai International Airport.



between 27 and 35 degrees from the forward to the aft doors. The door height varies with the aircraft weight.

Because the Aircraft was resting on its lower fuselage, the door height above ground level was reduced significantly to between 98 inches (249 cm) and 103 inches (262 cm), from forward to aft. Consequently, the escape slide slope angle for all doors was reduced to approximately 14 degrees.

During the evacuation, the wind direction at ground level varied between 286 and 304 degrees, with the recorded wind speed varying between 11.8 and 15 kt, gusting up to 18 kt.

After the Aircraft came to rest the cabin filled with white smoke, which quickly changed to dark grey, emanating from the center cabin, forming a barrier between the forward and aft sections of the cabin. This left passengers in the aft cabin with two available exits, L5 and R5, for most of the evacuation period. Only one exit (R2 door) was available for the remaining passengers in the forward cabin.

1.15.2.2 Evacuation operation

There were 282 passengers on board the Aircraft, consisting of 215 adults (115 males), 60 children (including one unaccompanied minor), and seven infants. Of the adult passengers, four had required assistance during boarding. Thirteen passengers were seated in business class and 269 in economy class. No passengers were seated in first class.

All of the passenger doors were armed in accordance with the Operator's procedures.

After the Aircraft came to rest, the Commander announced "Attention, crew at stations" via the passenger address system. He commanded "Evacuation" approximately one minute later. The Copilot continued communicating with the Tower from the cockpit for about 50 seconds after the initiation of the evacuation.

The cabin crewmembers stated that when the Aircraft impacted, and as it slid along the runway, some passengers unfastened their seatbelts and left their seats. An announcement was made by cabin crew for passengers to remain seated. When the Aircraft came to rest, some passengers grabbed their belongings and demanded that the cabin crewmembers open the doors. Although passengers were instructed to leave their carry-on baggage behind and evacuate, several passengers evacuated with their carry-on baggage.

The cabin crewmember at the L1 door was unable to fully open the door after it had moved only a few inches. She requested assistance from the senior cabin crewmember and the cabin crewmember from the R1 door. Together, they opened the door and the escape slide deployed automatically, but was affected by wind and then became detached from the Aircraft. The cabin crewmember consequently blocked the L1 door. The escape slide remained inflated on the pavement during the evacuation and firefighting operation.

A cabin crewmember at the R1 door opened the door and the escape slide deployed automatically. During the deployment, the slide was lifted up and blown forward by the wind. The cabin crewmember consequently blocked the exit and redirected passengers to the R2 door. Later, the R1 door escape slide was stabilized on the ground and became available for approximately two minutes for several passengers to evacuate. The slide then deflated and the cabin crewmember blocked the exit. Video of the evacuation showed that the R1 door escape slide had been in contact with a taxiway sign. The slide exhibited marks and tears which had caused it to deflate.

The L2 door required two crewmembers to open. The escape slide deployed automatically but was affected by the wind and was lifted up against the fuselage, preventing its use for evacuation. The assigned cabin crewmember blocked the door.

The R2 door was opened by the assigned cabin crewmember, and the escape slide deployed automatically. There was dense smoke in the area of the door and the cabin crewmember redirected passengers to another door. When the smoke cleared, some passengers and crew evacuated through the R2 door.

The cabin crewmember at the L3 door did not attempt to open the door as there was smoke and dust outside. She blocked the door and redirected passengers to the R2 door.

The cabin crewmember at the R3 door opened the door, but the slide ramp did not deploy. When the cabin crewmember noticed fire outside, she closed the door with the assistance of two passengers. She blocked the exit and redirected passengers to the aft cabin. A post-Accident inspection of the slide ramp, and video of the evacuation, indicated that the slide ramp remained stowed with the panel closed. There were no signs of fire damage to the door during the evacuation, however the door was completely consumed by the post-Accident fire, preventing further examination. The lower half of the slide ramp pressure cylinder was found on the runway.

A cabin crewmember opened the L4 door and the escape slide deployed automatically. During the deployment, the slide was immediately lifted up against the fuselage by the wind, which resulted in the cabin crewmember blocking the exit.

The cabin crewmember at the R4 door stated that she did not hear the 'evacuation' command because of the noise caused by panicking passengers. She opened the door after she observed the L4 door cabin crewmember opening her door. Several passengers evacuated from the R4 door, but evacuation using this escape slide was affected when the slide bowed. In addition to the passengers, R4 escape slide was filled with extinguishing agent. The evacuation from this door was interrupted for approximately 40 seconds. The cabin crewmember redirected the remaining passengers to the R5 exit. A cabin crewmember jumped onto the R4 escape slide to assist the passengers to egress. This cabin crewmember then climbed back along the escape slide into the Aircraft to continue the passenger evacuation from inside the cabin.

The cabin crewmember assigned to the L5 door opened the door, and the escape slide automatically deployed. A number of passengers evacuated through this exit, but when passengers left the slide, it became wind affected and was lifted against the fuselage, preventing its further use.

The cabin crewmember at the R5 door opened the door, and the escape slide automatically deployed, however, the wind lifted and twisted the escape slide immediately. Passengers were redirected to the L5 door while this exit was still available. A firefighter later stabilized the R5 slide and secured it for evacuation.

All of the cabin crewmembers in the aft cabin evacuated via the R5 exit, approximately 25 seconds after the last passenger had been evacuated.

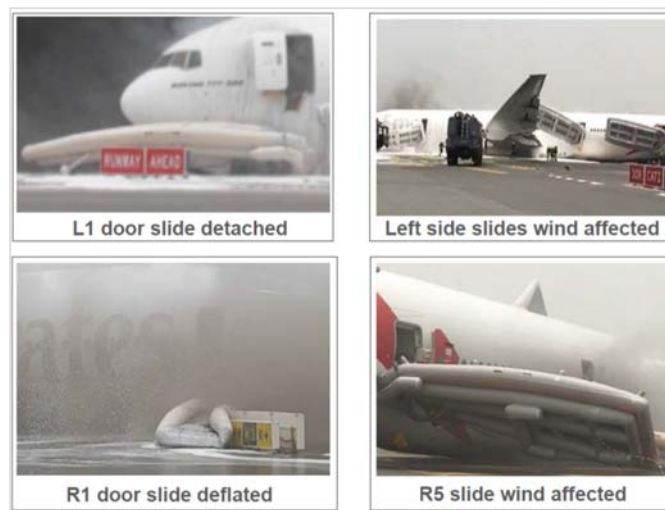


Figure 18. Door escape slides after deployment

Figure 18 illustrates the condition of the some of the door escape slides during the evacuation.

As stated to the Investigation, the Commander and the senior cabin crewmember remained in the Aircraft, donned protective breathing equipment and commenced a search for any remaining passengers. They were concerned about a girl who became separated from her family during the evacuation. As the smoke in the center cabin became denser, the Commander and the senior cabin crewmember were forced to abandon their search and returned to the forward cabin. After the explosion of the center wing fuel tank, a wall of smoke entered the cabin, forcing both to move the cockpit.

They attempted to evacuate through the evacuation windows, but were unable to locate the evacuation ropes above the windows because of the smoke. They decided to return to the cabin, jumped from the nearest exit, L1 door, and landed on the detached slide lying on the ground.

Except for the Commander and the senior cabin crewmember who evacuated after the center wing tank explosion, all of the other occupants evacuated via the operational escape slides in approximately 6 minutes 40 seconds.

Figure 19 shows an approximate timeline illustrating the availability of the emergency exits during the evacuation.

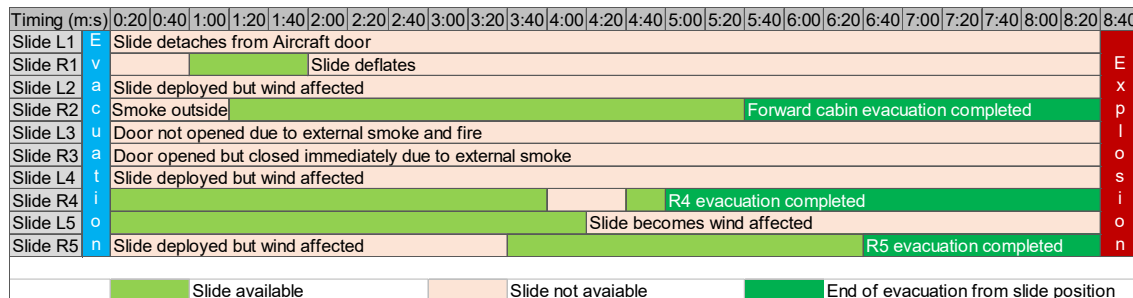


Figure 19. Timeline for emergency exit availability during evacuation

1.15.2.3 Evacuation questionnaire²⁰

Voluntary safety questionnaires were developed to collect data about the evacuation operation. Of 137 passenger questionnaires distributed, 54 were returned, providing information from 139 passengers. The passenger response ratio (49 percent) was considered by the Investigation as a good overall representation of the events as they affected the passengers on board. All of the cabin crewmembers responded.

The questionnaires were supported by a cabin layout, which illustrated the emergency exits by their description. The questions covered the passenger's seat location, cabin condition, passenger description of the Accident, the evacuation, passenger behavior, signs of smoke or fire, emergency support, and any injuries sustained.

Of the 54 passenger respondents, 24 stated that they and their companions retrieved and brought their personal belongings with them during the evacuation. The personal items ranged from passport bags to one or more carry-on bags.

²⁰ The investigation developed a passenger questionnaire to acquire first-hand accounts of passenger behavior during the evacuation of the Aircraft. The content of the questionnaire was aligned to questions suggested by ICAO *Document 9756 – Manual of Aircraft Accident and Incident Investigation*.

Videos provided by the respondents assisted the Investigation in determining a timeline of key events during the evacuation and the subsequent firefighting operation. The questionnaire response data revealed that:

- Only the Commander and the senior cabin crewmember evacuated from the L1 door.
- Three passengers and one cabin crewmember evacuated from the R1 door.
- Seven passengers and nine cabin crewmembers evacuated from the R2 door.
- Sixty-seven passengers (44 percent of the respondents) evacuated from the R4 door.
- Forty-two passengers (27 percent of the respondents) evacuated from the L5 door.
- Seventeen passengers and six cabin crewmembers (15 percent of the respondents) evacuated from the R5 door.
- 69 percent of the passengers evacuated using the right side exits, which was the side of the firefighting operation.
- 31 percent of the passengers evacuated in a direction away from the smoke and towards the direction of the wind.
- At the end of the evacuation, except for the senior cabin crewmember, all of the cabin crewmembers evacuated from the right side doors.
- 86 percent of all occupants evacuated through the three exits R4, R5 and L5.

Figure 20 shows the seat locations and exits used. Passengers who did not respond to the questionnaire are represented by grey dots.

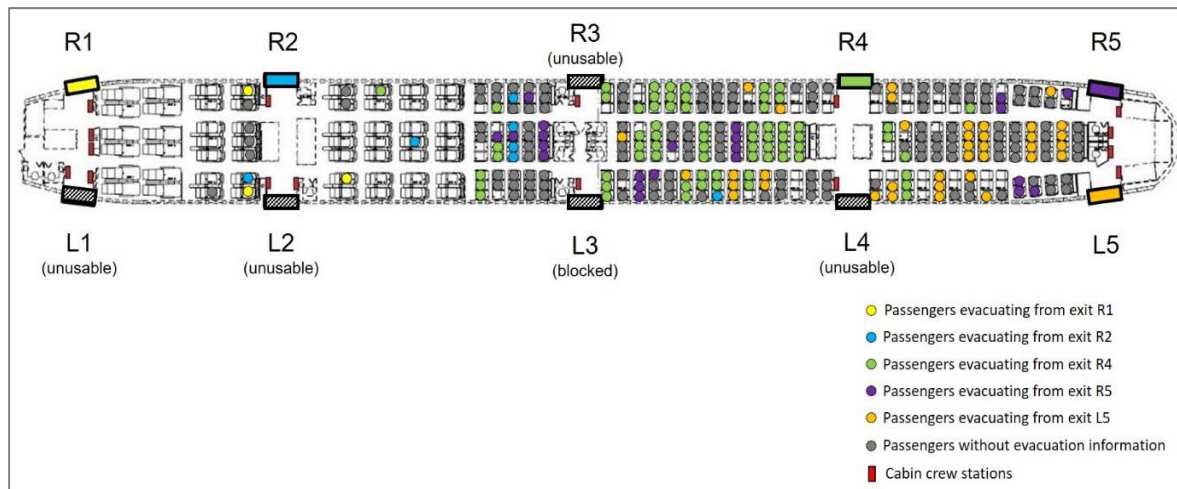


Figure 20. Passenger seating allocation and emergency exit status

One passenger, seated next to the right side over-wing exit (R3), stated that he was directed to the front of the cabin to evacuate from one of the forward exits, but he was then directed back because the forward exits were blocked. This passenger passed through dense smoke in the center cabin on his way to exit from the R4 door.

One passenger, seated forward of the L2 door, was directed to the L1 door for evacuation. When she arrived at the L1 exit, she found it blocked. She returned to evacuate from the L2 door but that exit was also blocked. This passenger evacuated from the R1 exit.



A passenger next to her initially went to the L1 exit, then to the L2 exit, and he evacuated from the R2 exit, where he saw less passengers evacuating than at the R1 door.

A passenger, seated forward of the R3 door, was directed to exit from the R2 door, but when he reached the door, it was already blocked. The center cabin was filled with dense smoke that limited his visibility. He identified daylight coming from the aft cabin, where he evacuated from the R5 door, with the assistance of a cabin crewmember.

A family, seated in the forward economy class section of the cabin, left their seats to evacuate from the R2 door, but when they realized that their 7-year daughter was not with them, they decided to turn back. This obstructed other passengers' evacuation until a cabin crewmember persuaded the family that the crew would take care of their daughter. The family evacuated from the R2 door. The daughter exited the Aircraft from the R5 door.

A passenger standing in the left aisle of the aft cabin was emotionally overcome by the Accident and was unable to move causing an obstruction for other passengers who were intending to evacuate from the L5 door. By the time a cabin crewmember was able to assist the passenger towards the L5 door, the escape slide had been lifted by the wind and blocked the exit. The distressed passenger was directed to the R5 door and evacuated with the remaining passengers.

1.15.2.4 Crew communication

The cabin crewmembers stated that they communicated with passengers and other cabin crew during the evacuation verbally and did not use megaphones.

The noise level in the cabin hindered communication among the crewmembers and between them and the passengers. Cabin crewmembers who were not assigned to door positions assisted in the evacuation by updating other crewmembers with information and by redirecting passengers.

When the center cabin had filled with dense smoke, communication between the cabin crewmembers was then restricted to the exits near their current location.

At the end of the evacuation, the cabin crewmember at the L1 door used a megaphone to advise the remaining cabin crewmembers to evacuate.

1.15.2.5 Protective breathing equipment (PBE)

Three cabin crewmembers and the Commander donned PBE and commenced a cabin search for passengers.

Six cabin crewmembers reported that they had difficulty in opening the PBE container, or the plastic pouch. The crewmembers had problems in sliding the metal latch of the container lid, and also in tearing open the plastic pouch. During the firefighting, after the impact, firefighting extinguishing agent from outside the Aircraft entered the cabin covering the cabin interior added to the difficulties.

The PBE manufacturer informed the Investigation that there had been no reports of difficulties in using the PBE in normal conditions. The manufacturer agreed with the crewmembers' statements, that wet conditions could make it more difficult to maintain a good grip of the plastic pouch and tear strips.

1.15.3 Passenger evacuation management

Passengers evacuated from the Aircraft on both sides, but mainly through the aft doors. The ARFFS had already commenced firefighting on the right side aft of the wing (near the R4 door) employing two MFVs. Evacuated passengers had to find a passage between the MFVs and the sideline firefighters in order to exit the Accident site. Passengers were observed assembled in two groups on both sides of the Aircraft.



While it was observed that at some point, passengers were guided away from the Aircraft after evacuating using the left aft door (L5), firefighters on the right side of the Aircraft were pre-occupied with removing passengers from the escape slides. Prior to the explosion of the center wing tank, it was observed that an effective passenger evacuation management system (PEMS) was not being implemented to secure a safe passage for passengers evacuating from the right side doors. Several passengers remained near the Accident site to take photographs and record video, and some were observed without shoes. At that time, the assembly area had not yet been determined. This caused a constant flow of passengers to walk across the closed runway 12L/30R and taxiway November.

Several passengers had already assembled close to a maintenance hangar G, belonging to the Aircraft Operator, located approximately 580 m from the Aircraft. This hangar became the triage and assembly area.

Medical support was provided to the passengers by the local health authority, and passengers who exhibited signs of heat stress and exhaustion were checked by the medical team and given medical aid. Passengers who suffered from various levels of severity of chest, head, neck, leg pain, heat exhaustion, smoke inhalation, difficulty in breathing, and hypertension, were transported to hospitals for further medical care.

After spending about 45 minutes at the assembly area, the passengers were transported to the survivors' reception center (SRC).

1.16 Tests and Research

1.16.1 Aircraft electronic components

Several Aircraft systems electronic components were shipped to the original equipment manufacturers for detailed examination. These included components of systems responsible for autoflight, weather radar, EGPWS and engine thrust management.

The components which were examined included: the engine electronic controllers, electronic units from the autopilot flight director system, the predictive weather radar units, the EGPWS units, electronic cards from the Aircraft information management system, and the proximity sensing electronic units.

The thrust lever assembly and the TO/GA switches, could not be tested as they were consumed by fire.

The examination reports for the weather radar and EGPWS indicated that these systems were functioning correctly up to the time of the Accident and were capable of providing predictive and immediate windshear warnings to the flight crew.

The following is a summary of the report provided by the manufacturer of the weather radar:

- The system functions by measuring the time between transmitting and receiving energy which is reflected by moisture. For UAE521, the wind conditions that existed had no reported or perceptible moisture in the air for reflectivity and the presence of dust in the air is typically insufficient for detection.
- UAE521 FDR data recorded wind conditions that would not have caused the predictive windshear to provide a caution or alert.



- RTCA DO-220 document²¹ describes the predictive windshear alert system and the “performance degrading” conditions required for the system to provide caution and alert messages. In a “performance degrading” condition, a downward movement of air results in the aircraft first arriving at a headwind, passing through the vertical air column and then through a tailwind. The wind conditions recorded by the UAE521 FDR were inverse, in which the aircraft encountered a tailwind, followed by a headwind.

As designed, the EGPWS manufacturer stated that the EGPWS issued one advisory message, ‘long landing’, and one warning, ‘don’t sink’, during the Accident sequence. The EGPWS did not detect a windshear condition.

The Investigation reviewed the examination reports and did not find any evidence of any component or system malfunctions.

1.16.2 Aircraft Performance Evaluation

The Aircraft manufacturer was requested to conduct an aircraft performance analysis that was presented to the Investigation as a *Performance Evaluation*²².

Additionally, the evaluation determined whether the Aircraft could have safely continued the landing in the remaining available runway length, and at what point, after the initiation of the go-around, could the thrust levers be advanced to enable a safe go-around to be flown.

1.16.2.1 Possibility of successful landing in the remaining available runway length

The evaluation calculations considered the Aircraft configuration and dry runway surface to determine whether sufficient runway length remained after both main landing gear were on-ground, which was three seconds after the initial touchdown. This was one second before the Commander called for a ‘go-around’ and prior to the ‘long landing’ automated cockpit annunciation. The Aircraft ground speed was 161 kt when both main gear were on ground.

The evaluation showed that, to remain within the LDA (3,600 m) of runway 12L, an autobrake level of at least ‘3’, or application of maximum manual braking, with or without the use of reverse thrust, would have been required. If autobrake level ‘2’ was selected, additional application of manual brake would have the effect of reducing the stopping distance to stay within the LDA. For UAE521 flight, of the four selectable autobrake levels, the flight crew had selected level ‘3’ for the landing.

Table 8 gives the *Performance Evaluation* stopping distances from the runway threshold.

²¹ Radio Technical Commission for Aeronautics (RTCA) DO-220 document is titled *Minimum Operational Performance Standards for Airborne Radar Systems*.

²² Boeing *Performance Evaluation* reference 66-ZB-H200-ASI-19004 issued on 7 September 2017. For this evaluation, Boeing used the same simulation model of aircraft certification and flight crew training.



Table 8. Performance Evaluation stopping distance from threshold [source: Boeing]

Distance from runway threshold (m)		Autobrake level				Manual braking
		2	3	4	MAX	MAX
Reverse thrust setting	None	3,765	3,417	2,991	2,564	2,146
	Maximum	3,652	3,414	2,991	2,564	2,096

1.16.2.2 Go-around initiated after touchdown

The *Performance Evaluation* used the Aircraft FDR data in order to determine the last point in time when the thrust levers could have been advanced to perform a successful go-around.

The evaluation showed that maintaining the same pitch attitude as the Accident flight, eight seconds after the Commander called for a 'go-around', pushing the TO/GA switch at 13,385 seconds FDR time, which corresponds to the time that the landing gear lever was moved to 'up', the Aircraft could have achieved a positive rate of climb as the engine thrust increased. After the TO/GA switch push, the A/T would have moved the thrust levers with a maximum rate of 10.5 degrees per second, to achieve an EPR of 1.414 in approximately eight seconds. During this time, the Aircraft would have descended and the minimum radio altitude reached by the Aircraft to safely fly away in the hypothetical scenario was 17 ft. Figure 21 illustrates the calculated simulation²³.

For UAE521, the actual thrust lever increase, which was a manual advancement by the Commander at 13,392 seconds FDR time, was performed fifteen seconds after the Commander called for a 'go-around'.

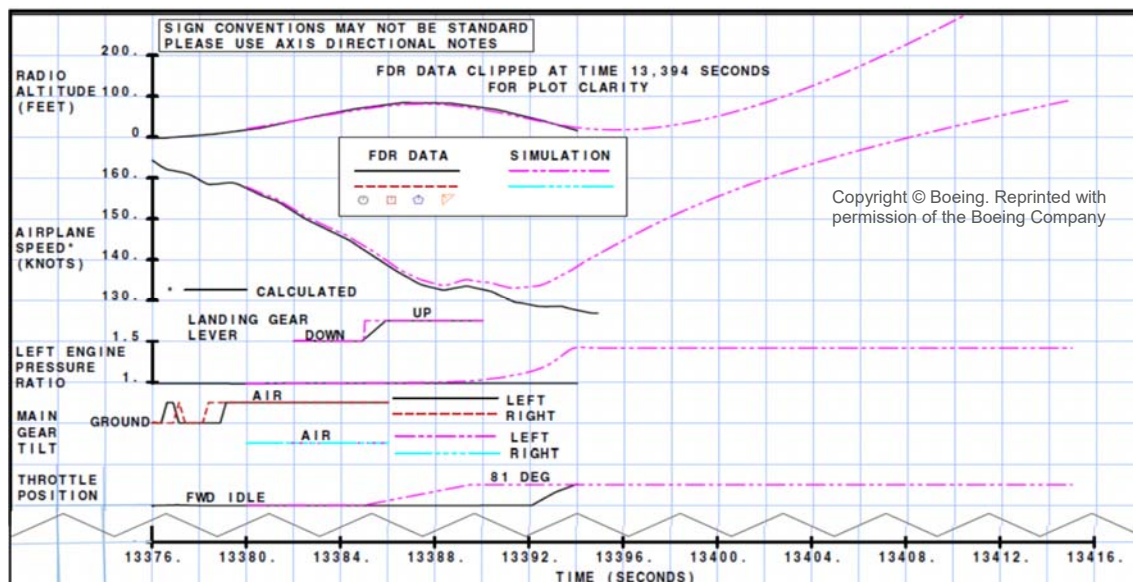


Figure 21. Calculated go-around after TO/GA switch push [source: Boeing]

²³ THROTTLE POSITION in figure 21 refers to thrust lever position.

1.16.3 L1 cabin crew seat examination

The L1 cabin crew seat parts recovered from the Aircraft were sent to the NTSB materials laboratory in Washington, DC, the United States. The examination found that the left seat pan lever was twisted outwards at the attachment location of the seat pan lever stop and lower back pivot. The left lower back pivot stop bolt (figure 22), attached to this lever, was found bent. The lower back pivot stop bolt hole (figure 23) of the right seat pan lever was found elongated with a plastic deformation of base material.



Figure 22. L1 cabin crew seat pan and left lever distortion [Source: NTSB]

From these findings, the Investigation concluded that the right lower back pivot stop bolt, most likely, fractured due to a force generated by the Aircraft impact. This caused the right seat pan base to be released, and the left lower back pivot stop to be extracted from its position, completely folding the seat base down.

Because the weight of the cabin crewmember was similar to that used for certification conformity test²⁴, the impact force most likely exceeded the cabin crew seat design limitations with its certified static 6g downward force, and 14g canted at 30 degrees dynamic downward force.



Figure 23. L1 cabin crew seat pan hole elongated [Source: NTSB]

²⁴ In certification conformity test, cabin crew seats are dynamically tested with 77.1 kg anthropomorphic test dummies to replicate an average occupant.



1.16.4 L1 door escape slide examination

The L1 door escape slide was located on the ground forward of the L1 exit, and the upper girt panel was found connected to the girtbar. These parts were sent to the slide manufacturer²⁵ for examination.

The examination found that the upper girt panel was peeled from the slide assembly along the bond line. The adhesive bond between both surfaces had separated with fabric coating transfer present on both sides of the bond line, indicating an appropriate bond at the time. The lower girt panel was torn away along the girt sleeve at the girt bar. Girt fabric fibers were more prominently displayed on the aft side of the tear-line, indicating that the tearing started at the aft end of the slide to girt bar attachment.

The inspection of the slide packboard revealed damage to the slide release mechanism similar to damage observed on slide release mechanisms of a previous B777 accident²⁶. As part of that investigation, dynamic testing of the release mechanism was conducted by the National Transportation Safety Board (NTSB) of the United States in an effort to duplicate the force required to cause a slide packboard mechanism failure. The failure was successfully duplicated with downward forces in excess of 13g, which is well beyond the certification requirements.

1.17 Organizational and Management Information

1.17.1 The Operator

Emirates was established in 1985, and was issued an air operator certificate (AOC) by the GCAA.

At the time of the Accident, the Operator's fleet consisted of 252 aircraft comprising Airbus A380, A330, A340, and Boeing 777 variants.

The 169 aircraft of the B777 fleet comprised of passenger and freighter versions. The -200ER variants was fitted with Rolls-Royce (RR) Trent 892 engines, -200LR with General Electric (GE) GE90-110B engines, -200 Freighter with GE90-110B engines, -300 with RR Trent 892 engines, -300ER with GE90-115BL engines; and -300ER/ULR with GE90-115BL engines.

In 2016, the Operator had 3,868 flight deck crew which consisted of predominantly expatriate pilots of mixed nationalities. Between 2014 and 2016, the number of pilots increased by 363. During this two-year period, the Operator's fleet of B777 aircraft increased by 25 aircraft²⁷.

Within the organizational structure, flight operations, flight operations quality, flight training, flight training facilities, crew operations and contingency planning, ground operations, engineering and aircraft continuing airworthiness and quality assurance, were under the responsibility of the Chief Operations Officer (COO), who was the delegated Accountable Manager.

The post holder of the Group Safety and safety management system (SMS) department reported directly to the Accountable Manager. Flight Safety was a unit within this department.

²⁵ The examination took part in presence of the Accredited Representative of the United States, an Evacuation Systems Engineer from the Boeing Company, and two members from the slide manufacturer (Air Cruisers Company).

²⁶ National Transportation Safety Board (NTSB) of the United States *Final Accident Report - NTSB/AAR-14/01*.

²⁷ Reference was made to Emirates *Annual Reports 2014-2015 and 2015-2016*.



The Operator's SMS is based on a system of data collection through various channels, which include written reports, recorded data and links from the Training and Audit departments. The data is shared and analysed at internal meetings, which include the Management Safety Review Board (MSRC), the Safety Action Group (SAG) weekly meetings and the Flight Data Review Committee (FDRC) meetings, where follow-up actions are decided.

According to the Operator's internal procedures, the Flight Training, Flight Operations, and Flight Safety departments were required to share their data and information. Any identified 'potential' or 'critical' events, that may require immediate training remedial action, were also to be shared.

1.17.1.1 The *operations manual*

The B777 *FCOM* and *FCTM* were provided to the Operator by the Aircraft manufacturer and included operating limitations, procedures, performance, and systems information. As part of the *FCOM*, the *quick reference handbook (QRH)* listed normal and non-normal procedures in a checklist format. Information and recommendations on maneuvers and techniques were stated in the *FCTM*.

The *operations manual (OM)* was issued by the Operator, and distributed to all operations personnel. The *OM* consisted of six parts: *OM-A*²⁸ was related to flight crew procedures; *OM-B* was an aircraft-related manual that included the *FCOM*, *QRH*, *configuration deviation list (CDL)*, *minimum equipment list (MEL)*, and *flight crew bulletins*; *OM-C* consisted of route and aerodrome instructions including a *LIDO route manual*; *OM-D* consisted of training policies for flight and cabin crew; *OM-E* consisted of emergency procedures for the different aircraft types; and the ground *operations manual (GOM)*. All manuals were developed as per the requirements of Part *OPS-1* of the *Civil Aviation Regulations*.

The Operator's guidance material as stated in the *OM-A – Reporting Procedures*, for reporting a safety issue and events, by use of an air safety report (ASR), is based on the International Air Transport Association (IATA) Threat and Error management structure. Under *OM-A – Latent Conditions* chapter, an ASR reportable event included deficient or absent SOP and operational policies; omitted training; and deficiencies in assessment of training or training resources such as manuals or computer based training (CBT) devices.

All ASRs submitted by pilots were to be assessed by the Group Safety department. This included all go-arounds executed below 1000 ft. After review of the ASR, Group Safety determines which ASR was required to be reported to the GCAA based on the guidelines for reporting of safety incident (ROSI) documented in the GCAA *Civil Aviation Advisory Publication (CAAP) 22 – Incident Reporting*.

Network control was responsible for flight operations related to *Crew Operations and Contingency Planning* and reported directly to the COO. Responsibilities included activation of the Operator's *contingency response plan* in case of an aircraft accident or serious incident. The procedures were described in the *Contingency Response Planning Manual*.

1.17.1.2 Flight crew training.

The Operator's Flight Training department was a training organization that conducted conversion training as specified in the *Approved Training Organization (ATO) manual*. The *ATO manual* was issued in accordance with the organization requirements for aircrew in the *Civil Aviation Regulations CAR-ORA*. The *ATO manual* complied with the *Flight*

²⁸ The *OM-A* in effect was revision 12 dated 21 July 2016.



Crew Licensing Regulations, CAR-FCL and with the terms of the Air Operator's Certificate. The *ATO Manual* is considered to be an annex of the *OM-D*.

According to the Operator's organizational structure, the Senior Vice President Flight Training (SVP-FT), who was the Operator's training post holder, was assisted by a standards training manager, respective training managers for the Airbus and Boeing fleets, a human factors manager, and a regulatory and compliance office. The flight training post holder was responsible for establishing the syllabus and detailed structure of each training course, and continuous compliance.

The standards training manager responsibilities included updating of the *OM-D*, and reviewing the evaluator's assessments of pilots who did not meet the Operator's 'adequate' performance requirements.

The training managers were responsible for the initial and ongoing qualification of the flight crew in accordance with the Operator and regulatory requirements.

In addition to audit functions, the regulatory and compliance officer was also responsible for assuring that all flight training manuals complied with the *Civil Aviation Regulations* and the Operator's policies. The officer was required to report to the standards training manager any identified discrepancies between the manuals and standards.

Every six months, a Training Review Committee (TRC) reviewed the performance of the training system. The Committee comprised representatives from Operations, Training, Flight Safety and Audit. The GCAA principal flight operations inspector also attended the TRC meetings. As stated in the *OM-D*, the Committee was responsible to "Review trends and feedback from the outputs of the training and assessment systems. The committee's prime responsibility is to identify any critical events that may require immediate training intervention, and address training system issues and improvements related to trend analysis of training system output and audit activities. The Operator stated that the TRC was not responsible to identify aircraft system related threats.

According to *OM-D* section *Performance Review Board (PRB)*, the board was responsible for reviewing inadequate pilot performance including failure of a skills test, recurrent line proficiency check, OPC, line check, other training syllabus check events, or unacceptable progress in training as recorded in the Online grading system (OGS) forms.

At the time of the Accident, the Operator was converting from the principles of the alternative training and qualification program (ATQP) to evidence-based training (EBT) as recommended by ICAO *Doc 9995 - Manual of Evidence-based Training*.

The Operator provided the GCAA with *ATQP annual reports* comprising the recurrent phase cycle of the 3-yearly ATQP recurrent training and checking program. The objective of the report was to indicate to the GCAA the continued validity of the ATQP safety case by statistical analysis of collated performance data and the integrity of the feedback loop.

Three ATQP reports, 2013 to 2015, was provided to the Investigation. As stated in the ATQP reports, the Operator had identified that a number of inaccurately executed all-engines-operating go-around events had been highlighted by the FDM data. Action taken by the Operator was to keep this as a training item in subsequent recurrent phases and during manual handling simulator sessions.

The Operator stated that all engine go-around training has been included in every recurrent phase since 2009 because this maneuver was being poorly flown. The Operator also identified that the training trend for the pilot assessment marker (PAM) average was around '4', with application of procedures (P) the lowest of the nine PAMs.

The Operator's training program did not identify any threats associated with the TO/GA switches inhibit logic and therefore, no specific procedure or training was implemented



to address the non-availability of the A/T during a normal go-around maneuver that is initiated after the TO/GA switches become inhibited. The Operator stated that “the non-availability of the autothrust [autothrottle] for a go-around after touchdown was trained in Manual Handling session phase 2”.

1.17.1.3 Training records and checking forms

The Operator’s *ATO manual* stated that flight training records on pilot performance during training and assessment were to be entered on the electronic OGS forms. The OGS consisted of two selectable training and examining forms. Both forms were required to be completed by the evaluators following a simulator or aircraft flight check.

Pilot performance was graded based on a scale established to a standardized assessment. The grade was based on a scale of five performance levels. Grades 3, 4 and 5 were considered ‘acceptable’ which indicated that the pilot achieved a consistent completion standard while retaining an adequate margin of safety. Grades 1 or 2 indicated that the performance did not meet the required standard, which would require the fleet training manager to determine the required remedial actions.

Within the OGS, pilot performance was measured based on a PAM system which comprised nine discrete markers. The PAM covers both technical and non-technical competencies.

The five non-technical skills of the PAM included workload management, communication, problem solving/decision-making, situational awareness, and leadership/teamwork/support. The four technical skills included knowledge, application of procedures, handling, and use of auto-flight. Each skill was graded according to the 5-scale performance level. Procedures for grading were provided in the Operator’s *B777 training manual* and evaluators were required to make comments for grades 1, 2 and 5. However, the *OM-D* stated that additional comments were encouraged irrespective of the grade awarded.

The Operator stated that pilots who are graded 1 or 2, or were required to repeat a section of the training, irrespective of the final competency grade, were automatically highlighted to training management for review. For pilots who were graded as ‘acceptable’, the Operator did not have a policy to review and assess the evaluator comments posted on the OGS forms, or to determine if any follow-up was required.

As per the *OM-D*, the evaluator was required to complete an OGS form after each manual handling simulator training session. However, there was no requirement to grade the session except when the pilot’s performance was considered to be not acceptable by the evaluator.

1.17.1.4 Crew resource management (CRM) training

The *Civil Aviation Regulations, CAR-OPS 1.943 (AC OPS 1.943) – Crew Resource Management (CRM)*, states:

“Crew Resource Management (CRM) is the effective utilisation of all available resources (e.g. crewmembers, aeroplane systems, supporting facilities and persons) to achieve safe and efficient operation.”

The flight crew CRM training was conducted according to the Operator’s *crew resource management manual*. This manual was available to all crewmembers.

Pilots were required to attend an initial 2-day CRM course and a 1-day recurrent course. In addition, a half-day type conversion CRM course was delivered for new joiners or pilots changing type, where the main topic discussed was the automation of the type (B777 or A380).



Both the Commander and the Copilot had completed initial and recurrent CRM training which contained the following elements:

- “ Pilot monitoring duties, which was complemented with dedicated video examples;
- Problem solving and decision-making, with focus on different modes of decision-making;
- Communication module, with specific focus on communication threats;
- Module on ATC, with focus on ATC distractions, which was initiated by showing a short video;
- ATC/pilot communication along with the results of the NASA lead research indicating that more than 4 pieces of information has the greater possibility of errors;
- The Aviate – Navigate – Communicate concept.”

The material discussed during CRM training for pilots in the monitoring role included the concept of ‘ask, suggest, direct, and take over’. The pilot monitoring is encouraged to use the trigger word ‘uncomfortable’ at any time to clearly express concern regarding the actual or future aircraft state. The discussion also included either pilot asking ‘why’ especially when the mental model of the future aircraft state is not shared completely between the pilots. The pilot monitoring is encouraged to provide the pilot flying with clear guidance.

In order to counter the threat of aircraft automation, the Operator’s *CRM manual* stated:

“A lack of, or subtle, feedback results in a reduction of situational awareness. The Emirates’ procedure of calling FMA changes is designed to counter this threat.”

The CRM subject matter experts were required to review cases of pilots who had not met the acceptable standard set by the Operator.

1.17.1.5 B777 type training

As per the *OM-D*, the Operator was approved by the GCAA to use a training manual specific to the B777, which contained detailed syllabi and further information regarding the content and conduct of the B777 training courses. Specific training topics in the manual referred to the *operation manual*, *FCOM*, *QRH*, *FCTM* and *LIDO* plates. Pilots were required to self-study these manuals. The Operator’s *B777 training manual* was an annex to the *OM-D*.

The B777 type rating course was based on the Aircraft manufacturer’s type rating course and the standards contained in the *operational suitability data (OSD)*²⁹. The Operator stated that the minimum training requirements for the B777 variants are contained in the operator differences requirements (ODR) published in either the FAA *Flight Standardization Report (FSB)*, the OSD or the original Joint Operational Evaluation Board (JOEB) requirements.

The Operator developed a *flight training course footprint manual* specific to the B777. The *manual* contained detailed guidance on how the requirements, established in the *OM-D* and the *B777 training manual*, were implemented and managed. The Operator’s training program for the B777 was based on the Aircraft manufacturer and FAA approved training program, which did not include the TO/GA inhibition logic.

²⁹ The Operational Suitability Data (OSD) is issued by the European Union Aviation Safety Agency (EASA) that requires aircraft manufacturers to establish certain data that is considered important for safe operation of the aircraft type. This data is approved by EASA under the aircraft type certificate and used by operators and training organizations.



The Operator's B777 course was based on the -300 series variant powered by Rolls-Royce Trent 800 engines. The *OM-D* states that the B777-200/200ER//200LR/200F and B777-300ER are considered variants of the B777-300 and are a single license endorsement, and a description of the familiarization training required is detailed in the applicable type specific training manual.

Both the Commander and the Copilot had attended the initial CBT for the B777. The CBT did not cover TO/GA switch inhibiting, or FMA changes resulting from a go-around initiated after the TO/GA switches became inhibited.

1.17.1.6 Flare

During the manual landing, the *FCTM – Flare and Touchdown*, states that after the aircraft nose passes the threshold, the pilot is recommended to change his visual sighting point to the far end of the runway in order to control the pitch attitude during the flare. The *FCTM* recommends initiation of the flare when the main gear is approximately 20 to 30 ft above the runway by increasing the pitch angle approximately 2 to 3 degrees in order to slow the rate of descent.

For airspeed control, the *FCTM states* that when the A/T is engaged and active, the thrust levers are automatically retarded to idle at 25 ft radio altitude and the 5 kt addition to V_{REF} will be bled off and the engine thrust will reach idle power at touchdown.

The *FCTM* stated that small pitch adjustments will be required in order to maintain the desired descent rate after flare initiation and to hold sufficient back pressure on the control column to keep the pitch attitude constant.

Pilots are trained that, ideally, and at an airspeed of approximately V_{REF} , the main landing gear will touch down simultaneously with the thrust levers reach idle. The *FCTM* stated that touchdown should occur at no less than V_{REF30} minus 5 kt.

For the landing flare profile, the *FCTM – Landing Flare Profile*, mentioned that typical landing flare distance is between 1,000 ft (305 m) and 2,000 ft (610 m) beyond the threshold and lasts from 4 to 8 seconds (depending on the approach speed) until touchdown (threshold to touchdown in figure 24).

For the touchdown body attitude (pitch angle), the *FCTM* recommended that the body attitude should be reduced by 1 degree for each 5 kt above the approach speed (V_{APP}) and the touchdown speed ($V_{REF30} + 0$). Based on the *FCTM – Touchdown Body Attitude*, for UAE521 landing weight, the body attitude at V_{REF30} (147 kt) would have been approximately 3.8 degrees.

The *FCTM – Factors Affecting Landing Distance*, states that landing distance is increased before touchdown due to:

- floating above the runway before touchdown;
- height of the aircraft over the threshold. For example, on a 3 degrees glide path, passing over the runway threshold at 100 feet altitude rather than 50 feet could increase the total landing distance by approximately 950 feet;
- flatter approach glide path angle.

The *FCTM* stated that "If the flare is too abrupt and thrust is excessive near touchdown, the airplane tends to float in ground effect. Do not allow the airplane to float or attempt to hold it off. Fly the airplane onto the runway at the desired touchdown point and at the desired airspeed."

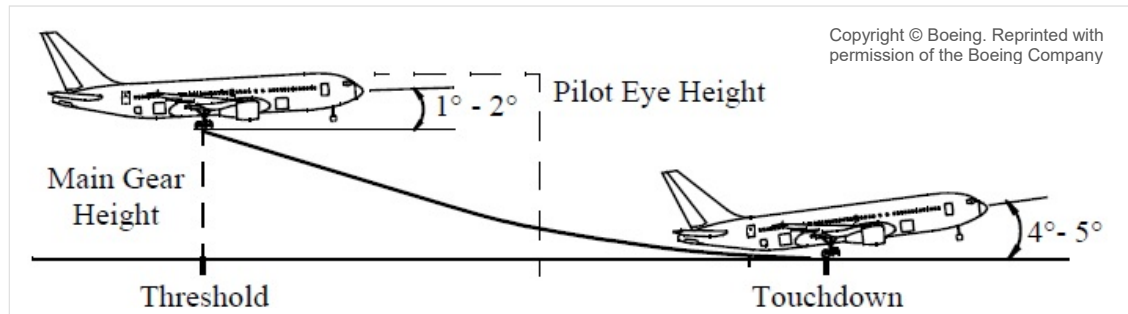


Figure 24. Threshold height and touchdown [source: FCTM]

The FCOM described in the *Landing Roll Procedure*, that the pilot flying verifies that the speedbrake is in the 'up' position, and that the pilot monitoring verifies this by calling "Speedbrake up". Other than the speedbrake handle deployment, the B777 systems do not indicate that the aircraft has touched down and has changed from 'air' to 'ground' mode.

1.17.1.7 Go-around procedures

The FCOM, the FCTM and the Operator's B777 training manual, were the references used by the Operator for go-around training and procedures. The QRH contained additional go-around checklist items for non-normal conditions. Examples of non-normal conditions included go-arounds for single engine, airspeed unreliable, fuel quantity low, hydraulic system inoperative, and jammed flight control.

The OM-A considers an approach to be stabilized when all briefings and checklists are completed, the aircraft is configured for landing and is on the correct flight path, airspeed is not more than final approach speed (V_{APP}) plus 10 kt and not less than V_{REF} , and the power is set appropriately for the aircraft configuration. The FCTM states that a stabilized approach concept is to maintain a stable speed, descent rate, and vertical/lateral flight path in landing configuration, and for pilots to announce any significant deviation.

The policy of the Operator for aircraft touchdown was stated in OM-A – *Touchdown* section. Pilots were required to land on the touchdown zone markings (TDZ) and touchdown should be at 1,000 ft, or 300 m, from the threshold if TDZ markings are not available. If touchdown cannot be accomplished within the desired touchdown zone, a go-around should be considered. During touchdown, the OM-A states that for a valid 'long landing' annunciation, the pilot monitoring shall announce 'go around', which shall be immediately initiated by the pilot flying.

OM-A – *Missed Approach* section states that the decision to initiate a go-around and conduct a missed approach shall be clearly announced by the pilot flying in accordance with standard operating procedures and that this decision is irrevocable.

In case of a missed approach, OM-A *Missed Approach* flight procedures requires that the pilots shall advise ATC as soon as practicable. There was no guidance in the OM-A on what should be reported to ATC in the case of a go-around.

Under the title *Automatic Flight – Go-Around*, the FCOM stated that "Pushing either TO/GA switch activates a go-around. The mode remains active even if the airplane touches down while executing the go-around." In addition, the FCOM stated that "The TO/GA switches are inhibited when on the ground and enabled again when in the air for a go-around or touch and go." The FCOM normal *Go-Around and Missed Approach Procedure* described the actions and callouts required by the pilot flying and pilot monitoring. The Operator stated that this is the procedure followed for all go-arounds.



According to the *FCOM – Go-Around and Missed Approach Procedure* (Appendix B to this Report), a normal go-around is initiated by the pilot flying pushing the TO/GA switch. The pilot flying then calls for ‘flaps 20’, and the pilot monitoring positions the flap selector lever to ‘20’. Both pilots then verify rotation to go-around attitude and that engine thrust increases. The pilot monitoring will verify that the thrust is sufficient for go-around and will adjust as necessary. After a positive rate of climb is verified on the altimeter, the pilot monitoring calls ‘positive climb’. The pilot flying will verify the positive rate of climb on the altimeter and call for ‘gear-up’. The pilot monitoring selects the gear-up and confirms that the flight directors are ‘on’. The pilot flying will limit the bank angle to 15 degrees if the airspeed is below the minimum maneuvering speed. When the aircraft is above 400 ft radio altitude, the pilot flying selects or verifies a roll mode. The pilot monitoring will verify that the missed approach altitude is set, after which further procedures follow for the climb and navigation until the *after takeoff checklist* is completed.

It is stated in the *FCOM – Autopilot Flight Director System (AFDS) Procedures* that the pilots must always monitor airplane course, vertical path and speed. Additionally, the AFDS procedures state that pilots must verify manually selected or automatic AFDS changes; use the FMA to verify mode changes for autopilot, flight director and autothrottle; and should announce changes on the FMA and verify changes to the thrust mode display when they occur.

The *General Information* section of the *FCTM* states that when the term “Set thrust” or “Verify that thrust is set” is used in various places in the *FCTM* and *FCOM*, pilots are required to verify the EPR indication.

The *FCOM* normal procedure did not require a callout of thrust setting when the pilot flying pushes the TO/GA switch in a ‘normal’ go-around.

For the normal go-around and missed approach, with all engines operating, the *FCTM* stated:

“The go-around and missed approach is generally performed in the same manner whether an instrument or visual approach was flown. The go-around and missed approach is flown using the Go-around and Missed Approach procedure described in the *FCOM*. The discussion in this section supplements those procedures.

If a missed approach is required following an autopilot approach, leave the autopilots engaged. Push either TO/GA switch, call for flaps 20, ensure go-around thrust for the nominal climb rate is set and monitor autopilot performance. Retract the landing gear after a positive rate of climb is indicated on the altimeter.

At typical landing weights, actual thrust required for a normal go-around is usually considerably less than maximum go-around thrust. This provides a thrust margin for windshear or other situations requiring maximum thrust. If full thrust is desired after thrust for the nominal climb rate has been established, push TO/GA a second time.

If a missed approach is required following a manual instrument approach or visual approach, push either TO/GA switch, call for flaps 20, ensure/set go-around thrust, and rotate smoothly toward 15° pitch attitude. Then follow flight director commands and retract the landing gear after a positive rate of climb is indicated on the altimeter.

During an automatic go-around initiated at 50 feet, approximately 30 feet of altitude is lost. If touchdown occurs after a go-around is initiated, the go-around continues. Observe that the autothrottles apply go-around thrust or manually apply go-around thrust as the airplane rotates to the go-around attitude.

Note: An automatic go-around cannot be initiated after touchdown.”

The *FCTM* provided no explanation as to why an automatic go-around cannot be initiated after touchdown. In addition, the *FCTM* did not mention FMA changes or airspeed monitoring.



The training manuals used by the flight crew, *FCTM*, *FCOM* and the *Operator's B777 training manual*, did not contain information that the A/T will not advance the thrust levers to increase engine thrust if the TO/GA switches are pushed before touchdown and the aircraft is below 2 ft radio altitude for more than 3 seconds. Similarly, the training manuals do not mention that the A/T go-around mode becomes available when the aircraft radio altitude increases above 2 ft.

The *FCOM* did not contain procedures for a go-around initiated after touchdown. The *FCTM* contained a section entitled *Go-Around after Touchdown*, but the procedure in this section did not differentiate between go-arounds initiated before and after touchdown. The *FCTM* stated:

"If a go-around is initiated before touchdown and touchdown occurs, continue with normal go-around procedures. The F/D [flight director] go-around mode will continue to provide go-around guidance commands throughout the maneuver.

If a go-around is initiated after touchdown but before thrust reverser selection, continue with normal go-around procedures. As thrust levers are advanced auto speedbrakes retract and autobrakes disarm. The F/D go-around mode will not be available until go-around is selected after becoming airborne."

For a rejected landing maneuver, the *FCTM – Rejected Landing*, states:

"A rejected landing maneuver is trained and evaluated by some operators and regulatory agencies. Although the *FCOM/QRH* does not contain a procedure or maneuver titled Rejected Landing, the requirements of this maneuver can be accomplished by doing the Go-Around Procedure if it is initiated before touchdown. Refer to Chapter 5, Go-Around after Touchdown, for more information on this subject."

1.17.1.8 Go-around training

Go-around classroom training was part of the ground based initial training, commander upgrade training, and recurrent training. The training covers A/T involvement in go-arounds, and the FMA changes associated with pushing the TO/GA switch. Pilots were required to self-study the *FCOM* procedures for go-around.

The *OM-A* contained the Operator's policy and guidance for the autoflight and A/T, and stated "use of autothrust/autothrottle is mandatory unless unserviceable". The *FCTM* recommended that A/T be used during all phases of flight, even in manual flight.

The *FCOM – Flight Mode Annunciations (FMA)*, stated that the pilot flying shall call out any FMA changes, with the exception of any FMA change below 200 ft during landing. The pilot monitoring shall verify the annunciation and, if satisfied that the mode is applicable, acknowledge with the response "Check".

Go-around at minima, missed approach, windshear maneuver, and rejected landings were included in the ground school training and full flight simulator sessions. All maneuvers, including rejected landing, were performed solely in the 'air' mode.

Recency training included three full flight simulator sessions that covered normal two-engine and non-normal single engine go-arounds. The timing and altitude initiation of the go-arounds were at the discretion of the evaluator. A go-around involving an A/T failure may also have been practiced at the discretion of the evaluator.

The recurrent training included manual handling simulator sessions, which each pilot attended twice a year. The training consisted of six phases detailed in the *Operator's B777 training manual*. Except for phase 2, the other five manual handling phases covered go-arounds and missed approaches before touchdown.

As per the *B777 training manual*, manual handling simulator training emphasized handling skills along with instrument scanning. It was stated that aircraft attitudes and power



settings are critical to manual handling, and pilots are required to follow the normal standard operating procedures. There were no means employed by the Operator during the training sessions to verify effective instrument scan.

Manual handling phase 2 training was specific to go-arounds after touchdown. The evaluator's pre-flight brief included procedure and limitations for a go-around initiated after touchdown. The preflight preparation for *manual handling phase 2* required that the autothrottle, autopilot, and flight directors were selected to 'off'. The Operator's *B777 training manual* instructor notes stated:

"At touchdown, and prior to reverse selection, call "Airline 2 go around". Observe PF make standard call of "GA Flap 20", press TO/GA switches (ineffective, no F/D), and pushing thrust levers fully forward and holding them there. A momentary CONFIG alert may activate as the flaps retract to 20. Rotate at VREF (approx. equal to V1) and pitch toward 15°."

There was similarity with the phase 2 training go-around after touchdown training and the *FCTM – Touch and Go Landing – General*. It is stated under the section for Landing:

"

- Note: Flaps 20 is recommended after touchdown to minimize the possibility of tail strike during takeoff.
- At VREF, the instructor calls "ROTATE" and the trainee rotates smoothly to approximately 15° pitch and climb at VREF + 15 to 25 knots. The takeoff configuration warning siren may sound momentarily if the flaps have not retracted to flaps 20 and the thrust levers are advanced to approximately the vertical position."

The Investigation noticed that the pilots keep their hand on the thrust levers during practice approaches, landings and go-arounds during full flight simulator sessions. The Operator stated that this was a teaching point for all pilots during the training. However, there was no reference to guarding the thrust levers in the Operator's training or procedures manuals. The only reference related to awareness of the position of the forward and reverse thrust levers during the landing phase is in *FCTM – Reverse Thrust Operation*, which states:

"Awareness of the position of the forward and reverse thrust levers must be maintained during the landing phase. Improper seat position as well as long sleeved apparel may cause inadvertent advancement of the forward thrust levers, preventing movement of the reverse thrust levers.

The position of the hand should be comfortable, permit easy access to the autothrottle disconnect switch, and allow control of all thrust levers, forward and reverse, through full range of motion."

1.17.1.9 Windshear and Windshear escape maneuver

The Operator's *OM-A* section titled *Windshear* reminds pilots that they must remain alert to the possibility of windshear, and be prepared to react positively and without delay to its onset, whether or not the aircraft is fitted with a predictive windshear function and/or windshear recovery guidance. The *OM-A* requires that if windshear is predicted or encountered, the *FCOM* procedures shall be followed. The policy of the Operator is that if windshear is reported or expected, the following precautions should be considered; delayed take-off or landing; selection of the most favorable runway considering length, obstacles and climb-out direction; and use of maximum thrust for takeoff.

A windshear, as stated in the *FCOM*, is a change of wind speed and/or direction over a short distance along the flight path. Clues as to the presence of windshear include pilot reports and low-level windshear alerting warnings.

For approach and landing, the *FCOM* gives precautions if a windshear is suspected along the flight path that requires the flight crew's attention. These include:



“

- Use either Flaps 25 or 30 for landing
- Establish a stabilized approach no lower than 1000 feet above the airport to improve windshear recognition capability
- Use the most suitable runway that avoids the areas of suspected windshear and is compatible with the crosswind or tailwind limitations. Use ILS G/S, VNAV path or VASI/PAPI indications to detect flight path deviations and help with timely detection of windshear
- If the autothrottle is disengaged, or is planned to be disengaged prior to landing, add an appropriate airspeed correction (correction applied in the same manner as gust), up to a maximum of 20 knots
- Avoid large thrust reductions or trim changes in response to sudden airspeed increases as these may be followed by airspeed decreases
- Crosscheck flight director commands using vertical flight path instruments
- Crew coordination and awareness are very important, particularly at night or in marginal weather conditions. Closely monitor the vertical flight path instruments such as vertical speed, altimeters and glide slope displacement. The pilot monitoring should call out any deviations from normal. Use of autopilot and autothrottle for the approach may provide more monitoring and recognition time.”

The *QRH* section titled *Windshear*, states that an indication of a windshear is unacceptable flight path deviations of the aircraft. This is recognized when there are uncontrolled changes from normal steady state flight conditions below 1,000 ft above ground level (AGL), in excess of any of the following:

“

- 15 knots indicated airspeed
- 500 FPM [feet per minute] vertical speed
- 5 degrees pitch attitude
- 1 dot displacement from the glideslope
- unusual thrust lever position for a significant period of time.”

A predictive windshear warning during approach is indicated by the aural announcement of “GO-AROUND, WINDSHEAR AHEAD”, and the *QRH* states to either perform the windshear escape maneuver or, at the pilot’s discretion, perform a normal go-around.

The *QRH – Non-normal maneuver*, detailed procedures that required the pilot flying to fly a *windshear escape maneuver*. There were separate *windshear escape maneuver* procedures for manual and automatic flight. Both procedures required the pilot flying to call ‘Windshear TOGA’. In manual flight, the pilot flying is required to first push the TO/GA switch then ‘aggressively’ advance both thrust levers fully forward. In automatic flight, the pilot flying is required to push the TO/GA switch and ‘verify’ TO/GA mode annunciation. Both procedures cautioned not to change the landing gear or flap configuration, and required that the pilot monitoring verify maximum or go-around thrust, monitor vertical speed and altitude, and call out significant airspeed changes.

1.17.1.10 Flight data monitoring

The Operator had established flight data monitoring (FDM) program in compliance with the *Civil Aviation Regulations, CAR-OPS 1.037 – Safety Management System*, and advisory circular to appendix 1 to *CAR-OPS 1.978 (b)(9) – Data Monitoring/Analysis Program*.

Within the Flight Operations department, the Senior Vice President Fleet (SVP-F) was responsible for the FDM program. The FDM program was a main element of the Operator’s SMS. All of the Operator’s flight operations were monitored through the FDM



program. According to the *flight operations procedure manual*³⁰, all go-arounds were to be reviewed by Flight Operations using the FDM program. Pilots were required to report all go-arounds below 1,000 ft above aerodrome level (AAL) through the Operator's air safety reporting (ASR) system, according to the Operator's policy. Go-arounds above this altitude were not required to be reported unless the reason for the go around met one of the other stated required reporting categories in the OM-A.

The Flight Data Review Committee was responsible for reviewing the recorded FDM program data on a monthly basis and identifying 'trends, spikes and critical events'. The outcome of the review was intended to assess the safety performance of the operation as well as to be used to provide continual improvement of the recurrent training phase. Analyzed FDM data was used for crew procedural errors, causal factors and to determine if additional mitigation strategies were required.

Based on the Operator's B777 FDM data, over a 1-year period (July 2015 to July 2016), the data showed a rate of 2.75 go-arounds for every 1,000 landings. At OMDb, during the same period 214 go-arounds, a rate of 3.04 for every 1,000 landings were performed. For the same period, there were no go-arounds reported at OMDb attributed to windshear.

The Operator's deep landing monitoring was divided into three classes with events triggered based on landings exceeding specific set limits. The touchdown distance used global positioning system (GPS) coordinates with a margin of error of 100 m. The three classes were:

- Class 1 was classified yellow or minor deviation from a set standard, and flagged when the landing was greater than 750 meters past the runway threshold.
- Class 2 was classified amber, or medium deviation from a set standard, and flagged when the landing distance was greater than 900 meters past the runway threshold.
- Class 3 was classified red, or significant deviation from a set standard, and flagged when the landing distance was greater than 1100 meters past the runway threshold."

Class 1 and class 2 events were used for statistical analysis. Class 3 events were highlighted to Flight Operations Safety Board and Management Safety Review Committee.

From July 2015 to July 2016, landings beyond the touchdown zone occurred at a rate of 3.06 for every 1,000 flights. None of these landings was beyond 1,100 meters.

During this 1-year period, four go-arounds were initiated after touchdown. In three of the go-arounds, the QAR data indicated that the A/T was automatically disconnected because the crew advanced the thrust levers manually. The A/T disconnect would have caused an associated AUTOTHROTTLE DISC message on the EICAS. In one of the go-arounds, the A/T remained armed and active after touchdown because the TO/GA switch³¹ had been pushed before touchdown.

The flap setting in the four go-arounds remained in the landing configuration (flaps 30). In two of the go-arounds, the aircraft were rotated at indicated airspeeds lower than the landing reference speed (V_{REF}). The FCOM normal go-around procedure did not have a reference for flap settings and rotation airspeeds for a go-around performed after touchdown.

³⁰ The FDM program process is referred to in the Operator's *flight operations procedures manual appendix F* (Flight Data Monitoring/Flight Operations Data Monitoring Programme Procedures Manual).

³¹ The QAR includes a parameter VGASW which indicates the TO/GA switch voted position. It is a logic driven discrete produced by the autopilot flight director computer (AFDC) and is not the TO/GA switch physical discrete. The AFDCs receive a discrete signal from the TO/GA switch, processes the data and then the AFDCs sends a digital voted TO/GA signal which is recorded by the QAR.



The Operator's *B777 training manual* reference for *manual handling phase 2* training required that in performing a go-around after touchdown to select flaps 20 and rotate at V_{REF} . The *FCTM* training for *Touch and Go Landing* stated that after touchdown, select flaps 20 and rotate at V_{REF} . The thrust management in these events was in accordance with the procedures and included manual thrust applications.

The Operator's B777 FDM data analysis of 194 go-arounds showed an average time between flap and landing gear up selection of 4.65 seconds. Of these go-arounds, 39% showed a time interval below four seconds.

1.17.1.11 FCOM and FCTM – Notes and Advisories

Within the *FCOM*, the following levels of advisories were mentioned:

“

- WARNING: This is an operating procedure, technique, etc., that may result in personal injury or loss of life if not carefully followed.
- CAUTION: An operating procedure, technique, etc., that may result in damage to equipment if not carefully followed.
- Note: An operating procedure, technique, etc., considered essential to emphasize. Information contained in notes may also be safety related.”

Under the *FCOM Automatic flight – Go-Around*, inhibition of the TO/GA switches was included as a statement of information, without any associated procedure. The *FCOM* stated that “The TO/GA switches are inhibited when on the ground and enabled again when in the air for a go-around or touch and go.” The *FCOM* did not consider the TO/GA switches inhibition to be at a level of an advisory.

In the *FCTM*, under the heading *Go-Around and Missed Approach – All engines operating*, a note stated that “An automatic go-around cannot be initiated after touchdown.” The *FCTM* did not provide a clarification for this statement.

1.17.1.12 Cabin crew evacuation training

The Operator's cabin crew training facility is equipped with B777 and A330/A340 full motion cabin simulators, ditching platforms from fixed cabin simulators into a water pool, a full height A380 cabin simulator with upper and lower deck slides and fully functional operating doors, a full cockpit setup, a firefighting trainer, and individual exit door training rooms.

The training was developed as a competency-based cabin crew safety and emergency training program. The topics for the cabin crew course included: induction, safety and emergency procedures with aviation medicine and aviation security, onboard leadership, service training, and company image and uniform standards.

Scenarios, based on the Operator's previous incidents and human factors topics, were integrated into practical and simulated training. The human factor topics covered situational awareness, decision-making, communication, teamwork, assertiveness, and individual performance.

The cabin crewmembers were trained in different challenging situations that may occur during evacuations. These included severe cabin conditions, smoke in the cabin, obstructive passengers, and adverse outside conditions such as fire, smoke, or obstacles. Challenging situations caused by wind-affected slides were not included in the cabin crew evacuation training.

The cabin crewmembers were trained in managing passenger behavior, including crowd control, passenger stress and conflict management. Another part of the training



included overcoming obstacles to effective communication in changing visual and auditory conditions.

1.17.1.13 Protective breathing equipment

The Operator introduced a new type PBE in June 2015 as a result of an evacuation incident that occurred in Karachi in October 2014. The change was managed by an internal change management process in accordance with the Operator's safety management system and included a formal process for the selection of alternative equipment.

The selection criteria for an alternative PBE according to the Operator's documentation were low maintenance of the equipment, secure stowage, simple and reliable operation, and minimal possible injuries or fire from chemical reactions.

The introduction of the new PBE was supported by a training package for trainers and crew. This training consisted of a distance learning program and practical application, as well as an educational video produced by the Operator. To increase awareness, an article covering details of the Karachi incident was published in the Operator's internal flight safety publication in September 2015.

The Operator's change management process stated that the selected PBE addressed all the risks and performance issues that had been identified with the previously installed type, such as difficulties in accessing the stowage container and opening the plastic pouch, delays in donning the PBE, discomfort when activating the donned PBE, and difficulties in communication when the PBE had been donned. Difficulties in opening the stowage container to access the plastic pouch were not previously identified as a risk in the change management process.

The Operator's risk assessment for the introduction of the PBE installed in the Aircraft identified only one new risk, pertinent to the PBE training timeline for flight and cabin crew across the fleet. Difficulties in opening the stowage container to access the plastic pouch were not identified as a risk in the risk assessments.

1.17.2 The GCAA oversight

1.17.2.1 The Operator

The GCAA, as the regulatory Authority, approved sections of the Operator's manuals based on part *CAR-OPS 1 – Commercial & Private Air Transportation (Aeroplanes)*, of the *Civil Aviation Regulations*, using the *Aviation Safety Procedures Manual – Control of Manuals*. The guidance provided in this *manual* was used by the GCAA inspectors to accept and approve the Operator's policies and procedures.

The GCAA stated that the methods utilized by the regulatory authority responsible for approving the Aircraft manufacturers' FCOMs were satisfactory, therefore the GCAA followed a policy of adhering to the approvals granted by the regulatory authority of the State of the Aircraft design.

The GCAA approved the Operator's training system under the Alternative Training Qualification Program (ATQP). The ATQP was assessed and approved by the GCAA in accordance with *Civil Aviation Regulations, CAR-OPS 1.978 – Alternative Training Qualification Program*. The ATQP approval process required the Operator to define the training program for variants of an aircraft in accordance with appendix 1 to *CAR-OPS 1.978*.

Go-around training requirements necessary for compliance with the *Civil Aviation Regulations* were limited to the following:

- Appendix 1 to *CAR-OPS 1.965 – Recurrent Training and Checking – Pilots* required a missed approach from minima with, in the case of a multi-engine aeroplane, one engine inoperative;



- Appendix 1 to *CAR-OPS 1.968 – Pilot Qualification to operate in either seat* required one engine inoperative approach and go around; and
- Appendix 1 to *CAR-OPS 1.450 – Low Visibility Operations* required one engine inoperative approach and go around.

Appendix 9 to the *Flight Crew Licensing* regulations (*CAR-FCL*) stated that for multi-pilot aeroplanes and single-pilot high performance complex aeroplanes, the missed approach procedures require that pilots have practical training in a full flight simulator or aeroplane, for a rejected landing at 15 m (50 ft) above the runway threshold and go-around. Rejected landing was only mentioned in the *CAR-OPS* under appendix to *CAR-OPS 1.785–HUD or Equivalent Displays* and highlights the training requirements for operators having an aeroplane with a head up display or vision system engaged in international air navigation.

The Flight Operations department within the GCAA, was responsible for regulatory oversight functions of the Operator which included safety, operations and flight crew training. The GCAA conducted annual audits of the Operator based on progressive audit methods, supervised by the principal inspector designated for the oversight functions. Audits were conducted using the specific checklist that detailed the applicable *Civil Aviation Regulations CAR-OPS 1 – Commercial & Private Air Transportation or Organization Requirements for Aircrew (CAR-ORA)*. The GCAA clarified that as the *Regulations* are not prescriptive in nature, the inspector's audit checklist *FOF-CHK-002*, contained rejected landing as a check item option.

The requirement for an operator to establish FDM program was stated in the *CAR-OPS 1.978 and CAR-OPS 1.037*. Advisory circular to *CAR-OPS 1.037 (AC OPS 1.037 (c)–Flight Data Monitoring Programme*, stated that “the accountable manager of the safety management system Postholder, which includes establishing and maintaining the FDM system, is accountable for the discovery of issues and the transmission of these to the relevant manager(s) responsible for the process(es) concerned.”

However, the Operator's FDM program was under the management of the Flight Operations department with post holder SMS having a member of staff on the FDRC. Additionally, the post holder SMS was also a member of the Flight Operations Safety Board (FOSB) at which meetings there was a recurrent agenda item regarding ‘Review Summary of FODM Events and Trends.’

The Investigation reviewed the records of the GCAA audit findings on the Operator during the period from January 2010 to August 2016. There were no significant findings related to Operator's go-around training standard, pilots' grading system or SMS hazard identification for go-around procedures and training.

1.17.2.2 Airport emergency system

In its audit of May 2015, the GCAA found that the OMDB Airport ARFFS training team and firefighters were unable to clearly define the objective of the maintenance of competency (MoC). The audit also found it difficult to verify regular and comprehensive training in specialist equipment, such as the MICC, the forward commander vehicles, rescue stairs, and high reach extendable turret (HRET)³². The records of MoC training did not contain adequate records of trainee achievements and assessments.

In a post-Accident regulatory review of the report issued by Dubai Airports following an emergency exercise carried out in June 2015, it was concluded that the operational ARFFS commanders have different core competencies, roles and responsibilities; therefore, it was

³² The Investigation made reference: to a report issued by the GCAA after the periodic surveillance audit carried out during the period from 3 to 7 May 2015.



necessary to develop a specific competency-based training and assessment program. According to the report, there was also a need to review the training programs of the crew managers, watch managers and duty managers.

1.17.2.3 Meteorological services

The *Civil Aviation Regulations* for meteorological services is *CAR Part VIII Subpart 7- Meteorological Services*. The main objective of *Subpart 7* is to provide the rules governing the certification and operation of organizations providing meteorological services to aviation in the United Arab Emirates. Even though this regulation refers to *Annex 3 — Meteorological Service for International Air Navigation*, *Subpart 7* contains limited information regarding the requirements of aviation meteorology including forecasting and reporting of windshear.

Under the heading *Applicability*, *CAR Part VIII subpart 7.1* states:

“(b) Civil Aviation Regulations Part VIII, Subpart 7 is issued by the General Civil Aviation Authority in pursuit of its obligations to ensure enforcement of accepted international regulations and standards within organisations providing Meteorological Services within the UAE FIR as designated by the Authority³³.”

In accordance with *Annex 3 — Meteorological Service for International Air Navigation* chapter 2 *General Provisions* states in the following paragraphs the responsibilities of the designated meteorological authority:

- “
- 2.1.2 – “This objective shall be achieved by supplying the following users: operators, flight crewmembers, air traffic services units, search and rescue services units, airport managements and others concerned with the conduct or development of international air navigation, with the meteorological information necessary for the performance of their respective functions.”
- 2.1.4 – “Each Contracting State shall designate the authority, hereinafter referred to as the meteorological authority, to provide or to arrange for the provision of meteorological service for international air navigation on its behalf. Details of the meteorological authority so designated shall be included in the State aeronautical information publication, in accordance with Annex 15, Appendix 1, GEN 1.1.”
- 2.2.2 – “Each Contracting State shall ensure that the designated meteorological authority referred to in 2.1.4 establishes and implements a properly organized quality system comprising procedures, processes and resources necessary to provide for the quality management of the meteorological information to be supplied to the users listed in 2.1.2.”

The GCAA conducted audits on Dubai Air Navigation Services ('dans'), as they were the meteorological certificate holder for OMDB, and also on the NCMS as they were the meteorological service provider. The GCAA accepted the NCMS manuals with respect to meteorology. The GCAA oversight was performed by air traffic control inspectors who possessed limited meteorology training and experience as the GCAA did not have qualified and experienced meteorology staff who were subject matter experts with respect to aviation meteorology.

The *Civil Aviation Regulations* did not contain guidance regarding the issuing of windshear warnings. On preparation of a windshear warning, *Annex 3 — Meteorological Service for International Air Navigation* section *Wind shear warnings and alerts* states:

“Windshear warnings shall be prepared by the aerodrome meteorological office designated by the meteorological authority concerned for aerodromes where wind

³³ It is stated in the Foreword of *Civil Aviation Regulations Part VIII, Subpart 7*, that the General Civil Aviation Authority (hereinafter “Authority”) has implemented *CAR Part VIII, Subpart 7* based on ICAO *Annex 3* but with additional paragraphs where considered appropriate.



shear is considered a factor, in accordance with local arrangements with the appropriate air traffic services unit and the operators concerned. Wind shear warnings shall give concise information on the observed or expected existence of wind shear which could adversely affect aircraft on the approach path or take-off path or during circling approach between runway level and 500 m (1 600 ft) above that level and aircraft on the runway during the landing roll or take-off run. Where local topography has been shown to produce significant wind shears at heights in excess of 500 m (1,600 ft) above runway level, then 500 m (1,600 ft) shall not be considered restrictive.”

1.17.3 Dubai Airports

Dubai Airports operates Dubai International Airport and Dubai World Central – Al Maktoum International Airport under an aerodrome certificate issued by the GCAA in accordance with national legislation promulgated in *Civil Aviation Regulations, Part IX- Aerodromes*.

1.17.3.1 Airport aerodrome emergency manuals

The *Airport emergency plan (AEP) manual* consisted of three parts, and the most recent revision had been incorporated into part 2 in February 2015. The *manual* listed various stakeholders tasked to respond to aircraft accidents and other classes of occurrences. The responsibilities of each stakeholder were listed in *part 1* which also illustrated the *operational command and control structure* in the case of an aircraft accident. The accident response structure consisted of three levels:

- The bronze command level: site-level, responsible for crash site management, rescue, and firefighting.
- The silver command level: responsible for operational level support and coordination with the external agencies including government authorities.
- The gold command level: responsible for the strategic level of command and for national crisis management.

The JCR was responsible for activating the emergency operations center, managing the airport public notification of flight status through the passenger address and flight information display system, and arranging for evacuation.

Among other responsibilities, Airport airside operations is responsible for controlling the rendezvous point, providing support to the fire commander, and deploying one airside operations vehicle to assist with the safe evacuation and control of the passengers.

Part 1 of the *AEP manual* stated that:

“To ensure that emergency services work effectively together, a Mobile Incident Command Center (MICC) is established at the incident [accident] site and all agency Incident Commanders report to the MICC is established at the nominated Airport Incident Commander (AIC), normally the Senior Airport Fire and Rescue Service Officer or scene, who assumes responsibility for overall management of the emergency response and for organizing and deploying all available resources in a safe and efficient manner. Dubai Airports designate this level of crash site command and control as ‘Bronze Level’.”

According to *part 2* of the *AEP manual*, the fire commander is required to communicate with ATC, establish initial incident command, and liaise with the responders. The fire commander is also required to confirm the number of passengers and crew as per the list provided by the aircraft operator. All information shall be exchanged between the fire commander and the MICC.

The *Airport fire service (AFS) manual*, the operations manual of the ARFFS, contained standard operating procedures for:



- response to an aircraft accident/incident on the airfield,
- watchroom duties,
- casualty shelters,
- control of evacuating passengers, and
- training of airport fire service personnel.

The fire commander is responsible for the on-site management of rescue and firefighting. He may be assisted by his nominated sector commanders depending on his division of the accident site.

The crew manager is required to manage operational crew deployed on one fire vehicle, ensure personnel maintain their firefighting competencies and welfare, ensure all operational fire vehicles and rescue equipment are maintained and servicable, and ensure minimum staffing levels are maintained.

The firefighter function is the control of fire and the saving and preservation of life during all types of emergencies at the airport.

According to the *AFS manual*: “The AFS [ARFFS] will be deployed to ensure the response time operational objective of two minutes³⁴ to the end of each runway, as well as other parts of the movement area, in optimum visibility and surface conditions is achieved aligned to regulatory requirements.”

The *AFS manual* states that: “It is important that procedures are in place to ensure that the AFS can deal with an incident safely and at the same time allow evacuating passengers to leave a danger area, without impeding AFS actions or endangering themselves further.” For this purpose, the Airport issued a PEMS document.³⁵

³⁴ CAR part XI – *Aerodrome Emergency Services, Facilities and Equipment*, paragraph 10.1 – *Response Time*, states that: “The operational objective of the rescue and firefighting service shall be to achieve a response time of not exceeding two minutes to any point of each operational runway in optimum visibility and surface conditions.”

³⁵ According to CAR Part XI – *Aerodrome Emergency Services, Facilities and Equipment*, paragraph 20.3.3, the AEP shall, among other things, include procedures for leading passengers from aircraft, to secure areas away from the accident site. PEMS is required by the GCAA-issued *Notice to Aerodrome Certificate Holders (NOTAC)* number 01/2014.

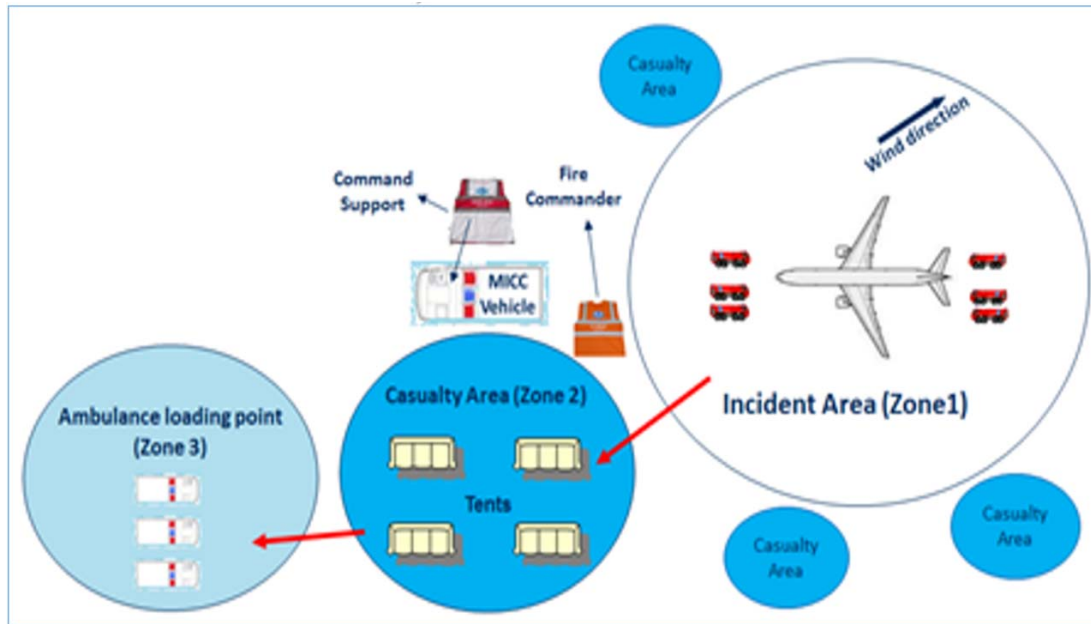


Figure 25. Example of accident site zones. [Source: MoC 38]

The ARFFS training guidance³⁶ required the evacuated passengers to be guided to the opposite side of the fire and smoke and away from the 'incident area' (zone 1 in figure 25) to a 'casualty area' (zone 2) in order to protect them from heat and smoke. Injured passenger were to be taken to an 'ambulance loading point' (zone 3).

According to the PEMS, the Airport's airside operations personnel are responsible for choosing a safe area, outside the incident area, and to use their passenger address system or megaphones to attract the attention of passengers. The airside operations officer was to request buses from the contracted handling agent and manage the transportation of the evacuated uninjured passengers from the casualty area, where all evacuated occupants are triaged.

The ARFFS personnel were to receive information about the location of fire on the aircraft, the type of aircraft involved, and the number of people on board, while the vehicle was in transit to the accident site.

To test the AEP, the Airport carried out full and partial scale emergency exercises to test the overall functions in a major event with the participation of the various concerned agencies. The exercises were assessed by the GCAA for aerodrome continuous compliance with the *Civil Aviation Regulations*.

1.17.3.2 ARFFS personnel training

According to paragraph 14 – *Training and Development*, of CAR Part XI, the aerodrome was to employ a training needs analysis method to assure the competency of its personnel. The analysis included an evaluation process to measure the training outcomes in comparison with the published objectives. The evaluation was carried out periodically and the personnel were issued with a certificate of competency as part of a structured learning program.

³⁶ Reference: MoC 38 – *Aircraft Internal Fire*.



According to the *AFS manual*, newly recruited firefighters were required to successfully fulfill recruitment criteria and to complete basic training, site-specific induction, on-watch assessment (limited role), and continuation training, as part of a maintenance of competency (MoC) scheme.

The MoC scheme was intended to demonstrate how operational ARFFS personnel are initially trained and continue to maintain competency to operate firefighting and rescue equipment.

Reviewing the training records of the fire commander indicated that the MoC training was completed as per the training schedule. This training included aircraft evacuation procedure, risk management, incident site safety, aircraft landing gear fire tactics and techniques, and aircraft combination fire with search and rescue.

The Airport utilized a B777 and A380 simulator for different external and internal fire scenarios. The training on external fire scenarios covered fires on fuselage, engines, combination of engine-landing gear, landing gear, and cargo compartment door fire, whereas the internal scenarios covered fires in the cockpit, and cabin, galley, and flashover.

The ARFFS did not provide a procedures manual for rescue and firefighting tactics and techniques. This information was contained in 83 MoC training sessions delivered to firefighters, vehicle drivers, crew managers, watchroom personnel, and fire commanders. One session discussed the positioning of fire vehicles in relation to the aircraft and illustrated eight scenarios of positioning depending on the location of the fire and the wind direction.

The fire commander was trained to divide the accident site into sectors controlled by sector commanders, who were identified by yellow vests. In some cases, two sectors could be controlled by one sector commander. The firefighters were to update their sector commanders about any new situation and the sector commanders would pass the information to the fire commander.

According to the training guidance, the fire commander was required to stay out of the 'incident area' (zone 1) so that he could communicate with the sector commanders and receive frequent information updates about the situation and communicate with the MICC.

1.17.3.3 Airport emergency exercise

A report issued by the Airport regarding an emergency exercise carried out in June 2015 described the objectives of the exercise as a test of the implementation and operation of the incident command system, information management with the JCR, passenger rescue from the aircraft to an agreed medical zone, execution of the PEMS, and control of passengers in a potentially dangerous and hot environment.

The exercise scenario was a runway overrun involving an Airbus A380, with approximately 140 persons on board. The scenario considered 20 fatalities and 44 injuries.

The exercise observations revealed that the incident command system was insufficient due to inadequate competency of the incident commander. The emergency operations center was poorly equipped, and communication between the command centers was poor. In addition, the notification system to the JCR required standardization and structured information gathering.

Rescuing the evacuated injured passengers and crew was not given the required level of attention. The report stated that the uninjured passengers were assembled close to the injured and deceased passengers, and they were not transported to the SRC in a timely manner due to a lack of command and control at the incident site. The test of the triage process revealed that the uninjured passengers were left unattended for a considerable time. Some of the passengers were sent to the SRC without being triaged.



The exercise highlighted deficiencies in the communications system and the consequences of decisions taken based on poor information. The information about persons on board the aircraft and their condition and location was not consistent among the MICC stakeholders. This resulted in different numbers being provided to their representatives in the emergency operations center, which caused considerable confusion.

The report concluded that there was a need to develop procedures for the handling of injured passengers; that the PEMS needed to be improved to deal with a large number of evacuated people who were assisted by only a limited number of staff; that the PEMS required suitable passenger signaling equipment; and an improved method of quickly mobilizing passenger busses to the site.

1.17.4 Air navigation service provider for OMDB

Dubai Air Navigation Services ('dans') is certificated by the GCAA to provide air navigation services for Dubai Airports. Procedures for 'dans' air traffic controllers providing air traffic services is implemented in the *Dubai Manual of Air Traffic Services (DMATS)*³⁷.

The *DMATS – Selection of Runway direction in use*, stated that the runway direction should be that most closely aligned to the surface wind direction. For selection of the runway direction, it was required that the Tower watch manager in consultation with the Approach watch manager shall take into account other factors such as traffic patterns, the landing distance available, the serviceability of approach aids and any other local conditions pertinent at the time.

DMATS section *Airfield Warnings* gives the criteria for promulgation of warnings. It is stated that the warnings shall be broadcast/added to the ATIS as required and includes the following:

“

- Airfield Warnings will be issued when the following criteria are expected to occur at the airport. Airfield warnings shall give concise information, in plain language, of meteorological conditions which could adversely affect aircraft on the ground, including parked aircraft, and the aerodrome facilities and services. These shall be broadcast/added to the ATIS as required.
- Strong Wind - Surface wind mean speed 20 knots or more.
- Low Level Wind Shear – Wind shear on the Final Approach which may endanger aircraft between the surface & 1600 ft. Threshold 5kts per 100 ft (often based on aircraft reports communicated via ATC).”

The criteria to issue a SPECI report, *DMATS* section *SPECI CRITERIA* states the following for surface wind:

“

- When the mean surface wind direction (10 minute mean) has changed by 60 degrees or more from that given in the latest report, the mean speed before and/or after the change being 10 knots or more.
- When the mean surface wind speed has changed by 10 knots or more from that given in the latest report.
- When the variation from the mean surface wind speed (gusts) has increased by 10 knots or more from that given in the latest report, the mean speed before and / or after the change being 15 knots or more.”

The decision as to whether information is passed from one aircraft to another is left to the discretion of the air traffic controller. Stated in *DMATS* 2.18.2 *Sources of Information*:

³⁷ The *DMATS* manual in effect was Version 4.1 dated 04 January 2016.



"As a general rule controllers shall only transmit to aircraft meteorological information that has been supplied by the meteorological office. The exceptions are:

- Sudden or unexpected deterioration which, in the interests of safety, a controller considers it advisable to warn aircraft immediately and consult with the meteorological office afterwards;
- Information from an aircraft may be passed to other aircraft when a controller considers that it may be useful to them. Whenever this is done, the ATCO [air traffic controller] shall state that the information originated from an aircraft in flight and the time at which the observation was made. Aircraft reports of meteorological conditions which affect safety shall always be passed to other aircraft likely to be affected."

The Investigation confirmed with ATC that for the two Operator's B777 aircraft that landed before UAE521, tailwind information was neither requested by the ground movement controller (GMC), nor passed to the GMC by the Operator's flight crews. *DMATS manual Reporting of a Tailwind on Final Approach* stated:

"Crews from Emirates have been advised to notify GMC of tailwinds experienced once they have vacated the runway. The crews have also been requested to advise GMC only if tailwind experienced is outside the parameters already being reported on the ATIS."

For runway 12L, the *DMATS* required missed approach aircraft to be directed to OSTIN climbing to 3,000 ft. ATC clarified to the Investigation that the *DMATS* missed approach was superseded by an internal supplementary instruction to the air traffic controllers, effective 31 March 2016, which introduced turning missed approaches. Direct OSTIN was removed.

The *DMATS Missed Approach Procedures* stated that the air traffic controllers:

"Should always try to turn the missed approach [aircraft] rather than allow it to climb straight ahead. This negates any vortex separation requirement for departures from the parallel runway providing the missed approach [aircraft] has turned before the departure runway threshold."

A letter of agreement was established between the OMDB Tower and Approach units, which described the details for handling go-arounds. The letter contained a clause that in the case of a missed approach with the radar serviceable, the air traffic controller was to instruct the aircraft to climb straight ahead to 4,000 ft. If the radar was unserviceable, the air traffic controller was to instruct the aircraft to perform the missed approach as per the published procedure. This agreement was still effective on the day of the Accident.

For UAE521, the missed approach published in the flight crew *LIDO* plate (Appendix C to this Report), required the aircraft to turn left tracking 103 degrees, and to climb to DAMOR at 3,000 ft. This information was in accordance with the United Arab Emirates OMDB *aeronautical information publication* (AIP) missed approach.

According to the *DMATS* manual, for a rejected takeoff above 80 kt, air traffic controllers are reminded not to distract the flight crew with unnecessary radio calls during this high workload situation. A similar caution was not included for other high workload situations, such as go-arounds, especially those initiated from low altitudes.

1.17.5 Meteorological services

In 2007, the United Arab Emirates Ministry of Presidential Affairs issued a decree for the establishment of a national center for meteorology referred to as the National Center of Meteorology and Seismology³⁸ (NCMS). The NCMS, in accordance with the decree, took over

³⁸ The National Center of Meteorology and Seismology name was changed sometime after the Accident to National Center of Meteorology (NCM).



the operations of the Abu Dhabi Aviation Weather Office in 2013 and the Dubai Aviation Weather Office in 2015. Rules and guidelines to be followed by NCMS forecasters are stated in the NCMS SOP applicable for each weather office.

In accordance with the *Civil Aviation Regulations, CAR Part VIII subpart 7 – Meteorological Services*, at the time of the Accident, 'dans' held the GCAA certificate for meteorology at OMDB. The NCMS Dubai weather office provided the meteorology services under contract to 'dans' and provided the meteorological documentation.

For wind information at OMDB, data is collected from the anemometers and a wind profiler. An anemometer was installed at the threshold of each runway (12L/30R and 12R/30L) and two at the mid-point of runway 12R/30L. The anemometer for runways 12L and 12R was located approximately 300 m forward of each runway threshold. The wind profiler, located near the threshold of runway 30R provided wind information above 500 ft. NCMS also had weather stations situated outside of OMDB. The Investigation was informed by the NCMS that the Hyatt aviation weather station, located outside of OMDB, was not functional at the time of the Accident as it was removed from service in 2014 for safety reasons.

The NCMS SOP – *Wind Shear warnings*, states:

"Warnings will be issued when the following conditions are considered by the Forecaster to exist, or are forecast to occur, between runway level and 1600 ft above that level:

A change of headwind component of 5 knots or more per 100 ft (vertical) especially if this change is concentrated in a narrow layer (for example: 240/07 kt at the surface to 310/20 kt at 200 ft)."

The SOP – *Forecasting Wind Shear without aircraft reports*, states:

"The Forecaster must monitor closely the data from the Wind Profiler and data from the wind-reporting stations in the Vaisala system [NCMS meteorology system], particularly the Hyatt AWS [aviation weather station] compared to the stations along the runways. The Forecaster must ask ATC to request from aircraft winds at 500 ft, 1000 ft and 1500 ft, and any reports of wind shear."

The NCMS had issued ATIS information Zulu at 0735 with windshear forecast warning based on an analyses of the synoptic situation over the general Dubai region, with support from the atmospheric numerical model. At the time when the warning was issued the weather stations located outside OMDB and within the Airport did not indicate the existence of windshear conditions.

Additionally, the NCMS SOP gives examples of forecasting windshear. It is stated that OMDB can experience windshear due to the onset of a sea breeze with a moderate or strong easterly gradient. The forecasters are required to brief the ATC watch managers at OMDB about the timeframe of the expected weather. To help improve capacity at OMDB, the SOP – *SOP3.GEN.005 Weather Briefings and Handovers item 1.15. Sea Breeze / Land Breeze Briefing* states that the weather briefing will enable "ATC to plan and synchronize runway changes based on both air traffic flow and the meteorological situation. This will also assist with reducing the number of go-arounds that can disrupt the smooth flow of arriving aircraft at both airports [OMDB and OMDW]."

At the time of the Accident, there was no agreement between the NCMS and the Aircraft Operator to provide additional weather information along the approach flight path. Except for the wind stations and wind profiler, the Airport was not equipped with additional means for low-level windshear detection near the runways. In addition, the NCMS OMDB weather office had no ability to create, issue, or distribute automated windshear alerts.



1.18 Additional Information

1.18.1 TO/GA switches inhibit

The Aircraft manufacturer stated that the reason for inhibiting the TO/GA switches is to prevent pilots from inadvertently activating TO/GA mode at or after touchdown. Inadvertent activation of TO/GA could result, among other things, in the aircraft departing the runway. The TO/GA switch design logic is in accordance with the guidance from *FAA Advisory Circular 120-29A – Criteria for Approval of Category I and Category II Weather Minima for Approach*. The relevant section of AC120-29A is found in paragraph 5.14.b – *Go-Around Capability* which states:

“If an automatic or flight director go-around capability is provided, it should be demonstrated that a go-around can be safely initiated and completed from any altitude to touchdown. If an automatic go-around mode can be engaged at or after touchdown, it should be shown to be safe. The ability to initiate an automatic or flight director go-around at or after touchdown is not required or appropriate. Inadvertent selection of go-around after touchdown (either an automatic or flight director go-around capability) should have no adverse effect on the ability of the aircraft to safely rollout and stop.”

1.18.2 Fire extinguishing agent

1.18.2.1 Application of fire extinguishing agent

At the time of the Accident, all the Airport MFVs had undergone the required foam generating system tests as required by *CAR Part XI – Aerodrome Emergency Services, Facilities and Equipment*. This included foam concentrate induction accuracy, expansion ratio and foam drainage time. All test records sampled indicated that the MFV foam systems were functioning correctly.

Foam produced by most vehicles used for aircraft firefighting will utilize solutions, either in premixed forms or by the use of a proportioning system, which are delivered at a predetermined pressure to the monitors or nozzles. Both non-aspirating and aspirated monitors and sideline branches can apply the firefighting agent concentrate used by Dubai Airports. The MFV vehicle system will produce an acceptable foam blanket only if the solution is delivered in the appropriate concentration at the correct pressure range and by the correct application methods.

Video evidence as well as statements from attending firefighting personnel indicated that the finished quality of the foam applied to the Aircraft was not of the required standard and appeared to be lacking the characteristics of a secure foam blanket. The Investigation concluded that this was because of the application method utilized by the firefighters. The firefighting agent was applied from non-aspirating (jets) main and bumper monitors against the Aircraft structure at near right angles causing the foam bubbles to breakdown on impact. Additionally, some firefighters were applying foam, while other firefighters in a different section of the Accident site were applying water. This had the effective of breaking down the foam blanket and washing it into the airport drainage system.

ICAO Doc 9137 – *Airport Services Manual*, Part 1, states:

“

- *Aspiration by inducted air* - This is where a foam solution inducts air into the stream of foam solution by the venture effect. As the foam solution passes air holes the negative pressure induces air into the stream and baffles or plates may assist the process. The optimum performing foam is dependent upon the correct ratios of foam concentrate to water and the expansion ratio achieved by the mixing action.
- *Aspiration within the jet* - This is where the foam solution is delivered non aspirated from the branch and air is entrained into the stream as it travels through the air to the fire.”



1.18.2.2 Testing of fire extinguishing agent samples

The fire extinguishing agent was supplied to the Airport ARFFS fire vehicles from five batches. Two batches were granted a certificate of conformity issued on 9 September 2014, and three were certified on 27 March 2015. According to the certificate of conformity, the agent's performance complied with the requirements of the *European Norm EN 1568:2008*, part 3 and 4 specification and the ICAO *level B* standard at 3% and 6% concentration. At 6% concentration, the agent complied with the ICAO *level C* standard.

Foam conformity certification was available at the Airport for all batches of foam concentrate for both operational stock and stock in storage. According to the extinguishing agent data sheet, it is a concentrated fire extinguishing agent supplied by Solberg Scandinavian AS, Norway. The agent was suitable for jet fuel fire types.

The agent storage temperature ranges between minus 30 to 65 degrees centigrade with no limitations on storage quantity or shelf life.

On 13 September 2016, tests were carried out at the supplier's facilities on samples taken from the same batches that were used during the Accident. The tests were performed in accordance with ICAO level B³⁹ standards, and concluded that the foam performance and the re-ignition resistance met the specifications of the test standards.

A report was also issued by the supplier on the quality testing of samples taken from the MFV 5 and MFV 7 tanks. The report concluded that all samples were in a satisfactory condition.

1.18.3 Evacuation slide certification

The FAA published technical standard orders for inflatable emergency escape slides and over-wing slide ramps, to provide the minimum performance standards for design and manufacture.

Part 25 of the *Federal Aviation Regulation (FAR)*, Sections 803 and 810, prescribed the requirements for aircraft emergency evacuation, egress assist means, and escape routes. Additionally, *advisory circular AC25-17A* issued by the FAA, provided acceptable certification methods for demonstrating compliance with these requirements.

Technical standard order (TSO) TSO-C69b issued by the FAA on 17 August 1988, described the minimum performance standards for escape slides, ramps and slide raft combinations. The *TSO* stated:

“4.6 Length. The slide device must be of such length after full deployment that the lower end is self-supporting on the ground and provides safe evacuation of occupants to the ground when the aircraft is on the ground with the landing gear extended and after collapse of one or more legs of the landing gear.

4.22 Wind. The device must have the capability, in 25-knot winds directed from the most critical angle, to deploy and, with the assistance of only one person, to remain usable after full deployment to evacuate Occupants safely to the ground.”

TSO-C69b did not define ‘the most critical angle’. It was superseded by *TSO-C69c*, issued on 18 August 1999.

TSO-C69c introduced some additional sections, including Section 5.2 – *Functional Tests* which prescribed requirements for testing at maximum and minimum sill heights. The minimum sill height was defined as the lowest height above the ground of the exit sill with the collapse of one or more of the aircraft landing gear legs.

³⁹ Conformity of a foam concentrate to the ICAO Fire Test Method, ICAO Doc. 9137 – *AN/898- Airport Services Manual*, Part 1 – *Rescue and Firefighting*, Chapter 8. Level B.



Other relevant sections that were revised in *TSO-C69c* were about the minimum number of evacuees per minute who must egress the device without assistance, and about wind conditions. It states:

“4.20 Wind.

The device must be shown, in 25-knot winds directed from the most critical angle, to deploy and, with the assistance of only one person who has evacuated down the device, to remain usable after full deployment to evacuate occupants safely to the ground. The device shall be tested while it is properly attached to the exit or location on the airplane on which installation is intended or on an equivalent mock-up.

4.20.1 To determine the most critical angle, the wind shall be directed at the device from at least the following directions: aft along the centerline of the aircraft (0 degrees position) and then every 45 degrees on the same side of the fuselage as the device is intended for installation.”

The main differences between *TSO-C69b* and *TSO-C69c* were in defining that at least one person could evacuate down the escape slide to assist in maintaining the slide usability, and determining the most critical wind angle that was to be simulated during the slide testing. *FAR Part 25, Section 810 – Emergency Egress Assist Means and Escape Routes*, required, during the aircraft conformity test, the slides to be on-wing tested for the capability to deploy and remain usable in wind speeds of up to 25 kt, with the assistance of only one person. The *FAR* does not specify whether this person has evacuated from the same slide.

The Aircraft escape slides were approved and manufactured under *TSO-C69b*, therefore, were not required to be tested to demonstrate compliance with the additional requirements of *TSO-C69c*.

FAR Part 25, Section 803 – Emergency Evacuation, required aircraft capability to facilitate rapid evacuation in crash landings, with the landing gear extended or retracted. It required aircraft with a seating capacity of greater than 44 passengers to be evacuated under simulated emergency conditions within 90 seconds.

Appendix J to *FAR Part 25* outlined the test criteria, which prescribed evacuation timing with the aircraft in a normal attitude with the landing gear extended. Appendix J stated that the test group consist of 40 percent females, 35 percent passengers over 50-years, 15 percent are females and over 50-years, and three life-size dolls simulating infants. Children were not part of the certification test.

*Advisory Circular (AC) 25-17A*⁴⁰, issued by the FAA on 18 May 2009, provided acceptable certification methods to demonstrate compliance with the crashworthiness requirements of *FAR Part 25*. It stated that evacuation with a collapsed landing gear is possible but the evacuation rate need not to be the same as that with a normal slide angle. If the slide does not rest on the ground after deployment, it must be usable and appear to be usable to passengers. When the passenger uses the slide, the bottom end should rest on the ground and allow the passenger to egress. The AC further states:

“In order to meet the 25 knot wind requirement, the escape slide presses against the fuselage and the end of the unoccupied slide may not be in physical contact with the ground, especially in the most adverse attitude (gear collapse). This condition has been found to be acceptable provided the slide is self-supporting on the ground shortly after an evacuee has entered the slide and prior to the evacuee reaching the end of the slide. The unoccupied slide, when viewed from the exit, should not give the visual impression that the slide is unsafe for use.

...

⁴⁰ FAA Advisory Circular AC 25-17, issued on 15 July 1991 was cancelled by AC 25-17A on 18 May 2009.



The person who assists should come from the airplane. This capability should be demonstrated by test.”

1.18.4 Survivability

1.18.4.1 Evacuation problems in previous accidents

The Investigation reviewed previous accidents to better understand the behaviour of passengers during an evacuation, and the effect on the evacuation process and time.

A 1985 accident involving a Boeing 737 at Manchester Airport⁴¹, the United Kingdom, resulted in a heightened industry interest in aircraft evacuations and a number of safety studies on evacuations were undertaken.

On 2 July 2003, a B747 experienced a brake fire on arrival at the stand in Sydney⁴², Australia. An evacuation was commanded while a number of passengers were standing in the aisles for normal disembarkation with their carry-on baggage. The re-direction of passengers from blocked exits, combined with the bags that had been removed from the passengers at the usable exits, led to increased congestion. The crew decided to give priority for evacuation over the requirement for passengers to remove bags and high heeled shoes, which caused damage to a slide and resulted in a serious injury to a passenger, and delayed the evacuation.

On 2 August 2005, an A340 overran the runway at a speed of approximately 80 kt during a landing attempt at Toronto Airport⁴³, Canada, and came to rest in a ravine, where it caught fire. Cabin crewmembers were faced with challenging conditions due to the proximity of the fire, the rough terrain and the limited serviceability of the escape slides. A post-accident survey of the aircraft occupants found that half of the respondents stated that they had attempted to bring their carry-on baggage while they exited the aircraft. This caused blockage in the aisles and at the exits, and slowed the evacuation. This passenger behavior led to the Department of Transportation Canada including in the passenger safety briefings a requirement for clear directions to leave all carry-on baggage behind during an evacuation.

In 2009, a B737 crashed in a field 1.5 kilometers short of runway 18R at Amsterdam's Schiphol Airport⁴⁴, the Netherlands. The tail section separated during the impact and the fuselage sheared forward of the center wing section. The investigation found that none of the four evacuation slides on the aircraft had deployed as designed during the opening of the doors, but could not determine the cause.

In 2013, a B777 struck a seawall during approach to San Francisco International Airport⁴⁵, the United States. The investigation report identified that two evacuation slides had deployed inside the cabin, two slides fully deployed and two slides did not deploy. The NTSB recommended that the FAA, in conjunction with the slide manufacturers, evaluate the adequacy of slide and slide raft certification standards and test methods specified in the FARs for future slide and slide raft design. The FAA responded that modifying current requirements was not warranted because it was not supported by current rulemaking standards based on the single instance of one accident.

On 17 January 2008, a B777 landed short of the runway at London Heathrow⁴⁶, the United Kingdom, when both engines spooled down to idle thrust on descent due to fuel filter

⁴¹ AAIB Report 8/88/Manchester International Airport/22 August 1985.

⁴² ATSB Report BO/200302980/Sydney Aerodrome/2 July 2003.

⁴³ TSB Canada Report A05H0002/Toronto International Airport/2 August 2005.

⁴⁴ DSB Report M2009LV0225-01/Amsterdam Schiphol Airport/25 February 2009.

⁴⁵ NTSB Report AAR-14/01/San Francisco/6 July 2013.

⁴⁶ AAIB Report 1/2010/London Heathrow/17 January 2008.



icing. The commander initiated the evacuation approximately 35 seconds after the aircraft came to rest, and the evacuation was completed in 2 minutes 20 seconds. The expedited evacuation command was a result of the operator's good practice of having the evacuation instructions printed on a placard, attached to both pilots' control columns as a quick reference for the prompt initiation of an evacuation.

1.18.4.2 *Civil Aviation Regulations* on passenger briefing

CAR-OPS 1.285 –Passenger Briefing, prescribed the requirements for passenger safety briefing contents at relevant times throughout the flight. It stated:

"Before takeoff:

- (1) Passengers are briefed on the following items if applicable:
 - (i) Smoking regulations;
 - (ii) Back of the seat to be in the upright position and tray table stowed;
 - (iii) Location of emergency exits;
 - (iv) Location and use of floor proximity escape path markings;
 - (v) Stowage of hand baggage;
 - (vi) Restrictions on the use of portable electronic devices; and
 - (vii) The location and the contents of the safety briefing card, and,
- (2) Passengers receive a demonstration of the following:
 - (i) The use of safety belts and/or safety harnesses, including how to fasten and unfasten the safety belts and/or safety harnesses;
 - (ii) The location and use of oxygen equipment if required (CAR–OPS 1.770 and CAR–OPS 1.775 refer). Passengers must also be briefed to extinguish all smoking materials when oxygen is being used; and
 - (iii) The location and use of life jackets if required (CAR–OPS 1.825 refers).

After takeoff:

- (1) Passengers are reminded of the following if applicable:
 - (i) Smoking regulations; and
 - (ii) Use of safety belts and/or safety harnesses including the safety benefits of having safety belts fastened when seated irrespective of seat belt sign illumination.

Before landing:

- (1) Passengers are reminded of the following if applicable:
 - (i) Smoking regulations;
 - (ii) Use of safety belts and/or safety harnesses;
 - (iii) Back of the seat to be in the upright position and tray table stowed;
 - (iv) Re-stowage of hand baggage; and
 - (v) Restrictions on the use of portable electronic devices.

After landing:

- (1) Passengers are reminded of the following:
 - (i) Smoking regulations; and
 - (ii) Use of safety belts and/or safety harnesses.

In an emergency during flight, passengers are instructed in such emergency action as may be appropriate to the circumstances."

These provisions in the *Civil Aviation Regulations* did not contain briefing items regarding carry-on baggage during an evacuation.

1.18.5 Persons on board

During the Aircraft evacuation, the exact number of persons on board was not transmitted to the fire commander as the information was not immediately available to the ARFFS watch room.

Following an aircraft accident, ICAO DOC 9137 *Airport Services Manual Part 7 - Airport Emergency Planning* states the responsibilities and role of each agency with implementation of the airport emergency plan. It is stated in chapter 4.1 - *Aircraft Accident on the Airport*:

"4.1.2 Action by air traffic services

4.1.2.2 - Notify the rescue and firefighting service and provide information on the location of the accident, grid map reference and all other essential details, including time of the accident and type of aircraft. Subsequent notification may expand this information by providing details on the number of occupants, fuel on board, aircraft operator, and any dangerous goods on board, including quantity and location, if known."

Additionally, it was stated:

"4.1.8 Action by aircraft operators

4.1.8.2 - The senior representative of the aircraft operator will provide information regarding passenger load, flight crew complement and the existence of any dangerous goods together with their loading position."

ICAO Annex 2 – *Rules of the Air* – in the section titled *Contents of a flight plan* states that "A flight plan shall comprise information regarding such of the following items as are considered relevant by the appropriate ATS [air traffic services] authority". Included in the list of items required to be transmitted in the flight plan is "Total number of persons on board."

ICAO Annex 2 – *Rules of the Air* – in the section titled *Changes to a flight plan* states:

"Note 1.— Information submitted prior to departure regarding fuel endurance or total number of persons carried on board, if incorrect at time of departure, constitutes a significant change to the flight plan and as such must be reported."

ICAO Doc 4444 – *Air Traffic Management (PANS-ATM)*, in appendix 2 *Flight Plan* has a *model flight plan form*. Persons on board, with the symbol 'P', is considered supplementary information to the flight plan and it was stated in the flight plan instructions to "Insert the total number of persons (passengers and crew) on board, when required by the appropriate ATS [air traffic services] authority. Insert TBN (to be notified) if the total number of persons is not known at the time of filing."

ICAO Doc 4444 chapter 16 on use of *Repetitive Flight Plans (RPLs)* states that when the ATS authority considers the information relevant, in submission of an RPL, the operator shall provide "indication of the location where the following information may be obtained immediately upon request: alternate aerodromes; fuel endurance; and total number of persons on board."

The *Civil Aviation Regulations CAR-OPS 1*, the section *Operational flight plan* mentions what must be transmitted in the flight plan. The *CAR-OPS 1* does not state that number of persons on board is required to be part of the flight plan. The *Civil Aviation Regulations* did not have guidance on a model flight plan form similar to ICAO Doc 4444.

The Aircraft Operator OM-A – *Content of the Operational Flight Plan* section does not state that the number of persons on board is required to be submitted as part of the operational flight plan.



The Operator's OM-C section 'J' *operational flight plan (OFP) Format and Description*, the description for the LIDO OFP format "UAE-OFP – Main Body: Boeing 777-300 and Boeing 777-200" required that the number of crew, passengers and total persons on board be submitted as part of the OFP. The OFP for UAE521 that was carried on board the flight was not retrieved as it was destroyed by the fire. A copy of the UAE521 OFP, with a time stamp of 03 August 2016 at 0449 UTC, provided to the Investigation by the Operator, did not contain the number of crewmembers, passengers and total on board. The relevant fields were blank.

For UAE521, in accordance with the *Civil Aviation Regulations, CAR-OPS1.625 – Mass and Balance Documentation*, and the Operator's OM-A – *Mass and Balance Documentation* section, the number of persons on board the flight was stated and transmitted in the mass and balance documentation known as the loadsheet.

1.19 Useful or Effective Investigation Techniques

The Investigation was conducted in accordance with the Legislation and *Civil Aviation Regulations*, and in accordance with the AAIS approved policies and procedures and the Standards and Recommended practices of Annex 13 to Chicago Convention.



2. Analysis

2.1 General

Both flight crewmembers were appropriately licensed and medically fit to operate the flight. The Investigation found no evidence that the flight crews' performance was affected by either any condition related to a behavioral or medical condition, or to the use of a psychoactive substance.

The Aircraft was maintained in accordance with the maintenance program approved by the General Civil Aviation Authority of the United Arab Emirates, and there were no technical anomalies prior to the Accident. The Aircraft systems and engines performed as designed. The landing weight was within limits.

Data from the cockpit voice and digital flight data recorders was successfully retrieved and analyzed.

The environmental conditions encountered during the approach and landing were within the operating limits of the Aircraft.

2.2 Flight Sequence

The Aircraft was correctly configured for the area navigation (RNAV) approach to Dubai International Airport (OMDB). From 1,000 ft radio altitude and until the flare, the approach had been flown according to the stabilized approach criteria established by the Operator. The autopilot was disconnected at 930 ft radio altitude, the flight directors remained 'on', and the autothrottle (A/T) was 'armed' and active as per the Operator's policy for a manual landing⁴⁷.

The flight crew were prepared for a tailwind landing as per the wind information provided by the Tower as the Aircraft was descending through 1,000 ft radio altitude, approximately one minute before it passed over the runway threshold. ATC did not provide information to the UAE521 flight crew about windshear experienced by an aircraft that had landed prior to UAE521 or about two previous go-arounds.

Elevated temperatures are common at OMDB during the month of August and the flight crew were familiar with these conditions as this was their home base. Over the Commander's flying experience on the B777 of approximately seven years, he had performed landings at OMDB in conditions of similar elevated temperatures. The runway surface temperature was recorded at 68 degrees centigrade.

Four seconds before the Aircraft passed over the runway 12L threshold, the flight crew were aware that the magnitude of the tailwind component decreased from 16 kt to 13 kt.

The Aircraft passed over the runway threshold (see figure 1 and Appendix E of this Report) at approximately 54 ft radio altitude, and 159 kt IAS, which was 7 kt above the approach speed ($V_{REF30} + 5$ kt). The airspeed was within the Operator's stabilized approach criteria.

At approximately 40 ft radio altitude, 159 kt IAS, approximately 100 m beyond the threshold, a pull on the control column was recorded on the FDR. This was an indication of the Commander's intention to flare the Aircraft. Over the next 5 seconds, until 7 ft radio

⁴⁷ Manual landing is defined by the Aircraft manufacturer as a landing with the autopilot disconnected. The Operator's published policy is to set the A/T to armed and active for all landings, including manual landings.



altitude, there was a steady increase in the Aircraft pitch angle from 0.4 to 2.6 degrees, with a corresponding decrease in the sink rate from approximately 700 ft per minute towards 350 ft per minute

The flight crew were trained to refer to the automated radio altitude callouts during the approach as a prompt to commence the flare, which is normally initiated close to the “THIRTY” callout. As the initiation of the flare started earlier than recommended, this action most likely contributed to an increase in the landing distance. The *flight crew training manual FCTM – Flare and Touchdown*, stated that the initiation of the flare occurs when the main gear is approximately 20 to 30 ft above the runway. The Commander had stated to the Investigation that he could not recall at what height the flare was initiated.

After the A/T had changed from ‘SPEED’ to ‘IDLE’ mode at 25 ft radio altitude, the airspeed decreased by 6 kt and was 153 kt at 10 ft radio altitude. As the Aircraft passed the runway aiming point and approximately 480 m beyond the threshold, the airspeed started increasing and at 2 ft radio altitude, it reached 165 kt IAS with the Aircraft approximately 840 m beyond the threshold. There was a 12 kt airspeed increase over approximately four seconds, during which time the groundspeed decreased by 5 kt, and the descent rate decreased from 432 ft per minute to 80 ft per minute. The airspeed increase was 18 kt above the landing reference speed of 147 kt V_{REF} .

The flight crew did not notice the increase in airspeed as their attention was focused outside the Aircraft after the runway threshold was passed. This practice was in accordance with the *FCTM – Flare and Touchdown* recommendation for the pilots to change their visual sighting point to the far end of the runway in order to control the pitch attitude during the flare.

The Investigation concludes that the 12 kt airspeed increase was due to a horizontal windshear as the wind shifted from a tail wind to a head wind component. The wind shift most likely occurred as the Aircraft was descending below 7 ft radio altitude as this was when the Commander first felt the Aircraft being affected by the environmental conditions of hot air raising from the runway surface and the wind shift. During this period, the Commander first exclaimed “Oops” followed by “Thermals”. The Commander made several inputs on the control column, control wheel and rudder in order to maintain wings level and keep the aircraft aligned with the runway centerline.

Except for the Airport wind anemometer located approximately 300 m forward of runway 12L threshold, there were no additional anemometers along the touchdown zone. Based on the FDR data, the increase in Aircraft performance due to the airspeed increase of 12 kt over a four second period most likely started to occur as the Aircraft was approximately 650 m beyond the runway threshold.

A review of the Aircraft FDR and CVR and technical examinations of the weather radar and EGPWS indicated that during the entire flight sequence up to and including the Aircraft impact with the runway, no windshear warning or windshear alert/caution was generated by the Aircraft systems (weather radar or EGPWS). The flight crew also confirmed that there were no cockpit annunciations related to windshear.

The B777 *quick reference handbook (QRH) – Windshear*, stated that an indication of windshear is when there are unacceptable flight path deviations. For UAE521, for the approach from 1,000 ft radio altitude until the Aircraft main landing gear ‘until’ after the brief touchdown, none of the conditions as stated in the *QRH* were met. The airspeed increase of 12 kt was below the 15 kt criteria of the *QRH*. In addition, the vertical speed never exceeded 500 ft per minute and pitch attitude change was always less than 5 degrees.

The Operator’s *FCTM – Airplane Performance in Windshear*, stated:



"The wind component is mostly horizontal at altitudes below 500 feet. Horizontal windshear may improve or degrade vertical flight path performance. Windshear that improves performance is first indicated in the flight deck by an increasing airspeed. This type of windshear may be a precursor of a shear that decreases airspeed and degrades vertical flight path performance."

The additional lift created because of the increasing performance of the Aircraft contributed to the prolonged floating of the Aircraft over the runway. Even though the Commander was not aware of the increasing airspeed, he had responded to the increasing performance and in an attempt to land, three times made small pitch attitude corrections to lower the nose of the Aircraft. During this time, the Aircraft pitch angle decreased from 2.6 degrees to an average of 1.2 degrees between 5 ft and just prior to the touchdown.

The action taken by the Commander was in line with the recommendation of the *FCTM – Landing Flare Profile* as it was stated that the touchdown body attitude (pitch angle), should be reduced by 1 degree for each 5 kt above the touchdown speed. For UAE521, the touchdown speed was calculated by the flight crew to be 147 kt ($V_{REF30} + 0$).

The *FCTM – Landing Flare Profile* stated that the estimated time from the moment the flare is initiated until touchdown is between four to eight seconds depending on the approach speed. The Aircraft manufacturer training recommended that the flare should not be prolonged and the aircraft should be flown onto the runway in the normal touchdown range. For UAE521 flight crew, they did not consider flare duration during the attempted landing, as it was not a requirement of the Operator.

As the Aircraft continued to float over the runway, it rolled to the left due to the wind effect and the Commander corrected with right control wheel input. This action caused the right main landing gear to contact the runway and 'untilt' approximately 1,090 m beyond the threshold, approximately 10 seconds after the flare was commenced.

Approximately 2.5 seconds after the right main landing gear contacted the runway, the Commander had decided to go around and called "Go-around". He stated that he felt that the Aircraft would not land even though he tried to lower the nose and that the Aircraft was towards the end of the touchdown zone.

He then initiated the *flight crew operations manual (FCOM) Go-around and Missed Approach Procedure* by pushing the left takeoff/go-around (TO/GA) switch a fraction of a second before an EGPWS 'long landing' automatic cockpit annunciation occurred. The Commander and the Copilot stated that they were not aware that the right main landing gear had contacted the runway.

With the TO/GA switches inhibited because of the right main gear weight-on-wheels (WOW) ['ground' mode], pushing the TO/GA switch had no effect on the A/T mode. As designed, when the Commander pushed the left TO/GA switch, the FMA A/T mode remained at 'IDLE'. As neither pilot had observed the FMA, they were not aware that the A/T mode had not changed to 'THR'.

The Aircraft CVR analysis indicated that the first 'long landing' annunciation occurred just after the Commander called "Go-around", approximately 1,280 m beyond the threshold (380 m beyond the touchdown zone). This was 92 m further along the runway than the Operator's programed long landing alert distance. The runway landing distance available after the first 'long landing' annunciation was 2,320 m.

The FDR indicated a 1.4 degree movement of the No.1 engine thrust lever, which returned to the idle position in a fraction of a second. This movement of the thrust lever occurred just after both main landing gear 'untilted' and the Aircraft transitioned to 'ground'



mode for the first time, approximately 1.5 seconds after the go-around command. The forward movement of the thrust lever was most likely caused when the Commander pushed the left thrust lever TO/GA switch. The Operator confirmed that this slight forward movement of the thrust lever can occur when the TO/GA switch is pushed. As the palm of the hand pivots on the thrust lever, the downward push of the TO/GA switch can cause the thrust lever to move forward slightly. Because the A/T mode was in 'IDLE' this would have returned the thrust lever back to the idle thrust lever position.

After the go-around was initiated, both the left and right main landing gear completed two cycles of the 'air' and 'ground' modes, causing the speedbrake lever to partially deploy twice, each deployment lasting less than one second. On each occasion that the speedbrake lever deployed, it returned to the 'arm' position. The Aircraft manufacturer's post-Accident *Performance Evaluation* confirmed the two movements of the speed brake lever and stated that the speedbrake lever takes approximately 1.5 seconds to fully deploy from the 'arm' to the 'up' position. As the flight crew's attention was focused outside the cockpit, they were unaware of the speedbrake lever movements.

When the Commander called for 'flaps 20', 2.5 seconds after the go-around command, both main landing gear were in 'ground' mode, with the Aircraft pitch angle increasing towards 7.4 degrees. Although the flight crew stated that they were not aware that the Aircraft had touched down, the Commander was aware that the Aircraft was close to the runway and therefore he limited the pitch angle in order to avoid a tail strike.

From the initial contact of the right main landing gear with the runway until the Aircraft started to gain height for the go around, a distance of approximately 500 m was travelled in six seconds, with either one or both main landing gear in contact with the runway. The nose gear remained airborne throughout this period. As the Aircraft travelled along the runway, the airspeed decreased by 8 kt to 153 kt IAS.

The Aircraft continued into a headwind component of 8 kt, almost aligned with the runway centerline. With the headwind benefit, stowed speedbrake and the flaps still at the flaps 30 position, the Aircraft became airborne approximately 1,590 m beyond the runway threshold. Both main gear moved to the 'tilt' position 3.7 seconds after the go-around initiation at an airspeed of approximately 153 kt IAS, 6 kt above V_{REF30} . The Copilot confirmed 'flaps 20' as the Aircraft was climbing through 22 ft radio altitude.

According to the *FCTM –Rotation and Ltoff –All Engines –after rotation*, with a normal take-off pitch (7 to 9 degrees) and take-off thrust, the aircraft will reach a height of 35 ft radio altitude in 2.5 seconds. A similar performance was attained by the Aircraft as it reached a height of 35 ft in two seconds at a vertical speed of 512 ft per minute, even though the engine thrust levers and EPR remained at idle.

The Operator's *Go-around and Missed Approach Procedure* required both pilots to verify rotation to go-around attitude and that engine thrust was increasing, after the pilot monitoring selected flaps 20. The pilot monitoring was then required to verify that thrust was sufficient for the go-around and adjust as necessary.

As the procedure did not require a verbal announcement of these two verifications, it was not possible for either crewmember to identify that the other crewmember had omitted these actions. Thus, the opportunity to identify an omitted action by a crewmember was lost and the need to take immediate recovery action and rapidly increase engine thrust was not identified.

The Copilot called "Positive climb" 1.5 seconds after confirming flaps 20, when the Aircraft vertical speed was approximately 592 ft per minute, and the airspeed was decreasing



towards 147 kt IAS. The Copilot's call was followed by the Commander's call for 'gear-up', four seconds after the Aircraft became airborne. The airspeed continued to decrease and was 145 kt IAS at 58 ft radio altitude with the pitch angle increasing towards 8.4 degrees.

During the time between the Commander's 'gear up' call and the Copilot's landing gear lever selection to 'up', the Tower contacted UAE521 and issued, over a period of about three seconds, a modified missed approach altitude and heading instruction. Just after the Copilot read back the Tower instruction correctly, the Aircraft reached its maximum height above the runway of 85 ft radio altitude with the airspeed at 131 kt IAS. The Copilot selected the new altitude of 4,000 ft in the MCP as the Aircraft started to sink. The Copilot did not check that the flight director was 'on' after selecting the landing gear lever to 'up' as required by the *Go-Around and Missed Approach Procedure*.

Less than 12.5 seconds from the time that the TO/GA switch was pushed, the Aircraft had insufficient energy remaining to gain further height. The energy loss was aggravated by the landing gear doors opening.

The Aircraft loss of airspeed was perceived by the Commander as a windshear effect, which prompted him to call "Windshear TOGA". The sink rate was increasing towards 500 ft per minute as the Aircraft sank below 67 ft radio altitude with the airspeed decreasing below 130 kt IAS. Soon after, the Commander pushed the TO/GA switch and manually advanced both thrust levers fully forward, as per the Operator's *windshear escape maneuver* procedure. Only at this time did the Commander realize that the engines were not producing sufficient thrust.

Eighteen seconds after the initiation of the go-around the Aircraft impacted runway 12L approximately 2,530 m beyond the runway threshold. The Aircraft was controllable until impact, but the height available was insufficient to prevent impact with the runway.

The Aircraft manufacturer's post-Accident *Performance Evaluation* calculated that, as the Aircraft gained height, at approximately 58 ft radio altitude when the landing gear lever was selected to the 'up' position, a successful go-around could have been flown had the thrust levers been advanced to go-around thrust by the A/T, or immediately by manual advancement of the thrust levers, and had the pitch been maintained at go-around pitch. The performance analysis indicated that as the engines accelerated, the Aircraft would lose some height but would clear the runway at a minimum height of 17 ft radio altitude before safely climbing away. This hypothetical recovery scenario was possible, had the UAE521 flight crew been aware of the Aircraft state, which was not the case.

The Investigation concludes that the Commander maintained the stabilized approach criteria established by the Operator during the attempted tailwind landing. However, the landing distance was increased due to the early flare, the updraft created by the thermals rising from the runway surface and flight in ground effect which caused the Aircraft to remain airborne beyond the *FCTM* recommended touchdown of between 305 m to 610 m. Beyond this point, the Aircraft entered a performance increasing windshear as the wind shifted to a headwind. The Copilot, as the pilot monitoring, did not observe that the Aircraft airspeed was increasing as it descended below 7 ft radio altitude and that it had reached 165 kt at 2 ft radio altitude.

The Investigation concludes that the Commanders' decision to go-around was because he was unable to land the Aircraft within the touchdown zone. His decision was in line with the Operator's policy and was based on his perception that the Aircraft would not land due to thermals and was not due to a windshear encounter. For this reason, the Commander elected to fly a normal go-around and not to fly the windshear escape maneuver.



Because the Commander was not aware that the Aircraft had touched down and that the TO/GA switches were inhibited, he relied on the Aircraft automation when he pushed the TO/GA switch based on his training for the initiation of a normal go-around. His perception, as well as that of the Copilot, was that the Aircraft was airborne when he pushed the TO/GA switch. However, neither pilot had monitored the engine thrust and Aircraft performance as required by the *Go-Around and Missed Approach Procedure*. By the time the loss of airspeed was recognized, the actions taken in executing the windshear escape maneuver were too late to avoid impact with the runway.

The Investigation recommends that the Aircraft Operator disseminate, to its pilots, knowledge, and information about factors affecting landing distance and flare duration, such as aircraft height and airspeed above the threshold, early flare, and weather conditions that may affect aircraft performance during the landing.

Additional recommendations related to flight crew training standards and procedures are contained in this Report.

Appendix E provides a summary of the Aircraft events, in a table format, starting when the Aircraft passed over the threshold until the impact with the runway. Only relevant distances beyond the threshold are stated in the table.

2.3 Aircraft Systems

2.3.1 TO/GA switch logic

The rationale for inhibiting of the TO/GA switches is included in the guidelines of the Federal Aviation Administration of the United States (FAA) *Advisory Circular 120-29A*, paragraph 5.14.b which states that the “ability to initiate an automatic or flight director go-around at or after touchdown is not required or appropriate.”

Even though the FDR does not record the input that inhibits the TO/GA switches, the Investigation believes that the Aircraft TO/GA switches were inhibited as a result of the right main gear initial touchdown based on analysis of the TO/GA inhibit logic.

The Investigation concludes that the TO/GA switches were most likely serviceable when the Commander pushed the switch because examination of the Aircraft historical maintenance records did not indicate any technical problem affecting the switches nor was any TO/GA switch defect observed by the UAE521 flight crew during the takeoff from Trivandrum.

When the right main landing gear contacted the runway, before the Commander pushed the TO/GA switch, the air/ground system sensed that weight was on the right main landing gear. As designed, the right main landing gear weight-on-wheels (WOW) signal fulfilled the conditions to inhibit the TO/GA switches. In this situation, the only means to increase engine thrust is manual advancement of the thrust levers, which will cause the A/T to disconnect and an AUTOTHROTTLE DISC message will appear on the engine information and crew alerting system (EICAS). The Investigation noted that neither the *FCTM* nor the *FCOM* mentions that this message will appear on the EICAS during a go-around initiated after touchdown.

Based on the analysis of the CVR recordings, the Investigation concluded that a click sound recorded by the CVR just before the Commander called ‘go-around’, was, most likely, the sound of the TO/GA switch being pushed by the Commander.

FAR 25.1329(k) states “Following disengagement of the autothrust function, a caution must be provided to each pilot.” However, there is no requirement to ensure that the



flight crew are informed when the A/T go-around mode becomes unavailable due to inhibiting of the TO/GA switches.

The Investigation agrees with the Aircraft manufacturer that any alerting messages during landing, especially close to or after touchdown, will cause flight crew distraction and may lead to crew errors. However, the Investigation believes that the TO/GA switch design logic may mislead pilots especially during high workload situations of a go-around close to the runway and/or after touchdown. With the A/T in 'arm' and active, pilots' reliance on A/T automation may allow them to overlook the non-availability of the A/T to make mode changes when the aircraft is within 2 ft radio altitude of the runway or when the flight crew are not aware that the aircraft has touched down.

For UAE521, both the Commander's and Copilot's situational awareness of the Aircraft state was that the Aircraft was still in 'air' mode. Therefore, the Commander applied the normal *Go-around and Missed Approach Procedure* of pushing the TO/GA switch to initiate the go-around based on his multiple training sessions where the A/T had automatically advanced the thrust levers. Additionally, pilots are trained to use the A/T for all phases of flight, including during takeoff when they are required to push the TO/GA switch below 50 kt in order for the A/T to advance the thrust levers to achieve take-off reference thrust.

The Investigation concludes that a manual advancement of the thrust levers, followed by pushing the TO/GA switch as the aircraft gains altitude, in a go-around will ensure that the crew remains in control and maintains full awareness of changes in engine thrust.

The Investigation recommends that the FAA perform a safety study, in consultation with the Aircraft manufacturer, for the purpose of enhancing the Boeing 777 autothrottle system and TO/GA switch inhibit logic so that pilot errors due to overreliance on automation will be avoided. The study should also consider procedures and training of the autothrottle system and TO/GA switches inhibit logic, and manual advancement of the thrust levers for a go-around initiated at low altitude and for a go-around initiated after touchdown.

2.3.2 Crew alerting system

As designed, the B777 crew alerting system provides cockpit alerts to warn the flight crew of an aircraft configuration inconsistency during the takeoff, landing and go-around after touchdown phases. However, for a go-around aircraft configuration that is inconsistent with the maneuver, no alert is provided to the flight crew.

The take-off configuration warning system warns the flight crew when the aircraft configuration is inconsistent with takeoff requirements and a CONFIG message is displayed in the EICAS, together with a 'master warning' (visual and aural).

During landing, a CONFIG GEAR message will be displayed in the EICAS, together with a 'master warning' (visual and aural) if the landing gear is not extended, and either thrust lever is at idle and the radio altitude is less than 800 ft, or the flap lever is in the landing configuration (flaps 30).

For a go-around after touchdown, a CONFIG FLAPS message will be displayed in the EICAS together with a 'master warning' (visual and aural) during a normal go-around after touchdown when the flap lever remains in the landing configuration (flaps 30) and the thrust levers are advanced to TO/GA thrust. If the A/T disconnect switch is not pushed, the advancement of the thrust levers will cause the A/T to disconnect followed by a cockpit AUTOTHROTTLE DISC caution message in EICAS, an aural alert and 'master caution' illumination.



When the UAE521 Commander pushed the TO/GA switch, the Aircraft pitch angle started to increase towards 7 degrees. The 'air/ground' system transitioned to 'air' mode, and the Aircraft started to climb. The speedbrake lever automatically returned to the 'arm' position and the flaps retracted from 'flaps 30' to 'flaps 20' as commanded by the Copilot's movement of the flap lever. The vertical speed changed from descent to climb and the landing gear was transitioning to the 'up' position. During this time, the airspeed continued to have a decreasing trend. As identified in the post-Accident Aircraft manufacturer's *Performance Evaluation*, the Aircraft could have safely performed a go-around up to and including the time when the landing gear was selected to 'up' had the TO/GA switch been pushed and/or the engine thrust levers been manually advanced to achieve go-around thrust.

Analysis of the EEC data by the engine manufacturer indicated that the EEC was responding to the Aircraft status during the go-around. Both engine idle speeds had stabilized at low idle and as the Aircraft started to climb above 5 ft radio altitude, the EEC changed from ground to flight status and commanded the engines to high idle. The EEC continued to adjust the idle speed as flaps 20 was selected and when the landing gear lever was selected to 'up'.

The Investigation concludes that the Aircraft configuration changes that were occurring after the Aircraft became airborne, together with the decreasing airspeed trend, was sufficient for the Aircraft systems to identify that the Aircraft was in an incorrect configuration for the attempted go-around maneuver. However, the crew alerting system was not designed to give a configuration warning for a go-around with the engine thrust levers not advancing towards the TO/GA position.

The Investigation recommends that the Aircraft manufacturer enhance the B777 crew alerting system to include configuration inconsistency when a go-around maneuver is commanded and the engine thrust is insufficient for the maneuver.

2.3.3 Windshear warning system

The Aircraft weather radar predictive windshear system (PWS) and the enhanced ground proximity warning system (EGPWS) immediate windshear warnings are inhibited from giving warnings/alerts below specific heights so as to avoid distraction to the flight crew during the critical landing phase when the aircraft is close to the runway. The systems are inhibited when the aircraft descends below 50 ft radio altitude for the weather radar, and below 10 ft radio altitude for the EGPWS.

The wind conditions that existed as UAE521 descended below 1,200 ft radio altitude did not contain moisture for reflectivity which is a requirement for the weather radar to detect windshear. A review of the FDR data for UAE521, indicated that the Aircraft performance was not degraded due to windshear⁴⁸ including when the Aircraft was below 50 ft radio altitude and the PWS was inhibited.

From the FDR data between 1,500 ft to 10 ft radio altitude, the Aircraft airspeed and pitch angle, did not exceed the predetermined threshold values⁴⁹ in the EGPWS for an immediate windshear alert. There was no Aircraft decreasing performance due to the change of wind from headwind to tailwind component as the Aircraft descended below 750 ft radio altitude. The Commander had maintained an almost constant rate of descent and indicated

⁴⁸ RTCA DO-220 document describes the predictive windshear alert system and the "performance degrading" conditions required the system to provide caution and alert messages. Radio Technical Commission for Aeronautics (RTCA) DO-220 document contains *Minimum Operational Performance Standards for Airborne Radar Systems*

⁴⁹ The threshold requirements are in accordance with FAA Technical Standard Order (TSO) TSO-C117a – *Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes*.



airspeed as the Aircraft descended below 750 ft radio altitude until the flare initiation at 40 ft radio altitude.

The Investigation concludes that both the weather radar predictive warning system and the EGPWS, as designed, were capable of providing windshear alerts. Even though the air was dry, during the approach, the wind conditions that existed up to 10 ft radio altitude did not have a decreasing and/or increasing performance on the Aircraft that exceeded the predetermined threshold values.

The Investigation noted that the EGPWS manufacturer document *Product Specification – Mode 7 – Windshear Alerting* was capable of providing a windshear caution alert for aircraft performance increasing due to increasing headwind (or decreasing tailwind) and severe updrafts. However, this feature was not available to the flight crew because it was not enabled on the Aircraft.

In accordance with the FAA *Technical Standard Order TSO-C117a – Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes*, the windshear systems are required to provide:

“(x) Windshear Caution Alert. An alert triggered by increasing performance conditions, which is set at a windshear level requiring immediate crew awareness and likely subsequent corrective action.”

Due to the Aircraft system design, there was no engineered defenses available to alert the crew to a performance increasing windshear. It is possible that if the flight crew had perceived the Aircraft to have encountered a windshear, the applicable procedure would have been to fly a windshear escape maneuver which includes the manual application of full thrust.

The Investigation recommends that the FAA perform a safety study, in consultation with the Aircraft manufacturer, for the purpose of enhancing the Boeing 777 windshear alerting system. This study should encompass both ‘predictive’ and ‘immediate’ *TSO-C117a/b* windshear systems.

2.4 The Operation

2.4.1 Go-around training

Go-around at minima, missed approach, windshear maneuver, and rejected landings were included in the Operator’s ground school based training and full flight simulator sessions. All maneuvers, including rejected landing, were performed in the ‘air’ mode. Except for rejected landings, the Investigation was unable to determine if the Operator practiced normal go-arounds below 25 ft radio altitude when the A/T would have begun to transition to ‘IDLE’ mode.

The Operator’s normal go-around training did not address TO/GA switch inhibit logic and its effects on FMA annunciations and on the flight director.

Contrary to the *FCOM – Go-around and Missed Approach Procedure*, the flight crew omitted⁵⁰ the critical step of engine thrust verification and the Copilot omitted the step that required him to adjust the thrust as required. Up until the time when the Copilot said “flaps 20”, the other steps of the procedure between ‘positive climb’ and ‘gear up’ were performed without consideration for engine response time.

⁵⁰ PARC/CAST Flight Deck Automation Working Group – *Operational use of Flight Path Management Systems* - September 2013.



The Operator's normal go-around training did not contain information regarding the time taken for the engines to achieve TO/GA thrust either by manual advancement of the thrust levers, or by use of the A/T after the TO/GA switch is pushed. With the thrust levers at the idle position, it can take between 6 and 8 seconds for the engines to achieve TO/GA thrust. The Investigation believes that this awareness is important for flight crews and that they should wait and verify/adjust the engine thrust increase before going to the next procedural step of *Go-Around and Missed Approach Procedure* of calling "Positive Climb".

The Investigation believes that besides missing the step to verify and adjust engine thrust, the Commander's and Copilot's apparent rush regarding executing the flaps 20 selection, positive climb and gear up procedural steps, most likely reflects familiarity with their go-around training sessions.

This conclusion is based on the information provided by the Operator's FDM go-around data which indicated that 39 percent of operational go-arounds, the timings between flaps lever movement to flaps 20 and landing lever to gear-up position was less than four seconds⁵¹. From the UAE521 CVR data (Appendix E of this Report), the timing between the Copilot's confirmation of 'Flaps 20' and the Commander's call for 'gear up' was 2.5 seconds. Therefore, considering that after the TO/GA switch has been pushed the engine thrust increase must be verified before confirmation of 'positive climb' may indicate, from the UAE521 data and the Operator's FDM data, that flight crews' are probably relying on the A/T automation and not monitoring the engine instruments for verification that engine thrust has actually increased to achieve TO/GA thrust.

Provided that both the Commander and the Copilot had become fully aware that the engine thrust was not increasing, the latest point in the go-around attempt whereby an action to increase thrust could have been taken with a certain level of confidence was when the command was given for 'gear-up'. When the Commander eventually advanced the thrust levers another seven seconds had elapsed from the time when he said 'gear up' which was too late to recover the Aircraft.

The training reference that is used by the Operator for a go-around after touchdown is stated in the *manual handling phase 2* training contained in the Operator's *B777 training manual*. As part of this manual phase training, the pilot was required to retract the flaps from position 30 to flaps 20, rotate the aircraft at V_{REF} and increase pitch towards 15 degrees.

This *manual handling phase 2* training requirement as practiced by the Operator's pilots, for a go-around after touchdown, were neither reflected in the *FCTM* nor the *FCOM*. One of the objectives of the manual phase training was to enhance manual handling skills and to practice manually flown all-engine go-arounds initiated just after touchdown.

In preparation for this simulator session the A/T, autopilot and flight directors were selected to 'off', and the trainee was made aware of this condition. The trainee was required to push the TO/GA switches and to note that there was no response and then to manually advance the thrust levers fully forward.

The exercise was not intended to replicate conditions of unforeseen TO/GA switch inhibiting during critical phases of flight, where the flight crew was required to be aware of the flight and aircraft status, and to react appropriately. This exercise was the only training opportunity where pilots encountered A/T unavailability for mode change after touchdown, and

⁵¹ See section 2.4.5 of this Report.



manual advancement of the thrust levers was the only available means to increase engine thrust.

In developing the training for a go-around after touchdown contained in the Operator's *B777 training manual*, scenarios for go-arounds in automatic flight, and in manual flight with the A/T armed and active, were not considered. The inhibit logic of the TO/GA switches, the effect on the FMA, and the flight director were also not considered, and as a result were not part of the training syllabus. Because the UAE521 flight crew, and other pilots at the Operator, were not trained for a go-around initiated after the TO/GA switches become inhibited, they would have not been aware that the A/T would stay at 'IDLE', and that the flight director would not have provided pitch and go-around guidance.

The investigation believes that the current training the Operator has in the *manual handling phase 2* training does not replicate a normal go-around whereby the TO/GA switches, by design, become inhibited after touchdown. A normal situation would be with the flight director 'on' and the A/T will be in 'arm' and will be active, and for an automatic flight, the autopilot would be 'on'. Pilots should be exposed to simulated normal go-arounds performed prior to touchdown as well as after touchdown so they become aware of the effects on the A/T, the FMA and the flight director. In addition, flight crew should be aware of the time it takes for the engines to achieve TO/GA thrust. This will require a procedural enhancement and training amendment to be established by the Operator.

The Investigation concludes that the Operator did not thoroughly review and identify hazards regarding go-around training standards and go-around procedures. As stated by the Operator, the training program implemented by the Operator during the *manual handling phase 2* training was accepted as a training standard for a normal go-around executed after touchdown, even though both go-around situations were different. In addition, the Commander's and Copilot's lack of training exposure to a normal go-around just prior to touchdown and after touchdown was not identified as a risk, and therefore was not addressed by the Operator. Neither the Aircraft manufacturer nor the Operator thoroughly addressed training and procedures dealing with times when the TO/GA switches become inhibited.

The Investigation recommends that the Operator enhance the normal go-around and missed approach training standards which should include simulated scenarios for a normal go-around initiated close to the runway and after touchdown when the TO/GA switches are inhibited, and pilot awareness of the engine response time to achieve go-around thrust.

The investigation recommends that the Operator enhance training standards regarding the TO/GA switches inhibit logic so that pilots are aware of the effect on FMA annunciations and the flight director, and the availability of the A/T after the aircraft becomes airborne.

2.4.2 TO/GA switch inhibit information

The Operator's training program for the B777 was based on the Aircraft manufacturer and FAA-approved training program, which did not include the TO/GA inhibit logic.

The Operator's *OM-A* policy, as well as the Aircraft manufacturer's recommendation, is for pilots to use the A/T for all phases of flight, including all normal go-arounds. However, when the A/T is controlling engine thrust, the TO/GA switch inhibit logic characteristics were not clearly demonstrated to the pilots. The exceptions to this policy are when there is a procedural action that requires the A/T to be disconnected, or when the A/T is unserviceable. Under either situation, pilots are made aware that manual intervention is required for any thrust changes.



Both the Commander and the Copilot had attended the initial computer-based training (CBT) for the B777. However, the CBT did not cover TO/GA switch inhibiting or FMA changes caused by a go-around initiated after the TO/GA switches became inhibited.

Neither the Commander nor the Copilot had a complete understanding of the TO/GA switches and they were not made aware during their training that the TO/GA switches become inhibited when the radio altitude is less than 2 ft for a time greater than three seconds prior to touchdown. The Operator's *crew resource management manual* stated:

"The major problem that has been identified with automation is due to a lack of understanding. If we do not fully understand the system, we are not able to anticipate the system response or evaluate its performance."

Therefore, based on his incorrect perception that the Aircraft had not yet touched down, the UAE521 Commander would have expected the A/T to be available when the TO/GA switch was pushed. In fact, the Aircraft had touched down and the TO/GA switch was pushed 2.5 seconds after touchdown.

The *FCTM* stated that if a go-around is initiated by pushing either TO/GA switch before the aircraft touches down, the A/T applies go-around thrust and the go-around would continue. It is then required to observe that the A/T provides go-around thrust, or to manually apply go-around thrust when the aircraft rotates to the go-around attitude. A 'note' in this section advised that an automatic go-around cannot be initiated after touchdown. The *FCOM* provided information that the TO/GA switches are inhibited on the ground and enabled again when in the air. As the TO/GA switches can be inhibited before touchdown, these statements could be misunderstood to imply that under all flight situations, pushing the TO/GA switch just prior to touchdown will cause the A/T to automatically advance the thrust levers.

Five seconds after the right main gear touchdown, the Aircraft started to gain altitude above 2 ft through nose-up control inputs. As per the TO/GA switch logic, the A/T was enabled again above 2 ft radio altitude, but now required the Commander to push the TO/GA switch in order to be activated. This action would also have enabled the flight director to provide guidance for the go-around. Similar to the logic inhibiting the TO/GA switches when the aircraft was below 2 ft for a time greater than three seconds, the availability of the A/T when the aircraft climbed above 2 ft radio altitude was not stated in the *FCOM* and *FCTM*.

The Investigation concludes that the use of the A/T during a normal go-around and missed approach and the effects of TO/GA switch inhibiting prior to and after touchdown were not given the necessary attention in the training information included in the *FCTM* and *FCOM*. In addition, TO/GA switch inhibiting information was not given the necessary advisory level (warning, caution or note) in the *FCOM* and *FCTM*.

The Investigation recommends that the Aircraft manufacturer enhance the Boeing 777 *FCOM* and *FCTM* for consistency in TO/GA switch inhibiting information. In addition, it is recommended to appropriately highlight the significance of the effects on the A/T due to the TO/GA switch inhibit logic in the *FCOM* and *FCTM*.

2.4.3 Go-around procedures

The Operator did not have an *FCOM* procedure for 'go-around after touchdown' as the Operator followed the *FCOM – Go-Around and Missed Approach Procedure* for all normal go-arounds.

For a go-around after touchdown, there was no reference in the Operators' *FCOM* regarding when to retract the flaps, the rotation speed, and crew awareness of associated warning/alert messages as the thrust levers are advanced. The only reference the Operator



had was stated in the *FCTM*, which referred to *Touch and Go Landing* and the Operator's *B777 training manual* which included *manual handling phase 2* training for go-around after touch down.

The Operator's *FCOM* procedure required both pilots to silently verify that the aircraft rotates to go-around attitude and that engine thrust increases. It also required the pilot monitoring to silently verify that the thrust is sufficient for the go-around or to adjust the thrust as necessary.

In comparison, the *FCOM takeoff procedure* requires verbal verification that the correct take-off thrust is set after the TO/GA switch is pushed. The pilot monitoring is required to adjust if needed and call "Thrust set". This procedure also requires the pilot monitoring to monitor the engine instruments and for the pilot flying to keep his hand on the thrust levers until V_1 . Additionally, the *FCOM non-normal checklist* confirmation calls for a go-around with an A/T inoperative, the pilot flying is required to call "Set go-around thrust".

The *FCTM* stated that when the term 'set thrust' or 'verify that thrust is set' is used in various places in the *FCTM* and the *FCOM*, the pilots are required to check that the proper thrust is set by verification of the engine pressure ratio (EPR). However, the procedure for a normal go-around did not require verbal verification of thrust setting.

The *FCTM* reminds pilots that the engine automation system does not relieve pilots from monitoring the engine parameters and verifying that proper thrust is obtained. The Investigation agrees with this statement and believes that the need for a thrust setting callout and verification is significant, especially in critical situations such as go-arounds.

During B777 simulator sessions performed by the Operator, the Investigation observed that the pilot flying keeps his hand on the thrust levers during approach and landing. The Operator stated that this technique is a key part of the simulator training, and trainees may be failed on this. However, there was no reference to this technique of guarding the thrust levers in the Operator's manuals. During his interview, the Commander stated that he had his right hand on the thrust levers during the landing and the attempted go-around.

When the Commander decided to initiate the go-around, he pushed the TO/GA switch while the switches were inhibited, unaware that the A/T would not have moved the thrust levers. Under this condition, the A/T mode 'IDLE' displayed on the FMA would have remained the same and the only means to adjust engine thrust changes is by manual movement of the thrust levers. Neither UAE521 flight crewmembers looked at the FMA during this phase of the go-around. As stated by the Copilot, his verification of FMA changes was normally performed after selecting landing gear lever 'up'.

Had the Commander pushed the TO/GA switch with the TO/GA switches enabled, the FMA would have changed, as designed for manual landing, from IDLE / LNAV / VNAV PTH modes to THR / TOGA / TOGA. The Operator's procedure, as per *FCOM – Flight Mode Annunciations (FMA)*, except for landing when the aircraft is below 200 ft, FMA changes are required to be announced by the pilot flying and checked by the pilot monitoring. However, after the Commander pushed the TO/GA switch, the absence of FMA changes went unnoticed by the flight crew. Callouts of FMA changes were not included in the Operator's *FCOM – Go-Around and Missed Approach Procedures*.

The Investigation concludes that the normal go-around procedures lacked guidance as there was no requirement in the procedure for the pilot flying to call 'Go Around' at the initiation of the go-around and to monitor changes in the FMA and verify flight director guidance. The go-around training and procedure did not describe actions that were required should any of the parameters to be 'verified' not be achieved. In addition, as there was no



procedure for go-around after touchdown, it was left to the pilots to initiate flap selection and rotation speed.

The Investigation believes that the Operator should have a single procedure for normal go-arounds as this will make it easier for pilots to recall and to execute. However, this procedure should take into consideration normal go-arounds initiated before touchdown as well as after touchdown.

The Investigation recommends that the Aircraft Manufacturer include in the *Go-Around and Missed Approach Procedure*, and amend the *FCOM* and *FCTM* accordingly, requirements for the pilot flying to give call outs for thrust setting with verbal verifications of thrust increase being made by the pilot monitoring. In addition, emphasis should be made on the importance of guarding the thrust levers. The existing thrust setting callout in the *take-off procedure* could be referred to.

The Investigation recommends that the Aircraft manufacturer should study the benefits of adding callouts on flight mode annunciations (FMA) changes to the *Go-Around and Missed Approach Procedure*, and amend the *FCOM* and *FCTM* accordingly.

The Investigation recommends that the Aircraft Manufacturer conduct a safety study to determine the benefits of developing a common procedure for normal go around and missed approach. This procedure should consider manual advancement of the thrust levers at low altitude and after touchdown, and the requirements for a go-around initiated after touchdown including flap position, aircraft rotation speed and crew awareness of associated warning/alert messages.

2.4.4 Flight crew training

The Commander and the Copilot flight training records indicate that they both met the competency standard established by the Operator.

Even though the Commander did have comments about his landing technique during his upgrade training to become a commander, the Investigation believes that this was appropriately addressed during the simulator sessions, which is reflected in his overall PAM acceptable grading and line operational flights.

The Commander and Copilot FDM data on landings indicated that they never touched down beyond the touchdown zone.

In 2014, the Commander attended the *manual handling phase 2* training which included a manually flown go-around after touchdown. However, this training was not similar to the experiences of the Commander and Copilot during the attempted go-around of UAE521. The Copilot lacked exposure to go-around after touchdown, as he did not attend the *manual handling phase 2* training, after he qualified as a B777 first officer, due to his training schedule. The Investigation believes that both the Commander and the Copilot did not have sufficient guidance on how to perform a normal go-around just prior to touchdown or after touchdown because the Operator's training sessions that they both attended did not include these scenarios.

The Commander had experienced the condition of 'tunnel vision' and becoming fixated on a specific task, as identified by an evaluator in 2015. Even though the Commander came out of the fixation after the call of 'uncomfortable' was made, the Investigation believes that because the evaluator commented meant he had a concern.

The Operator's *crew resource management manual* stated:



“When workload is high, humans tend to become victims ‘attentional selectivity’, as their brains try to accept large and unmanageable chunks of information. The effect is that pilots will become focused on a task, and mismanage priorities. This is referred to as ‘tunnel vision’.”

The Operator did not have a requirement to review comments made on the online grading system (OGS) when a pilots’ PAM grading met the Operator’s acceptable proficiency standard. Thus, there was no follow up by the Operator’s training system concerning the evaluator’s comment about the Commander. The Investigation noted that the evaluator’s assessment of the Copilot, as recorded on the OGS, did not have a similar comment about him becoming fixated or being affected by tunnel vision.

The OGS used by the Operator only required a review by the B777 fleet training manager when the pilots’ performance was graded as 1 or 2. This indicated that the performance did not meet the required standard, and the training manager decided the required remedial actions. The Operator’s training system did not contain processes to review comments or to identify any trends in the observations of the evaluators.

The Investigation recommends that the Operator enhance the pilot training and assessment system to include procedures for managing evaluator comments on pilot performance including comments on pilots who have met the competency standard.

2.4.5 Safety management system

The Operator’s safety management system records did not contain a safety case study for normal go-arounds performed close to the runway and/or after touchdown, including when the TO/GA switches become inhibited during a normal go-around.

As stated in the alternative training and qualification program (ATQP) reports, between 2013 and 2015 a number of inaccurately executed all-engines-operating go-around events were highlighted by the flight data monitoring (FDM).

Additionally, based on heightened industry concerns about loss of control during high energy go-arounds, as documented by the Flight Safety Foundation and the United Kingdom Civil Aviation Authority (UK CAA), the Operator’s Group Safety Department conducted a safety review of FDM recorded go-arounds. The review revealed occasional instances of non-compliance with standard operating procedures, which included landing gear retraction prior to flap selection, and occasional instances of altitude deviations when go-arounds were flown without having the missed approach altitude pre-set, which led to the aircraft exceeding the intended altitude.

The safety review results were presented and discussed by the Training Review Committee in January 2014. Following this, all engines operating go-arounds for various reasons and from various altitudes were introduced into several flight crew-training modules. Related flight crew information regarding mishandled go-arounds was also published in the Operator’s flight safety publication in May 2014.

Following the Accident, as part of the Operator’s internal investigation, FDM data was reviewed to determine the time difference between the go-around missed approach procedural requirement of selection of landing gear lever to ‘up’ position after movement of flap lever to flaps 20 was selected, since this was assumed as an indicator of the time available for the flight crew to perform the engine thrust verification.

An analysis of 194 go-arounds showed an average time between flap and landing gear lever ‘up’ selection of 4.65 seconds, a time interval where the flight crew potentially were able to focus on thrust verification. Of the go-arounds, 39 percent showed a time interval below



four seconds, which is considered insufficient to complete the thrust verification step as required by the normal go-around procedure.

The Operator's internal accident investigation concluded that although the monitoring of the time between flap and landing gear lever 'up' selection during go-arounds is a good parameter to monitor the thrust verification procedural step, the absence of a reference event, such as the UAE521 Accident, did not prompt the Operator to analyze the available FDM data in the required context to identify the related latent issue.

The Investigation believes that predictions of a multi-layered failure of the safety net are a challenge for a safety management system. However, some factors and recommendations pertinent to the UAE521 Accident were present within the industry but were not analyzed in context with thrust verification due to the absence of a reference event. It is therefore believed that the key to a proactive SMS is a coordinated and structured data sharing initiative within the industry, spearheaded by the aircraft manufacturers. This Accident could potentially lead to a set of identified precursors being shared within the industry, to be adopted and monitored by individual airlines' FDM programs.

The Investigation recommends to the Operator a safety management system review and enhancement of the go-around training standards taking into consideration the available analytical flight monitoring data as well as the recommendations made within the industry, e.g. United Kingdom Civil Aviation Authority *Information Notice No. IN-2013/198 – Go-around Training for Aeroplanes*.

The Investigation believes that the FDM data provided by the Operator for the go-arounds as well as the Investigation findings related to UAE521 timings in executing the normal go-around procedural steps, can be utilized by the aviation industry to enhance safety.

As an example, the time difference between landing gear and flap selections during go-arounds, indicates the time available for thrust verification and identifies a potential lack of time, when the time period between selections is too short. This precursor to a potential go-around with insufficient thrust can be identified through an air operator's FDM program.

The Investigation recommends that ICAO, together with participation of the aircraft manufacturers, to study the benefit of establishing a global, coordinated and structured data sharing within the industry, which derives the precursors to accidents and serious incidents. This initiative should provide clear guidance on how these precursors can be identified through data analysis.

2.5 Flight Crew Performance

The Investigation analyzed the flight crew performance based on information collected from various sources including interviews, flight data recordings, training records and adherence to procedures. This section describes the human factors which had, most likely, affected the flight crew perceptions, decisions, and actions at the time of the Accident.

2.5.1 Fatigue

A number of factors determine the fatigue level of a flight crew at any time of the day. The Investigation considered the flight crew's previous 28-day shift roster, 72-hour sleep pattern, rest periods, their CVR recorded speech pattern and response times to ATC communications, the time of day in relation to the flight crew's circadian rhythm, and the flight crew's self-assessed physical fitness level and alertness at the time of the Accident.

The Investigation concluded that the Commander and the Copilot were adequately rested and alert at the time of the Accident, and there were no signs of fatigue.



2.5.2 Cockpit authority gradient

The Investigation evaluated recorded conversations from the CVR and determined that the cockpit authority gradient was appropriate for the composition of the flight crew. The Commander displayed an appropriate level of authority and actively requested and listened to input from the Copilot. Even though the Accident flight was the first occasion on which both flight crewmembers had flown together, throughout the recording there was no confusion about the role that each flight crewmember occupied. Cultural factors, which could have influenced the cockpit authority gradient, were not identified.

The Investigation concluded that the trans-cockpit gradient was not a factor in the Accident.

2.5.3 Flight crew communication

The CVR recordings showed that the flight crew were maintaining normal operational cockpit communication in accordance with the Operator's *sterile flight deck*⁵² policy. Operational calls and instructions were acknowledged by both crewmembers in a prompt manner. The recording indicated, from the tone of the voices, that the crew were alert and comfortable with the workload during the approach and landing.

The Investigation reviewed the recorded verbal interactions between the Commander and Copilot as the Aircraft floated over the runway and during the attempted go-around. The recordings indicated that the crewmembers were aware of the verbal callouts required by the Operator's *Go-Around and Missed Approach Procedure*. Even though it is stated in the *FCOM Appendix 1 – Standard Calls*, the Operator's *FCOM – Go-Around and Missed Approach Procedure* does not require the pilot flying to call out 'GO AROUND'.

The verification of thrust increase and thrust setting are silent items in the *Go-Around and Missed Approach Procedure* and therefore were not recorded. The CVR recording indicated that the flight crew did not notice that the engines had remained in idle thrust after the TO/GA switch was pushed.

2.5.4 Flight handling

According to the Operator's *operations manual*, the pilot flying is responsible for controlling the vertical and horizontal flight path, and for the energy management of the aircraft. The pilot flying receives relevant information for this task from the various aircraft indication systems, the pilot monitoring, and external clues. The pilot monitoring is responsible for monitoring the actions, or omission of actions, of the pilot flying, providing effective crosschecks and backup, followed by appropriate communication and intervention, when required.

Due to the ATIS reported moderate windshear warning, the Commander, as trained, performed the brief for a windshear escape maneuver and reminded the Copilot that there should be no configuration change in case of encountering a windshear. The Commander stated that because the ATIS windshear warning did not contain any additional information, he did not think there was a threat to the safe landing of the Aircraft.

The possibility of windshear at the aerodrome did not attract any additional attention on the part of the flight crew and they did not discuss the potential threat during the windshear briefing. As a result, the flight crew did not use this opportunity to request any additional safety

⁵² The Operator's *OM-A – Sterile Flight Deck*, stated: "During critical phases of flight, flight crew shall not perform any non-essential activities, which could distract or interfere in any way with the proper conduct of essential duties and activities."



and weather information from air traffic control. Besides the mention of no configuration change, and even though it was not a flight operations briefing procedural requirement of the Operator, the flight crew did not consider it necessary to reappraise themselves as to the additional actions and monitoring required in case of a windshear encounter and execution of the escape maneuver.

The Aircraft windshear alerting systems are designed not to give alerts below 50 ft for the weather radar PWS and 10 ft for EGPWS immediate alerts. Below 50 ft the flight crew, especially the pilot monitoring, should be alert to sudden changes in the aircraft flight path especially with reference to airspeed, vertical speed and pitch changes especially when windshear is forecast. For UAE521, both flight crewmembers' attention was mainly focused outside on the runway as the Aircraft passed over the threshold. Provided that the airspeed was monitored after the A/T mode changed to 'IDLE', the Copilot as the pilot monitoring would have observed that the airspeed had started to increase below 7 ft radio altitude instead of decreasing towards the landing reference speed V_{REF} of 147 kt.

The Investigation believes that had the UAE521 flight crew observed the speed increase of 12 kt that occurred over a four second period, the Commander may have been prompted to execute a go-around before the Aircraft had touched down. This likelihood is based on the Commander's experience of approximately four months before the Accident, when he performed a normal procedural go-around because the approach became unstable due to a rapid speed increase.

The Commander perceived that the Aircraft floated over the runway as a consequence of an environmental effect caused by what he expressed as "Thermals". The Copilot had the same perception which he expressed by responding "Check" to the Commander's call. The similar perception⁵³ of both flight crewmembers caused them not to notice that the extended float was as a result of the increased performance of the Aircraft as it gained additional airspeed of 12 kt (153 kt to 165 kt) due to the wind shift after the Aircraft had passed 7 ft radio altitude. As a result of the flight crew's shared mental model of the Aircraft state, they were still comfortable to continue with the landing at this point.

The Investigation concludes that during a windshear warning, the flight crew should be particularly attentive to aircraft performance changes by effective monitoring of the flight instrumentation. This is also stated in the *FCOM Supplementary Procedure – Adverse Weather – Precautions – Approach and Landing* for flight crew to closely monitor and callout deviations in the vertical speed, altimeters and glide slope.

The Investigation recommends that the Operator reiterate to flight crew the effects on aircraft performance due to wind changes that can affect the landing, and the significance of effective monitoring of the flight instrumentation during a windshear warning.

The Commander and the Copilot had a combined 6,415 flight hours on the B777 over a period of seven years. The UAE521 go-around attempt was their first exposure, either in line operation or in the simulator to a normal go-around where the Aircraft was close to the runway. In addition, they would not have experienced a line operational flight and/or exposure to simulated normal go-around when the TO/GA switches become inhibited. Thus, for the UAE521 flight crew, their most recent memory would be that of a normal go-around before

⁵³ The Civil Aviation Authority of the United Kingdom (UK CAA), *Civil Aviation Publication (CAP) 737 – Flight-crew human factors handbook*, 2014.



touchdown by use of the TO/GA switches to initiate the A/T to automatically apply engine thrust during the go-around.

The Operator's OM-A policy that the A/T was used for all flight phases was further conditioned in pilots during simulator training sessions, as the majority of normal go-arounds were performed before touchdown and initiated by pushing the TO/GA switches. Reliance on automation was also required during takeoff, as pilots were required to push the TO/GA switch below 50 kt for the A/T to advance the thrust levers. When the Commander of EK521 pushed the TO/GA switch, his expectation was that the automation of the A/T would respond and automatically manage the engine thrust during the go-around. Considering the Commanders' inaccurate situation awareness of the Aircraft state (that the Aircraft had not touched down) his action in pushing the TO/GA switch was in accordance with his training.

The Investigation concludes that the flight crew relied on the Aircraft A/T automation⁵⁴, and did not execute the go-around procedural steps thoroughly as the Aircraft was gaining height while the engine thrust levers remained at idle. Their actions could have been conditioned by the training sessions where they had executed the normal go-around procedures when the A/T would have automatically applied go-around thrust after the TO/GA switch was pushed. The Commander initiated a normal go-around in accordance with his training for a go-around before touchdown. He pushed the TO/GA switch believing that the Aircraft was in the 'air' mode, and that the normal go-around procedure was applicable.

The flight crew had performed numerous flights at OMDB, which included landings during periods of elevated ambient temperatures. They were aware of the effects of thermals, the physical layout of the runway including the displaced threshold, and runway markings and slope. During their interviews, they did not indicate that their performance was affected by environmental conditions or by visual illusion during the approach, landing, or the attempted go-around.

When the decision was made to go-around, the flight crew became fixated on the go-around maneuver which severely affected their situation awareness of the Aircraft state, including lack of awareness of the autothrottle mode⁵⁵. The tangible clues available to the flight crew that the Aircraft had touched down were the two partial deployments of the speedbrake lever, physical sensation of the landing and the change of cockpit environmental sound. These clues were not noticed because the Commander had already initiated the go-around and the attention of the flight crew was outside the cockpit.

The Commander stated that he became fixated on the go-around and described it as "tunnel visioned". Even though the Commander had stated that his hand remained on the thrust lever, his memory of what happened during this 'tunnel vision' period could have also been affected. The Investigation believes that the Commander's attentional tunnelling⁵⁶ was most likely related to the situational stress⁵⁷ related to the increased mental workload of the

⁵⁴ Civil Aviation Authority (CAA) *Paper 2004/10 – Flight Crew Reliance on Automation*.

⁵⁵ Automation mode errors are among the most common on advanced aircraft (International Journal of Aviation Psychology & Human Factors; Sarter & Woods).

⁵⁶ Stated by France Bureau d'Enquêtes et d'Analyses (BEA) – *Study of Airplane State Awareness during Go-Around* – 2013, this phenomenon, called channelized attention is defined as being "the allocation of attention to a particular channel of information, diagnostic hypothesis or task goal, for a duration that is longer than optimal, given the expected cost of neglecting events on other channels, failing to consider other hypotheses, or failing to perform other tasks" (Wickens, 2005).

⁵⁷ National Aeronautics and Space Administration (NASA) NASA/TM-2015-218930 - *Effects of Acute Stress on Aircrew Performance: Literature Review and Analysis of Operational Aspects*.



go-around. This most likely affected his performance as he missed several clues during the six seconds touchdown as well as he did not realise that there was no tactile feedback of thrust lever movement.

The Investigation concludes that the performance of both UAE521 flight crewmembers was most likely affected by situational stress related to the increased workload due to the go-around and awareness of the need to avoid a tail strike on rotation, as neither pilot had physically sensed the brief touchdown nor recognized that there was a change in the cockpit environment sound level during this period. Additionally, a lack of training in carrying out a normal go-around close to the runway significantly affected the flight crew performance in a critical flight situation, which was different from that experienced by the flight crew during their simulated training flights.

The Investigation recommends that the Operator enhance the simulated training scenarios for a normal go-around before and after touchdown. The training and simulator sessions should emphasize the importance of performing and verifying each procedural step.

2.5.5 Flight crew monitoring

Both flight crewmembers had attended training on monitoring techniques. There was no specific training employed by the Operator to train and measure the effectiveness of pilot instrument scanning technique and identification of abnormal indications.

Although it was stated in the *FCTM – Improper Use of the Flight Director*, that the flight director would provide accurate pitch guidance only after the aircraft became airborne, both UAE521 flight crewmembers did not pay attention to the flight director during the attempted go-around and missed an opportunity to identify that the Aircraft was not correctly configured for the go-around.

The Commander did not observe that the flight director was not giving accurate pitch guidance and that the FMA modes did not change after he pushed the TO/GA switch. The Copilot, as the pilot monitoring, also did not observe that the flight director was not providing pitch guidance. Additionally, the Copilot did not monitor the Aircraft primary flight instruments and during the attempted go-around responded to an ATC instruction just after he had selected the landing gear lever to 'up', instead of concentrating on his role as pilot monitoring.

The Investigation concludes that neither the Commander nor the Copilot monitored for FMA changes and flight director guidance on the primary flight display (PFD) because a number of organizational factors influenced their performance. These included: the Operator's go-around training standards, the OM-A policy did not clearly state that FMA changes are required to be called during a go-around regardless of the phase of approach or landing, and the lack of FMA callouts in the *FCOM – Go-around and Missed Approach Procedure*.

Flight crewmembers must carefully monitor the aircraft flight path, energy state and systems, as well as actively crosscheck the actions of the other pilot. Effective crew monitoring is vital in ensuring air safety. When a crewmember identifies an error or an unsafe act, this detection may break an adverse chain of events and prevent an accident. The Investigation believes that crew monitoring performance can be significantly improved when based on a policy, procedures and training.

The Investigation recommends that the Operator examine the training system and assess its adequacy in enhancing the skills of pilots in monitoring the cockpit instruments.



2.5.6 Crew resource management training

Both the Commander and the Copilot had attended the Operator's CRM training. The importance of decision making, the pilot monitoring function and ATC distraction were all presented to the flight crew. In addition, the importance of the concept of aviate, navigate and communicate was part of the CRM training.

Regarding the events of UAE521, the flight crew did not apply their CRM training during the attempted go-around. The decision to go-around was the correct decision as the Operator's policy requires a go-around to be flown if the pilot is unable to land within the touchdown zone. However, other elements of the CRM training including pilot monitoring, calling FMA changes, and ATC communication, played a part in the degraded UAE521 flight crew performance.

In addition, the Copilot as the pilot monitoring did not believe that there was a need to question the Aircraft state and therefore he did not apply the CRM trigger word 'uncomfortable' to express a concern during the landing and go-around.

The Investigation believes that crew resource management during the increased workload imposed on the flight crew by the long landing and attempted go-around was ineffective. Prior to touchdown, the Commander had twice expressed his perception as to what was happening to the Aircraft as it flew over the touchdown zone. Even though the Commander's decision to fly a go-around, per the Operator's policy, was the correct decision at no stage during the landing and the attempted go-around did the Copilot feel uncomfortable with the Commander's actions or decisions.

The initial confirmation bias and shared mental model⁵⁸ the flight crew had started to develop during the early stage of the go-around was most likely influenced because the Aircraft was performing as expected during the climb. The Commander's confirmation bias was further reinforced by the Copilot's call of "positive climb". There was no negative feedback by the Copilot to influence the Commander's decision-making process. As a result, based on the positive input from the Copilot, and without the Commander verifying that the Aircraft was in a positive climb, the Commander continued the checklist items towards 'gear-up'.

Unlike the simulator session in October 2015 when the Commander suffered 'tunnel vision' and recovered when the trigger word 'uncomfortable' was uttered, the Copilot did not believe that there was any reason(s) to challenge the Commander's actions. The Commanders' degraded performance continued during the initial climb but he regained situation awareness after the Aircraft had started to sink due to the loss of airspeed.

The Investigation concludes that the lack of application of CRM between the Commander and the Copilot during the attempted go-around likely indicates that the CRM training they received did not have the desired effectiveness. This may be especially true when the training is applied during a high workload situation similar to that experienced by the UAE521 flight crew. As the CRM subject matter experts are not required to attend the pilot training simulator sessions, the Operator leaves the feedback of CRM training effectiveness to the trained evaluators.

The Investigation recommends that the Operator determine the effectiveness of its CRM training and implement appropriate changes, taking into consideration the UAE521 flight crew performance related to this accident.

⁵⁸ The Civil Aviation Authority of the United Kingdom (UK CAA) *CAP 737 – Flight crew human factors handbook*, 2014.



2.6 Safety oversight

2.6.1 Emirates

The Operator had met the compliance requirements of the UAE *Civil Aviation Regulations CAR-OPS 1–Commercial & Private Air Transportation* with regard to B777 go-around training in a single engine situation. However, the *CAR-OPS 1* did not specify that training was required for rejected landing, bounced landing recovery, go-around below 50 ft or go-around after touchdown under normal engine power.

The Investigation noted that in June 2016, the GCAA issued a *Directive*⁵⁹ 08-2016 – *Upset Prevention and Recovery Training*, with an effective date of implementation from 1 September 2016. The referenced documents for the *Directive* required that operators should conduct the go-around exercises from various altitudes during the approach with all engines operating, taking into account the following considerations:

“

- Un-planned go-arounds expose the crew to the surprise and startle effect;
- Go-arounds with various aeroplane [aircraft] configurations and different weights; and
- Balked landings between decision altitude and touchdown or after touchdown unless thrust reversers have been activated.”

The *Directive* was incorporated in the latest revision of the *CAR-OPS 1* after the UAE521 Accident.

A review of the records of the GCAA audits over a 6-year period prior to the Accident showed that there were findings raised concerning the Operator's flight operations, safety and training areas. However, there were no significant findings related to the Operator's B777 go-around training standards, the pilots' grading system, and the Operator's hazard identification and risk analysis system for go-around procedures and training.

The GCAA audits were also conducted on the Operator's safety management system. Even though *CAR-OPS 1* recommended that the Operator's FDM program is required to be under the control of the safety management system post holder, the FDM program was managed by the Flight Operations department. This was also an audit finding by the GCAA prior to the Accident. However, the GCAA accepted that the FDM program be maintained under Flight Operations without any change as an acceptable means of compliance under *AC OPS 1.037*.

The Investigation believes that there was insufficient guidance provided with the inspector's audit checklist. As identified by the ATQP reports from the Operator, FDM data indicated that a number of go-arounds were inaccurately flown. However, as the oversight function did not identify this as an area of concern, there were no audit findings on the Operator's go-around training standards including go-around training below 50 ft and after touchdown. In addition, the audits did not identify that the Operator's procedures and training had insufficient guidance to pilots on how to perform a normal go-around just prior to and after touchdown when the A/T becomes unable to move the thrust levers because of the TO/GA switch inhibiting logic.

⁵⁹ The Directive made reference to ICAO Documents 9868 and 10011, as well as to EASA Annex II to ED Decision 2015/12/R related to AMC and GM for ORO.FC 220&230.



The Investigation recommends that the GCAA implement measures to improve the audit program, and the checklist used by the inspectors, so that the effectiveness of the oversight function related to flight crew training and flight operations is enhanced.

2.6.2 Meteorological services

The *Civil Aviation Regulations* for meteorological services, *CAR Part VIII*, Subpart 7, provide requirements for the GCAA as the 'Authority' governing the certification and operation of organizations providing meteorological services to aviation in the United Arab Emirates. However, *CAR Part VIII* does not give guidance regarding forecasting and reporting of windshear.

Because there were no specific requirements for what is required to be broadcasted during a windshear warning in the *Civil Aviation Regulations*, the windshear information passed to the flight crew of UAE521 did not have additional local concise information that may have benefited their awareness. The Investigation believes that the GCAA should enhance the *Civil Aviation Regulations* so that there is clarity and guidance regarding the requirements of aviation meteorology, including forecasting and reporting of windshear as recommended in *ICAO Annex 3 – Meteorological Service for International Air Navigation*.

Additionally, the GCAA oversight function and audits on the United Arab Emirates meteorological certificate holders and meteorological service providers are performed by inspector/s who are subject matter experts responsible for air traffic services because the GCAA does not have a trained, qualified and experienced subject matter expert in meteorology to perform these functions.

The Investigation believes that the safety oversight function and contribution of services provided by the GCAA, including alignment of the UAE *Civil Aviation Regulations* with *ICAO Annex 3 – Meteorological Service for International Air Navigation*, should be enhanced by employing a dedicated subject matter expert in aviation meteorology.

The Investigation recommends that the GCAA establish a position and induct a subject matter expert in aviation meteorology who is appropriately trained, qualified and experienced inspectorate.

2.7 Dubai Air Navigation Services

2.7.1 Communication

The Tower air traffic controller observed that the UAE521 Aircraft main gear wheels touched the runway during the attempted landing. After noticing that the Aircraft had started to climb away for a go around, the controller issued a modified missed approach instruction, which was to climb straight ahead and maintain 4,000 ft. This Tower instruction occurred four seconds after the Aircraft became airborne during the attempted go-around and at a time when the flight crew workload would have increased as they were focused on accomplishing the go-around maneuver. At this time, the Aircraft was passing 58 ft radio altitude as the Commander called for gear-up.

The Copilot had correctly read back the Tower instructions after selecting the landing gear lever 'up' when his attention was required to verify that the flight director was 'on' as required by the *FCOM – Go-Around and Missed Approach Procedure*. Instead, the Copilot changed the missed approach altitude in the mode control panel (MCP). The MCP selection was required because the missed approach altitude issued by ATC was different to the published United Arab Emirates OMDB *aeronautical information publication (AIP)* missed approach altitude of 3,000 ft.



Additionally, the Tower communication coincided with the landing gear selection to the up position which was the phase of the go-around that the Copilot had stated he would have normally verified the FMA changes. The Aircraft reached its maximum height above the runway of 85 ft radio altitude just after the Copilot read back the Tower instructions.

The Investigation concludes that the ATC communication, which occurred seven seconds after initiation of the go-around, did not contribute to the flight crew omitting the procedural verification of engine thrust increase.

The Investigation concludes that the timing of the modified go-around instructions should have been delayed as there was no threat to UAE521 flight safety and separation from other aircraft. The Tower instructions occurred at a critical phase of the go-around four seconds after the Aircraft was airborne and coincided with the landing gear selection to 'up' position. The modification of the go-around procedure by the Tower, inserted unexpectedly during this time, added to the flight crews' workload as they attentively listened and the Copilot responded to the Tower instructions which required a new missed approach altitude to be set. The flight crews' concentration on their primary task of flying the Aircraft and monitoring was momentarily affected as both the FMA verification and the flight director status were missed.

A review of the Tower recordings from the two previous missed approaches prior to the Accident, showed similar timed communications were made to AIC933 and UAE706. The Tower instructed both flights to fly a modified missed approach procedure, which was to climb straight ahead and maintain 4,000 ft. The fact that all three flight crews correctly responded to the Tower modified missed approach may indicate a conditioned response since an air traffic control communication at this critical stage, from a pilot's perspective, most likely is safety or traffic separation related.

The Investigation concludes that air traffic control communication to flight crew in times of high cockpit workload should be avoided unless such interaction is essential and critical for the safety of flight. ICAO *Doc 8168 – Aircraft Operations*, Chapter 7– *Missed Approach*, states: "Unless a greater priority exists, the pilot shall fly the missed approach procedure as published".

The Investigation recommends that the ANSP guidelines for the transmission of air traffic control instructions to flight crews be reviewed and implemented into unit procedures and continuation training to all current and future air traffic controllers. These guidelines should include, considering appropriate times and conditions where air traffic controllers may establish communications and issue instructions, with particular emphasis regarding critical phases of flight.

The Investigation recommends that the ANSP implement procedures to ensure that the ATC *missed approach procedure* in the *Dubai manual of air traffic service (DMATS)* are consistent and aligned with the *AIP*. (Reference should be made to European Aviation Safety Agency (EASA) *Safety Information Bulletin (SIB) No. 2014-06*).

The Investigation recommends that the ANSP implement procedures and guidance that would limit the air traffic controller, to the maximum extent, distraction caused to the flight crew by the issuance of instructions to flight crews that would modify the published missed approach procedures in case of a missed approach. (Reference should be made to European Aviation Safety Agency (EASA) *Safety Information Bulletin (SIB) No. 2014-06*).

The Investigation recommends that the GCAA publish recommendations for air navigation service providers:



- (a) to implement procedures and guidance that would limit the air traffic controller, to the maximum extent, from issuing instructions to flight crews that would modify the published missed approach procedures in case of go around with the sole exception of transmitting essential instructions to ensure air safety;
- (b) to emphasize the benefits of consistently applying the published missed approach procedure and the risks associated with modifications to such procedure at a time of high flight crew workload when potential for distraction must be minimized;
- (c) to emphasize, during all phases of air traffic controller training, the importance of correctly timed, concise and effective communication to flight crew performing a missed approach;
- (d) to incorporate appropriate details of the accident described in this report and the lessons learned into air traffic controller training.

Missed approaches can occur for various reasons and the criticality of the go-around increases when this is executed close to the runway, or after touchdown.

Even though there are recommended practices issued by the International Civil Aviation Organization (ICAO) concerning go-arounds, the Investigation believes that except where necessary for safety reasons, ICAO should align the practices and procedures with that of the published missed approach procedures followed by pilots.

The Tower controller who communicated with UAE521 would not have been aware that the B777 would have taken at least 60 seconds for the Aircraft to reach 2,000 ft radio altitude after initiation of a normal go-around close to the runway. When he communicated with the flight crew, the Aircraft was airborne for four seconds and passing 58 ft radio altitude. The Investigation believes that air traffic controllers standards and recommended practices should include guidance on when to safely initiate communication with the flight crew after initiation of a go-around.

The Investigation recommends that ICAO define Standards and Recommended Practices (SARPS) and/or procedures for air navigation services so that air traffic controllers, except where necessary for safety reasons are aware of when it is safe to initiate communication with the flight crew during a go-around. Reference should be made to European Aviation Safety Agency (EASA) Safety Information Bulletin (SIB) No. 2014-06.

2.7.2 ATC communication of safety information

At OMDB, the ATIS with information Zulu was broadcast at 0800 included a warning of moderate windshear for all runways.

From 0800 to 0823, 12 aircraft landed having flown a single approach to runway 12L. During this period, the surface wind at the threshold had a headwind component. After landing at 0824, flight IAW123 had reported to the Tower that there was an indication of light to moderate windshear on short final.

Between 0825 and 0830, the 2-minute recorded average surface wind shift on the runway 12L threshold was approximately 157 degrees. At approximately 0830, seven minutes before UAE521 attempted to land, the surface wind at the runway 12L threshold had shifted from a headwind to tailwind component. Except for runway 12R, runways 30R and 30L also had a tailwind component.

From 0829, four of the five aircraft that approached the runway threshold were affected during the approach and tailwind landing as noted in sequence of the approach:



- (a) At 0830, AIC933 an Airbus A321, performed a missed approach after passing the threshold of runway 12L;
- (b) At 0832, UAE706 a B777, performed a missed approach after passing the threshold of runway 12L;
- (c) At 0833, UAE409 a B777, performed an uneventful landing;
- (d) At 0835, UAE545 a B777, landed long [deep landing] within the touchdown zone;
- (e) At 0837, the Accident Flight UAE521 unsuccessful landing and attempted go-around.

Except for AIC933, which was informed by the Tower that the preceding aircraft, IAW123, had reported windshear on short final during the landing, the other four flights (UAE706, UAE409, UAE545 and UAE521) were not informed of the windshear report from IAW123 nor were the last three B777 flights (UAE409, UAE545 and UAE521) informed about the go-arounds of AIC933 and UAE706.

UAE CAR Part VIII, subpart 4 – ATS Organizations – section 6.6.17.7 Windshears – requires that “Descriptions of Windshears notified by aircraft should be relayed to following arriving aircraft and to departing aircraft.”

The reasons for the go-arounds were neither reported to the Tower by the flight crews, nor was information requested by the air traffic control. During this time, UAE521 was still communicating with the ATC Director. Therefore, UAE521 flight crew were not aware of the windshear reported by IAW123 nor were they aware of the two go-arounds performed by AIC933 and UAE706. In addition, the DMATS procedure is for the Aircraft Operator [Emirates] to notify the ground movement controller (GMC) of tailwinds during the approach once the aircraft has vacated the runway. This information was also not requested by GMC, nor provided by the two Operator's B777 flight crews that landed prior to UAE521.

In accordance with the Aircraft Operator's OM-A flight procedures, it was required that the flight crew of the aircraft that went around to advise ATC as soon as practicable.

After 0830, even though runway 12L had an acceptable recorded surface tailwind for landing, only runway 12R had a surface headwind component. Both the Tower and Approach watch managers discussed the onset of the sea breeze and tailwind conditions on runways 12L and 30R (opposite end of runway 12L) after the two missed approaches but they did not want to commit to a change of runway at that time as the threshold tailwind on runways 30R and 30L was more than 15 kt. A runway change would have required the use of single runway operations intended for both arrivals and departures, as runway 12R is normally considered a departing runway only.

When UAE521 was transferred to the Tower frequency, the Aircraft was approximately 63 seconds away from the runway 12L threshold and descending below 2,200 ft radio altitude. Except for the clearance to land and the threshold surface wind information, the Tower did not pass relevant safety information to UAE521 that may have assisted their situation awareness and decision-making.

The Investigation concludes that several essential information was not communicated to UAE521 flight crew which may have aided their decision making process. These included the missed approaches, the reported windshear on short final by flight IAW123, the continued gusting and windshear conditions, and the wind shift at runway 12L threshold from headwind to tailwind starting from 0829. Similarly, the three flights prior to



UAE521, did not receive essential information about the missed approaches and pilot report of windshear. All of this occurred during a period of 11 minutes starting at 0824.

The Investigation recommends that the ANSP enhances procedures and air traffic controller training, so that whenever windshear warnings are in effect at an aerodrome, essential safety information, such as go-arounds or long/deep landings, when reported by preceding aircraft, and wind gusts and/or wind shift, is transmitted to the flight crew at an appropriate time during the approach.

The Investigation recommends that the ANSP enhances procedures and air traffic controller training, so that when windshear warnings are in effect at an aerodrome, when safe to do so, the reason for an aircraft go-around, including wind conditions for aircraft that have landed, should be requested by the air traffic controller if the information has not been passed by the flight crew.

The Investigation recommends that the GCAA enhance the *Civil Aviation Regulations* for the provision of flight information services related to information regarding significant changes (see **Note**) in meteorological conditions. In particular, information regarding the latest information on windshear and/or turbulence in the final approach area or in the takeoff or climb-out area, should be transmitted to aircraft without delay, except when it is known that the aircraft has already received the information.

Note. Significant changes in this context include those relating to surface wind direction or speed, visibility, runway visual range or air temperature (for turbine-engined aircraft), and the occurrence of thunderstorm or cumulonimbus, moderate or severe turbulence, wind shear, hail, moderate or severe icing, severe squall line, freezing precipitation, severe mountain waves, sandstorm, dust storm, blowing snow, tornado or waterspout.

2.8 OMDB Windshear Forecasting

The GCAA certificate for meteorology at OMDB was the responsibility of 'dans'. The Dubai weather office of NCMS provided the meteorology services under contract to 'dans' and provided the meteorological documentation

ICAO *Doc 9817 – Manual on Low-level Windshear* states, "The most generalized explanation of windshear is "a change in wind speed and/or direction in space, including updrafts and downdrafts". Low-level windshear, normally from 1,600 ft to runway surface, can adversely affect aircraft performance and recovery, especially during final approach, landing, take-off and initial climb.

At OMDB, windshear due to the onset of the sea breeze is a known weather phenomenon. The NCMS standard operating procedures (SOP) gives guidance to the forecasters about identification of sea breeze front as well as the requirements of issuing a windshear warning without pilot reports.

The broadcast windshear warning on the day of the Accident was based on analyses of the synoptic weather conditions over Dubai. The weather stations fitted outside OMDB and within the Airport did not indicate windshear conditions. Additionally, one of the weather stations was decommissioned two years before the Accident.

At the time of the Accident, there was no agreement between the NCMS that the Aircraft Operator to provide additional automated weather information generated by the aircraft. This weather information could have been used by the NCMS to enhance windshear warnings.



When the windshear warning was issued at 0735 by the NCMS, the influence of the onset of the sea breeze had just started. The classification was for moderate windshear affecting all runways at OMDB. As per the NCMS SOP, this classification meant that the wind change was expected between 5 to 11 kt per 100 ft vertically.

ICAO Annex 3 – *Meteorological Service for International Air Navigation*, Chapter 6.2–*Format and dissemination of wind shear warnings and alerts*, paragraph 6.2.4 states:

“Note 2 - Specifications for reporting the intensity of wind shear are still undergoing development. It is recognized, however, that pilots, when reporting windshear, may use the qualifying terms “moderate”, “strong” or “severe”, based to a large extent on their subjective assessment of the intensity of the windshear encountered.”

ICAO Doc 9817 *Manual on Low-level Wind Shear* - Chapter 5.2.6, reference Table 5-4 Interim criteria for windshear intensity, recommended by the Fifth Air Navigation Conference (Montreal, 1967) classification of windshear intensity states:

“ ‘Light’ from 0 to 4 kt inclusive per 30 m (100 ft); ‘Moderate’ from 5 to 8 kt inclusive per 30 m (100 ft); ‘Strong’ from 9 to 12 kt inclusive per 30 m (100 ft); ‘Severe’ from above 12 kt per 30 m (100 ft).

Except for the anemometers installed at locations close to the threshold of runways 12L/30R and 12R/30L, and the wind profiler, OMDB Airport was not equipped with a low-level windshear system to detect localized windshear near the runways. The forecaster did not have current information of the wind conditions along the approach flight path, which was possible to obtain either from incoming aircraft, or from a weather station transmitting along the landing track. In addition, even though there was a windshear warning in effect, air traffic control did not request any of the flight crew to pass weather information either during the approach or after landing.

As OMDB was not equipped to do so, the information on the transmittal, as well as the final landing wind information that was passed to UAE521 by the Tower at 0836, did not contain important additional information that there had been a change in the wind speed and direction during the approach, as well as along the runway touchdown zone.

At 0836 the runway surface wind information passed to UAE521 indicated that at the threshold the Aircraft would be landing with a tailwind component of 11 kt from the northwest at 340 degrees. Neither the flight crew nor the Tower was aware that the wind shift along the runway was after the runway aiming point and before the end of the runway touchdown zone. Based on UAE521 FDR data for wind information and Aircraft airspeed, the change to a headwind component occurred at approximately 650 ft beyond the threshold of runway 12L when the Aircraft had descended below 7 ft above the runway.

Information about the approximate position along runway 12L that the change from a tailwind to headwind was occurring could have been provided through anemometers suitably placed alongside the runway touchdown zone.

The NCMS post-Accident analysis of the weather conditions over runway 12L concluded that as the Aircraft was crossing the tailwind sea breeze front, the Aircraft entered an area of updraft followed by the headwind. The entire transition from tailwind to updraft to headwind was approximately 120 m to 150 m horizontally along the runway. The total shear encountered in this quick transition would have caused an airspeed gain, which was recorded as 12 kt on the Aircraft FDR. The conditions that existed over runway 12L because of the high ambient temperature and the effects of the slow moving sea breeze front stalling over the runway, as per the NCMS historical data, indicated that the wind conditions at the time of the Accident were unusual for OMDB.



As per ICAO *Annex 3 — Meteorological Service for International Air Navigation*, under the section — *Wind shear warnings*, it was recommended that the information on the windshear warning be in accordance with local arrangements with the appropriate air traffic services unit and the operators concerned. In addition, the windshear warning is required to give concise information on the observed or expected existence of windshear which could adversely affect aircraft on the approach path or take-off path or during circling approach between runway level and 500 m (1,600 ft) above that level and aircraft on the runway during the landing roll or take-off run.

At OMDB, the aerodrome weather office had no ability to create, issue or distribute automated windshear alerts. ICAO *Annex 3*, chapter 7.4 — *Windshear warnings and alerts*, states “Windshear alerts are expected to complement windshear warnings and together are intended to enhance situational awareness of windshear.”

ICAO Annex 3, chapter 7.4 — *Windshear warnings and alerts*, states:

“

- 7.4.3: At aerodromes where windshear is detected by automated, ground-based, windshear remote-sensing or detection equipment, windshear alerts generated by these systems shall be issued. Windshear alerts shall give concise, up-to-date information related to the observed existence of windshear involving a headwind/tailwind change of 7.5 m/s (15 kt) or more which could adversely affect aircraft on the final approach path or initial take-off path and aircraft on the runway during the landing roll or take-off run.
- Chapter 7.4.4 Recommendation - Windshear alerts should be updated at least every minute. The windshear alert should be cancelled as soon as the headwind/tailwind change falls below 7.5 m/s (15 kt).”

The Investigation concludes that the windshear warning issued at 0735 did not highlight the significance of the sea breeze that was affecting the Airport runways and approach flight path. Except for the moderate windshear affecting all runways, the warning had no information as to the wind speed, direction and expected height of the wind shift along the approach path, as well as wind shift along runway 12L touchdown zone. If this information had been available to UAE521 flight crew, it may have alerted them and influenced their go-around decision making. The Commander has stated that because the ATIS windshear warning did not contain any additional information, he did not think there was a threat to the safe landing of the Aircraft and as a result, did not need to add additional speed for the approach.

The Investigation recommends that the ANSP, as the meteorological service provider certificated by the GCAA, evaluate and install automated low-level windshear detection and alerting equipment to enhance the accuracy and conciseness of the weather information broadcasted from the National Center of Meteorology (NCM) aviation meteorological forecasters and air traffic controllers.

Annex 3 — Meteorological Service for International Air Navigation, the section — *Wind shear warnings*, recommends that windshear warnings shall give concise information on the observed or expected existence of windshear which could adversely affect aircraft on the approach. However, there was no guidance in the *Civil Aviation Regulations* on what is required to be broadcast in the windshear warnings. The Investigation believes that the *Civil Aviation Regulations* should define what is the concise information required to be broadcast in the windshear warnings in coordination with the requirements of the local aircraft operators, the air navigation service providers, the aerodromes, and the meteorological service providers.



The Investigation recommends that the GCAA study the benefit of specifying, and incorporating changes to the *Civil Aviation Regulations*, the required meteorological equipment used for detection of low-level windshear and alerts; placement of anemometers along the runways; and receiving current aircraft wind information, that will enhance the accuracy and conciseness of the weather information broadcasted from the aviation meteorological forecasters and air traffic controllers.

2.9 Rescue and Firefighting

2.9.1 Airport rescue and firefighting service (ARFFS) response

The fire commander and the first two ARFFS major foam vehicles (MFVs) arrived at the Accident site within 90 seconds of the Aircraft coming to rest and immediately started to apply fire extinguishing agent. Additional firefighting vehicles arrived shortly after.

After the Aircraft came to rest, the fire continued on the separated No.2 engine. Video footage recorded by a passenger showed the aft lower portion of the No.1 engine on fire.

Other video footage showed black smoke, without visible flames, issuing from the lower fuselage in the vicinity of the right wing root area and the right main landing gear bay. This smoke continued to increase in density from the time the Aircraft came to rest until the center wing tank explosion.

When Fire 6 and Fire 10 were positioned close to the R4 door, they narrowed the escape path of the passengers, slowed down the evacuation of the Accident site, and limited the ability of the ARFFS crew to observe the movement of the evacuated passengers on the ground and take necessary actions to preserve their safety.

Fire 6 continued to use its main and bumper monitors to apply extinguishing agent to the fuselage directly above the right wing root and forward of the R4 door. A sideline was deployed from Fire 6 and a firefighter commenced cooling the right wing root and fuselage area. These actions from Fire 6 and the sideline operator had no effect on the right main landing gear fire.

When the firefighters exited Fire 10, they deployed a sideline and commenced fighting the right main landing gear fire from a closer position. One of these firefighters was later fatally injured by the explosion of the center wing fuel tank. Other firefighters from Fire 10 approached the detached No.2 engine inlet with a sideline but were unable to extinguish the fire. The No.2 engine exhaust fire was eventually extinguished when Fire 5 arrived and applied extinguishing agent.

Fire 10 firefighters had used its bumper monitor to spray agent over the top of the right wing and towards the R3 door. However, video evidence showed that there was no fire in that area, and the application of extinguishing agent and water to this area did not control, extinguish or cool the restricted landing gear fire, or the center wing tank.

No fire vehicle or firefighters were appropriately positioned or investigated the forward right quarter of the Accident site, and no detailed assessment of this area was conducted by the crew managers. Therefore, there was also no change in the tactics to position a vehicle at the forward right side of the Aircraft. Although Fire 5 did stop in this area for a few minutes, no detailed assessment was conducted by the crew. Fire 5 then repositioned to the right wingtip area.

Three more firefighting vehicles (Fire 1, Fire 7 and Fire 16) and two domestic fire vehicles (Fire 9 and Fire 11) positioned on the left side of the Aircraft. Fire 16 produced foam



through its main monitor over the top of the fuselage and on to the small No. 1 engine cowling fire. MFV 1 deployed a sideline towards R4 to protect the exit.

The initial firefighting tactics prevented the potential of any fire spreading from underneath the lower fuselage adjacent to the right main landing gear bay. This provided a safe path for the evacuating passengers on the right side of the Aircraft. At that time, and when the cabin doors were opened after firefighting had commenced, there were no signs of interior fire that would require immediate attention.

The dense black smoke that was being emitted from underneath the right side wing root leading edge should have alerted the fire commander to assess the fire dynamics and the source of the smoke, and accordingly review and change the firefighting tactics. Such a change required sufficient communication and information updates from the sector commanders. This opportunity was not realized because no sector commanders had been assigned from the beginning.

The positioning of the fire commanders' vehicle inside the incident area (Appendix D of this Report) did not allow him proper surveillance capability of the Accident site. However, the fire vehicles crew managers and firefighters were positioned in close proximity to the right wing root, an area of dense smoke, and they should have realized the developing situation and communicated this to the fire commander.

The initially intact condition of the Aircraft, the direct contact of the lower right side of the fuselage with the runway surface, and the inadequate Accident site surveillance, prevented the fire commander from positively identifying the source of the smoke. The fire commander did not reconsider the firefighting tactics by attempting to prevent heating of wing center tank residual fuel and consequently minimize the possibility of an explosion. MFV forward looking infrared (FLIR) cameras could have provided visual indicators during the initial assessment for hot spots or overheated aircraft components, and provide indications about the effectiveness of the firefighting tactics.

The Investigation concludes that during the offensive mode, there was no clear firefighting tactical plan. The major foam vehicles were positioned from where the smoke was issuing, no clear sectors had been established or sector commanders appointed, and at no time during the firefighting was high reach extendable turret (HRET), or secondary media (dry powder) considered.

After the explosion, the fire commander decided to change the firefighting tactic to defensive mode where, in theory, the identified risks outweighed the potential benefits. His attention was towards the safety of the ARFFS personnel over saving the Aircraft, because he believed that there was no expectation that the Aircraft could be saved.

The fire commander did not consider the hazard of the remaining fuel in the left wing tank, which had the potential to cause another explosion. Firefighters with sidelines were moving in close proximity to the left wing without awareness of the explosion hazard.

ICAO Doc 9137 *Airport Services Manual Part 1 – Rescue and Fighting* – chapter 12.1 *Features Common to All Emergencies* states:

"If the source of heat and fire cannot be controlled, fuel tanks exposed but not involved should be protected by appropriate agents to prevent involvement or explosion."

During this period of defensive mode, large volumes of water were used in an uncoordinated tactic, which prolonged the time until the Aircraft fire was brought under control.



The Investigation concludes that the lack of communication, and the inability of the fire commander, crew managers, or firefighters to identify the landing gear fire as the source of smoke, prevented the fire commander from exercising proper decision-making in vehicle positioning and from developing optimum firefighting tactics.

The Investigation believes that utilizing the FLIR effectively could have enabled the fire commander to identify the restricted access to the right main landing gear fire and to develop further tactics. However, identifying the landing gear fire would have required appropriate site surveillance supported by proper site sectoring, and sufficient communication among the crew managers, sector commanders, and the fire commander. This would have required better understanding of how aircraft fuel tanks behave in cases where they are exposed to heat. Given that approximately eight minutes was available from when the fire commander and two MFVs arrived at the Aircraft until the wing explosion, identifying the main landing gear fire and taking appropriate firefighting actions, may have provided an opportunity to prevent the tank explosion.

The Investigation recommends that the Airport enhance training for the ARFFS personnel to enable them to identify confined heat sources based on indicators and smoke traces. This training should enable the fire commander to understand the fire dynamic and determine the appropriate tactics, depending on the site circumstances and considering utilization of unique capabilities of the fire vehicles. This should be supported by sufficient training in incident command.

2.9.2 ARFFS training

The Airport emergency exercise of June 2015 revealed a number of deficiencies in the ARFFS emergency response. Those deficiencies were accurate indicators of the real deficiencies observed during the Accident. The exercise found that the Airport emergency personnel training was insufficient. In addition, the exercise revealed that the incident command system, triage, handling of evacuated persons, communication between the MICC and the other centers were inadequate.

The Investigation believes that the remedial actions taken by the Airport to address the identified deficiencies were inadequate, as there were many similarities that were repeated during the Accident response.

Firefighting tactics should be developed from the moment of arriving at the accident site and should be continuously re-evaluated depending on their outcomes, or based on fire dynamic changes. Fire dynamic changes should be communicated to the fire commander who should continuously evaluate the situation and make the appropriate adjustments. Communication with the fire commander should always be effective. The fire commander should be easily identifiable and visible at all times, in order to maintain close liaison with all on-site personnel.

The deployment of vehicles, personnel and equipment, the establishment of the MICC, and the positioning of casualty areas, are all critical steps in emergency management. The MICC should be the main source of information for all responding resources. Information collected and shared in the MICC specific to the aircraft, the cargo carried, existing conditions, available resources and technology, contribute to collaborative decisions guiding the actions taken to manage the accident.

The basic training program for new joiners and the subsequent maintenance of competency (MoC) training were not adequate to enable the fire commander, crew managers, and firefighters to assume their roles in a competent manner.



A fully developed retracted right main gear fire was an unprecedented aircraft fire situation and one that had not been considered within the current training program or maintenance of competency scheme.

The training records of the fire commander indicated that he had completed scheduled MoC training in firefighting techniques, evacuation procedure, combination fire with search and rescue, and risk assessment. However, the post-training performance assessment had not assured that the fire commander had acquired the competency needed for incident command. Training records did not clearly record the level of competency attained by the fire commander.

Training is required to enhance the competency of firefighters, crew managers, and fire commanders to enable them to identify confined heat sources based on indicators and smoke traces. This training should enable the fire commander to establish effective incident command, understand the fire dynamic and determine the appropriate tactics, depending on the site circumstances and considering the utilization of unique capabilities of the fire vehicles.

The Airport employs Boeing 777 and Airbus A380 mockups for external and internal fire scenarios. The external fire scenarios include fuselage, engine, and landing gear fires, and a combination of these. In all scenarios, the mockups simulated an intact aircraft, standing on its landing gear, with unhampered accessibility to the lower surfaces and landing gear. The scenarios did not consider a case where the aircraft was resting on its fuselage.

Practical training exercises, involving fire training facilities and aircraft mockups, should not be limited to simple fire scenarios, which are currently practiced and end once the correct equipment and support are deployed. Scenarios need to be established, based on appropriate simulated techniques that challenge the firefighters, crew managers and fire commanders to assess fire dynamics and to develop and re-evaluate tactics.

Practical training should assure replication of real life accidents with conditions that are more dynamic and situations that are not normal such as an aircraft resting on its lower fuselage or an aircraft not standing normally on its landing gear. Different weather and environmental conditions should also be considered.

The Investigation recommends that the Airports enhance the ARFFS personnel practical training exercises by including new scenarios based on appropriate simulated techniques, that challenge the firefighters, crew managers, and fire commanders to assess fire dynamics and develop tactics. The scenarios should replicate the circumstances of actual accidents, with various aircraft states. Different weather and environmental conditions should also be considered.

2.10 Survivability

2.10.1 Protective breathing equipment

The protective breathing equipment (PBE) training is conducted in a safe environment, utilizing simulated emergencies. A re-usable demo PBE is donned by the trainees during the training exercise. The demo unit is an already opened PBE that is stored in different conditions to the PBE units installed on an aircraft. This is common industry practice.

The flight and cabin crew received PBE training according to the Operator's training procedures, and the Investigation found no evidence that the crewmembers lacked competence in PBE use.



The Operator and the PBE manufacturer gained information based on the crewmember's experiences in their use of the equipment in dealing with the Accident. It was demonstrated that while the metal container and the plastic pouch adequately protected the stowed PBE from damage, their design did not support easy access to the PBE in conditions where the container is covered by fire extinguishing agent or other fluids. The metal container design did not comply with the access certification requirements of technical standard order number *TSO-C116a* issued by the FAA. The difficulty in accessing the PBE delayed its use and also caused other crewmembers to abandon their attempts to use PBE and they continued their emergency actions without oxygen support or face protection.

Difficulty in accessing PBE in emergency situations, where the crew is under physical and mental stress, and where they have to rely on oxygen support and face protection to carry out their primary emergency functions, may create a life threatening situation for crew and passengers.

The Investigation recommends that the FAA require the manufacturer of the PBE to evaluate the current design features of the PBE container (stowage compartment) and pouch, and develop modifications to prove compliance with *TSO-C116a* and *TSO-C99a* regarding easy access.

2.10.2 Evacuation and medical response

2.10.2.1 Passenger behaviour

Before the seat belt sign was turned 'off', passengers started to stand up. The cabin crew, who had been instructed to attend to their stations, were prevented by passengers in the aisles from moving into the cabin and addressing passengers directly. Instead, the passenger address system was used in an attempt to have the passengers remain seated.

By the time the Commander ordered the evacuation, one minute had elapsed since the Aircraft had come to a stop. During this one minute, time was spent by the flight crew in locating the emergency checklist which had been scattered with other loose items in the cockpit as a result of the impact. Before the evacuation command, some passengers left their seats to retrieve their belongings from the overhead bins. These passengers blocked the aisles and passages to the exits. It was difficult for the cabin crewmembers to keep the passengers seated before the evacuation was commanded and by that time the cabin had started to fill with smoke, the Aircraft was visibly damaged, and the external fire had started and was visible to some passengers.

Expediting the evacuation command could have attracted the attention of passengers at an early stage and reduced the opportunity for passengers to gather their belongings. A readily accessible evacuation checklist is a key factor in facilitating an expeditious evacuation command.

The Investigation recommends to the Operator that the evacuation checklist is displayed securely in a place in the cockpit easily visible to the flight crew.

The cabin crewmembers were challenged by a situation in which they had to decide whether to remove belongings affirmatively from passengers, which would delay the evacuation and lead to blocking of the aisles and passageways by bulky bags, or to let the evacuation continue with some passengers carrying their belongings which would risk damaging the slides and causing personal injuries. The removed carry-on bags filled the galleys and blocked access, consequently the cabin crew decided to allow the passengers who were carrying their bags to evacuate with their bags.



The Investigation believes that removing carry-on bags may increase the personal safety of the evacuee, but will increase the evacuation time and so endanger the lives of other passengers. Removing bags affirmatively may compromise the safety of cabin crewmembers positioned near the open exits.

Regulations, and the Operator's procedures, became ineffective when more passengers arrived at the exits with their carry-on bags. The cabin crew were left with no choice but to let the passengers evacuate with their bags. The risk of damaging the two remaining useable slides was high, with potentially catastrophic consequences.

An aviation Safety Study⁶⁰, conducted by the National Transportation Safety Board (NTSB) of the United States, revealed that the majority of respondents had carried their carry-on bags during evacuations. The Study recommended that the FAA develop advisory material to address ways to minimize the problems associated with carry-on bags during evacuations.

The Investigation concludes that attempting to evacuate with carry-on baggage poses a significant threat to the lives of passengers which is not addressed in the *Civil Aviation Regulations, CAR-OPS 1.285 – Passenger Briefing*. Recommendation is addressed in this Report section 2.10.2.3 - Passenger safety briefing standards.

2.10.2.2 Crew performance during the evacuation

When the Commander initiated the evacuation, smoke had already started to fill the center cabin and quickly developed into a barrier between the forward and aft cabin areas. Of the cabin seating capacity, 77 percent was occupied, but the limited number of usable emergency exits, challenges for cabin crew to re-direct passengers to the available exits, and the tendency of some passengers to take their carry-on bags, prolonged the evacuation which lasted for approximately 6 minutes 40 seconds.

The two megaphones, located at door station L1 and door station L5, were not used during the evacuation by the cabin crewmembers at those stations, because they were pre-occupied at the exits in assisting the passengers to evacuate. Once the escape slide at door L5 became unusable, passengers were verbally, and without the need to use the megaphones, directed to the opposite doors, R4 and R5.

There was only one serviceable escape slide on the upwind (left side) of the Aircraft and the cabin crewmembers were forced to evacuate most passengers into the smoke and firefighting activities using the available right side exits.

Being unaware that all of the passengers had already evacuated, some cabin crewmembers stayed onboard for another two minutes, waiting for more passengers to appear until a cabin crewmember in the forward cabin directed them, by megaphone, to evacuate. The cabin crewmembers in the aft cabin evacuated after no more passengers were visible and an initial search towards the center cabin had to be aborted due to thick smoke. The Commander and the senior cabin crewmember remained in the forward cabin searching for occupants after they both donned PBE.

The explosion of the center wing fuel tank started a fire in the cabin, and generated a wall of smoke, which forced the Commander and the senior cabin crewmember to stop their search, and to quickly move towards the cockpit. After an unsuccessful attempt to evacuate through the cockpit sliding windows, both jumped onto the detached inflated L1 door slide, approximately one minute after the explosion.

⁶⁰ Reference: Safety Study No. PB2000/917002 NTSB/SS-00/01.



The history of aircraft accidents shows that smoke in the cabin is a major contributing factor to passenger and crew fatalities. The intact cabin, the absence of fire, and light smoke may provide passengers and crew with misleading indicators of latent but potential hazards. The sequence of events in this Accident showed that the situation can change dramatically in a short period of time.

A successful evacuation requires cabin crew professionalism, adherence to emergency procedures, assertiveness towards passengers, and situation awareness in order to manage the changing conditions in the cabin.

The cabin crewmembers were well-rested when they commenced their duty which provided the best basis for mental and physical capabilities. Additionally, the Accident occurred at a time when cabin crew were experiencing “awake” time in their circadian body clock.

The cabin crewmembers were from different national cultures and had not previously worked together, however this did not hinder their communication or teamwork during the evacuation.

The cabin crewmembers remained at their stations until the passengers had been directed towards usable emergency exits. Information was shared using additional cabin crewmembers to gain oversight and to maintain awareness of the conditions. A cabin crewmember exited the cabin to assist the extraction of passengers from an escape slide and he then re-entered the smoke filled cabin to support his colleagues.

The cabin crewmembers showed assertiveness when they had to instruct a family to exit the Aircraft while a younger family member was left behind. Their assertiveness was also tested when escape slides were determined to be unusable while passengers were ready to evacuate from these exits. Their level of assertiveness was appropriate to support their dynamic assessments of a rapidly changing situation.

The evacuation of 282 passengers, including 67 children and infants, presented a significant task for the crewmembers, particularly in the aft cabin, from where 86 percent of the passengers evacuated.

While it may have appeared to cabin crewmembers that blocking one exit meant that another nine exits were available to the evacuation, this assumption was quickly revised when it became apparent that most of the exits on the Aircraft were blocked.

The Investigation concludes that the cabin crew successfully managed the passenger evacuation to the highest professional standard, in line with their training, considering the numerous challenges they faced.

The cabin crewmembers were individually trained in different situations that may occur during evacuations, but they were not trained for an evacuation where the escape slides are affected by wind.

The Investigation recommends to the Operator include, in cabin crew training, evacuation scenarios where escape slides are affected by wind.

2.10.2.3 Passenger safety briefing standards

The *Civil Aviation Regulations* contain provisions for the operators to identify the location of emergency exits, highlight the floor proximity escape path lighting and provide an adequate number of safety briefing cards that contain clear instructions for evacuation.



The *Regulations* also require the operators to brief passengers before and after takeoff and landing. Only the *before takeoff* briefing contains the location of the emergency exits and items pertaining to evacuation. It is not a requirement to repeat these items in the *before landing* briefing. In addition, there is no regulatory requirement for announced instructions to passengers to leave behind their carry-on baggage during evacuations.

On flights where a long time elapses between the *before takeoff* briefing and the aircraft landing, passengers may need to be reminded about the location of the emergency exits and evacuation items in the *before landing* briefing.

During the Accident, passengers insisting on evacuating with their carry-on baggage contributed to the delay in the evacuation. This identified a need for cabin crew tactics to convince passengers to leave their baggage behind. These tactics begin with an announcement in passenger safety briefings, which is not a requirement under the *Civil Aviation Regulations*. The Investigation believes that the safety briefings should include reminders to passengers regarding carry-on baggage during an evacuation.

The Investigation recommends that the GCAA perform a safety study which should include a review of the *Civil Aviation Regulations* to determine the effectiveness to include a requirement that passenger safety briefings and passenger safety cards have clear instructions and illustrations clearly indicating to passengers that carry-on baggage must not be taken during an emergency situation and to leave carry-on baggage during an evacuation. The Investigation recommends that the GCAA refer to ICAO *Document 10086 –Manual on Information and Instructions for Passenger Safety*.

2.10.2.4 Passenger evacuation management

The ARFFS should assist in the evacuation process by providing a safe escape path from the accident site. The ARFFS is also responsible for assisting in the evacuation by stabilizing the slides. The evacuated Aircraft occupants shall then be properly guided to a safe area in a manner that assures their personal safety and also airport safety and security.

Narrowing the escape path by positioning Fire 6 and Fire 10 close to the R4 door slowed down passenger movement away from the Accident site and limited the ability of the ARFFS to observe the movement of the evacuated passengers on the ground.

At the Accident site, there was no direct communication between the ARFFS and the cabin crew.

The MICC was not established in time to enable efficient management of the emergency. Therefore, there was no Airport incident command center to control the evacuation, determine the need for establishing a triage area, and to request medical support.

There was no clear passenger evacuation management plan deployed by the Airport to manage the movement of passengers to an assembly area along a safe path. Passengers had to walk for approximately 580 m to reach the assembly area, which was an aircraft maintenance hangar. A small number of passengers were transported by Airport operations vehicles which were not designed or tasked for this purpose.

It took approximately 45 minutes for buses to transport the passengers to the survivors reception center (SRC). As stated by the Airport airside operations, the response of the bus transportation sub-contracted company was slow because of problems in communication between the airside operations team located at the Accident site and the central telephone operator in the sub-contractor's operations room.



Approximately 2 hours and 40 minutes after the Aircraft came to a stop the fire commander advised the ARFFS watchroom that there was no one left on the Aircraft. The unnecessary risk posed to the firefighters searching for non-existent remaining passengers and crewmembers could have been avoided had the fire commander been informed that all persons on board were accounted for.

The Investigation recommends that the Airports periodically test the Airport passenger evacuation management system (PEMS) by use of exercises, to ensure that the system is effective in providing a high level of safety to the evacuees from the time of evacuation to the time of assembly in the survivors reception center (SRC).

2.10.2.5 Persons on board information

Following an aircraft accident, ICAO *Doc 9137–Airport Services Manual, Part 7–Airport Emergency Planning*, stated that the responsibility for passing information regarding the number of persons on board is that of the air traffic [navigation] service provider as well as the operator. During the Aircraft evacuation, the exact number of UAE521 persons on board was not transmitted to the fire commander as the information was not immediately available to the Tower as well as the ARFFS watchroom. Eighteen minutes after the Aircraft came to a stop, the fire commander was informed by the ARFFS watchroom that there were 290 persons on board the Aircraft. As stated in the ARFFS watchroom log, this incorrect number of 10 persons less than the actual loadsheets numbers, was obtained from the Operator's network control.

Information related to persons on board as per the ICAO *Annex 2* chapter on *Contents of a flight plan* requires that, when considered relevant by the "air traffic service authority", the flight plan should contain the total number of persons on board and considers this as significant information that must be reported prior to departure in case there is any change. Additionally, ICAO *Doc 4444 - Air Traffic Management (PANS-ATM)* in the *Appendix 2 Flight Plan* model form requires that, as part of the supplementary information, persons on board be filled in and submitted as part of the flight plan.

The Operator's *OM-C* required that the Operator's flight crew report to air traffic control the number of persons on board prior to departure at several international airports. However, the air navigation service providers within the United Arab Emirates did not have a similar requirement.

The *Civil Aviation Regulations CAR-OPS 1* does not stipulate that persons on board is required information in the flight plan. In addition, there was no guidance in the UAE regulations on a model flight plan form similar to that contained in ICAO *Doc 4444*.

The Investigation noted that even if air traffic control wanted to access the operational flight plan (OFP) submitted for UAE521, the number of persons on board had not been filled in. The Operator's *OM-A*, which was similar to *CAR-OPS 1*, did not require that the persons on board be recorded as part of the operational flight plan. However, the Operator's *OM-C* sample of OFP as noted in section 'J' of the *OM-C* describes that the number of crew, passengers and total number of persons on board is to be filled in as part of the OFP.

The Investigation recommends that the GCAA revise the *Civil Aviation Regulations CAR-OPS 1* so that it is aligned with the requirements of ICAO *Annex 2* and ICAO *Doc 4444* with regards to submission of persons on board in the operational flight plan.

For UAE521, the correct information on the persons on board was found in the loadsheets. This was a requirement of *CAR-OPS 1* and the Operator's *OM-A* mass and balance requirements. Thus, the Investigation could not determine why an incorrect number of persons



on board of 290 instead of 300 was passed by the Operators' network control to the ARFFS watchroom.

Under the heading *Alerting service provided by aerodrome control towers*, ICAO Doc 4444 states:

"7.1.2.2: Procedures concerning the alerting of the rescue and firefighting services shall be contained in local instructions. Such instructions shall specify the type of information to be provided to the rescue and firefighting services, including type of aircraft and type of emergency and, when available, number of persons on board, and any dangerous goods carried on the aircraft."

Additionally, ICAO Doc 4444 chapter on *Emergency Procedures* stated that when an emergency is declared by an aircraft, the air traffic [navigation] service provider should take appropriate and relevant action. One of the actions required is for the air traffic [navigation] service provider to "obtain from the operator or the flight crew such of the following information as may be relevant: number of persons on board, amount of fuel remaining, possible presence of hazardous materials and the nature thereof."

The Investigation concludes that the coordination between the Aircraft Operator, the air navigation service provider and the Airport to provide the fire commander with the correct persons on board following the UAE521 Accident was ineffective. The triage area for UAE521 occupants was some distance from the Accident site and many passengers and crewmembers took time to assemble at the hangar. The Investigation was unable to determine when the actual headcount of all persons on board was completed but believes that it was done within the first hour following the Accident.

There are many flights departing and arriving at the various airports within the United Arab Emirates with varying numbers of persons on board with some in excess of 500. For a declared emergency, the flight crew upon request by air traffic control normally transmit the number of persons on board. However, following an aircraft accident that may occur during any flight phase, including during landing and takeoff, when the flight crew is not available to communicate for any reason, the need to know the number of persons on board as well as the location of any dangerous goods is critical information that is required by search and rescue as well as the firefighting services. As the loadsheets/passenger manifest and dangerous goods location may not be immediately available, the Investigation believes that there should be an effective means of obtaining and transmitting this critical information within a reasonable time.

The Investigation recommends that the ANSP implement changes to the procedures so that following an aircraft emergency, and the flight crew is not available, there are effective means of obtaining and transmitting to the search and rescue and firefighting services, information related to persons on board and dangerous goods within an acceptable time. This should be aligned with the procedures as stated in ICAO Doc 4444 chapter 15 on *Emergency Procedures* and ICAO Doc 9137– *Airport Services Manual*, Part 7– *Airport Emergency Planning*.

The Investigation recommends that the GCAA provide guidance to United Arab Emirates air navigation service providers, aircraft operators and airport operators, so that following an aircraft emergency where the flight crew is not available, there are effective means of obtaining and transmitting to the search and rescue and firefighting services, information related to persons on board and dangerous goods for flights departing and arriving at United Arab Emirates airports within an acceptable time. This should be aligned with the procedures as stated in ICAO Doc 4444 chapter 15 on *Emergency Procedures* and ICAO Doc 9137– *Airport Services Manual*, Part 7 – *Airport Emergency Planning*.



2.10.3 Escape slides

The escape slides were certified in accordance with *TSO-C69b* issued by the FAA in 1988. The slides were also in compliance with the B777 certification specification.

The certifications required the slides to be capable of facilitating an evacuation in a 25-knot wind directed from the most critical angle. The slides shall deploy and remain usable with, if necessary, the assistance of only one-person. The requirements did not explicitly define whether this person was an evacuee, or was already on the ground before the slide deployed. The *TSO* was revised in August 1999 where it is described that this person has to be an evacuee from the same slide, which means that after full deployment the slide shall be stabilized by this evacuee and shall remain usable to evacuate occupants safely to the ground. For UAE521, four Aircraft slides, which initially deployed were wind affected and remained unusable.

According to FAA *Advisory Circular AC-17A*, the unoccupied slide should not give the visual impression that the slide is unsafe for use when viewed from the exit. UAE521 R5 slide after deployment was wind affected and did not stabilize, and gave the impression to the cabin crew that it was unsafe to be used and they decided to block the exit.

During the evacuation of UAE521, the wind speed was approximately 13 kt which was significantly lower than the escape slide 25-knot wind speed certification requirement. The Investigation could not determine why five slides were affected by a low-speed wind to such an extent that their associated exits were permanently or temporarily blocked. The Investigation believes that similar conditions were not appropriately considered during the slide off-wing and on-wing certification.

The NTSB investigation of a B777 accident that occurred at San Francisco International Airport in 2013, found that only two of the eight escape slides had deployed as intended. The investigation identified that the forces on the airframe during the impact sequence had exceeded the certification requirements causing two slides to fully deploy and one slide to partially deploy into the cabin.

The NTSB recommended that the FAA, in conjunction with the slide manufacturers, evaluate the certification standards and test methods defined in the *Federal Aviation Regulations* and relevant guidance material, for adequacy for future slide and slide raft design. The FAA responded that the evacuation system performed 'Adequately' and this single instance would not warrant modifying the requirements.

The Investigation concludes that the inadequate performance of the Aircraft escape slides and the significant effect of this on the evacuation should be appropriately addressed.

The Investigation recommends that the FAA review the current *Federal Aviation Regulations* and the relevant guidance material for adequate performance of escape slides in evacuation situations with a collapsed, or partially collapsed, landing gear. The review should consider the effect of wind on escape slide performance.

2.10.4 L1 Cabin Crew Seat

The examination of the seat parts recovered from the Aircraft identified plastic deformation of the right seat pan lever stop attachment hole. The fact that the stop bolt was no longer attached to the right lever and that the jumpseat appeared intact during the flight, indicated that the right stop bolt had most likely fractured at the time of the impact. This led to the release of the right side of the seat pan base, twisting downward of the right side of the seat pan, and collapse of the seat pan down and to the right.



The weight of the cabin crewmember was similar to that used for certification evaluation, which concludes that the impact force most likely exceeded the jumpseat design limitations with its certified static 6g downward force, and 14g canted at 30 degrees dynamic downward force. This conclusion is supported by damage found on the L1 door slide packboard, indicating a downward force exceeding 13g.



3. Conclusions

3.1 General

From the available evidence, the following findings, causes, and contributing factors were determined with respect to this Accident. These shall not be read as apportioning blame or liability to any particular organization, or individual.

To serve the objective of this Investigation, the following sections are included in the Conclusions heading:

- **Findings.** Statements of all significant conditions, events or circumstances in this Accident. The findings are significant steps in the Accident sequence but they are not always causal nor do they indicate deficiencies.
- **Causes.** Actions, omissions, events, conditions, or a combination thereof, which led to the Accident.
- **Contributing factors.** Actions, omissions, events, conditions, or a combination thereof, which, if eliminated, avoided or absent, would have reduced the probability of the Accident occurring, or mitigated the severity of the consequences of the Accident. The identification of contributing factors does not imply the assignment of fault or the determination of administrative, civil or criminal liability.

3.2 Findings

3.2.1 Findings relevant to the Aircraft

- (a) The Aircraft was certificated under the Boeing 777 type according to the certification specifications in the *Federal Aviation Regulations (FAR)* of the United States.
- (b) The Aircraft was certified, equipped, and maintained in accordance with the *Civil Aviation Regulations* of the United Arab Emirates.
- (c) The Aircraft was airworthy when dispatched for the flight, and there was no evidence of any defect or malfunction that could have contributed to the Accident.
- (d) The Aircraft was structurally intact prior to impact, and mostly remained intact after the impact.
- (e) The Aircraft was eventually destroyed due to the subsequent fire.
- (f) The post-Accident examination reports did not find any evidence of any Aircraft component or system malfunctions.
- (g) The Aircraft was equipped with a long landing alerting system that annunciated a 'long landing' alert at a distance of 1,280 m beyond the runway 12L threshold, some 92 m further along the runway than the programmed alert distance.
- (h) The takeoff/go-around (TO/GA) switches were most likely serviceable when the Commander pushed the switch because neither was there any historical Aircraft maintenance records that indicated otherwise nor was there any reported defect by UAE521 flight crew during the takeoff from Trivandrum.



- (i) The TO/GA switches are designed to become inhibited prior to touchdown when the aircraft radio altitude is less than 2 ft radio altitude and 3 seconds has elapsed.
- (j) The TO/GA switches are designed to become inhibited after touchdown when the aircraft radio altitude is less than 2 ft radio altitude, the weight-on-wheels (WOW) is valid and either the left or right gear WOW indicates that the aircraft is in 'ground' mode.
- (k) The TO/GA switches are designed to be enabled when the aircraft radio altitude is more than 2 ft.
- (l) With the thrust levers at the idle thrust position and the aircraft above 2 ft radio altitude with the flaps out of the 'up' position, when the TO/GA switch is pushed for a go-around, the A/T will automatically advance both thrust levers to the TO/GA position and TO/GA thrust will be attained in approximately eight seconds.
- (m) Without the use of the A/T, and provided the manual advancement of the thrust levers from the idle thrust position to the TO/GA thrust position takes two seconds, from an engine thrust setting of idle to TO/GA will take approximately six seconds.
- (n) With the A/T armed and active, after touchdown or when the TO/GA switches are inhibited, the only means of increasing engine thrust for a go-around is manual advancement of the thrust levers. This will cause the A/T to disconnect and an AUTOTHROTTLE DISC message will appear on the engine information and crew alerting system (EICAS).
- (o) The B777 crew alerting system was not designed to give a configuration warning for a go-around with the engine thrust levers not advancing towards the TO/GA thrust position.
- (p) The B777 provides an alert to the flight crew and a EICAS amber caution message AIRSPEED LOW when the airspeed has decreased 30% into the lower amber band. For UAE521, this message occurred when the Aircraft speed was 128 kt indicated airspeed (IAS).
- (q) The predictive windshear system is inhibited from giving windshear warning/alerts below 50 ft radio altitude.
- (r) The enhanced ground proximity warning system (EGPWS) is inhibited from providing immediate windshear warnings/alerts below 10 ft radio altitude.
- (s) The EGPWS manufacturer document *Product Specification – Mode 7 – Windshear Alerting* was capable of providing a windshear caution alert for aircraft performance increasing due to increasing headwind (or decreasing tailwind) and severe updrafts. However, this feature was not available to the flight crew because it was not enabled on the Aircraft.
- (t) The escape slides were within their overhaul periods.
- (u) The escape slides were certified in accordance with a technical standard order (TSO) issued by the Federal Aviation Administration of the United States (FAA). The TSO considered a maximum wind speed of 25 kt, from the 'most critical angle', as one of the criteria for certification conformity testing.



- (v) During the evacuation, the prevailing wind speed and angle were within the TSO certification conformity testing criteria.
- (w) Due to the Aircraft coming to rest on its lower fuselage, the escape slides deployed at an angle of approximately 14 degrees. As per design, the escape slide deployed slope angle range is between 27 to 35 degrees, with the landing gear extended.
- (x) The R3 door escape ramp did not deploy automatically because the pressure cylinder was damaged due to the impact.
- (y) The protective breathing equipment (PBE) units were certified in accordance with two TSOs issued by the FAA. Some PBE units could not be used because the stowage containers or plastic pouches were difficult to open.

3.2.2 Findings relevant to the flight crew

- (a) The flight crew were licensed and qualified for the flight in accordance with the *Civil Aviation Regulations* of the United Arab Emirates.
- (b) This flight was the first time that the Commander and the Copilot had flown together.
- (c) The flight crewmembers were medically fit for the flight.
- (d) The Commander's total flying experience was 7,457 flight hours, including 3,950 hours as a copilot and 1,173 hours as a commander on the B777.
- (e) The Copilot's total flying experience was 7,957 flight hours, including 1,292 as a copilot on the B777.
- (f) The Commander and the Copilot flight training records indicate that they both met the competency standard established by the Operator.
- (g) The Commander and Copilot performed go-around and missed approach exercises during their training, and operationally each had performed one normal go-around as pilot flying on the B777 during their careers. Both go-arounds occurred four months before the Accident.
- (h) The Commander had received *manual handling phase 2* training on a go-around initiated after touchdown with all engines operating.
- (i) The Copilot had not received *manual handling phase 2* training on a go-around initiated after touchdown with all engines operating.
- (j) The Commander and Copilot flight monitoring data on landings indicated that they never exceeded a touchdown beyond the touchdown zone.

3.2.3 Findings relevant to the cabin crew

- (a) All sixteen cabin crewmembers were licensed and current on the Aircraft type, and met current medical and emergency training requirements.
- (b) The cabin crewmembers were medically fit for the flight.
- (c) The cabin crew were not trained in evacuation situations where the escape slides are affected by wind.
- (d) The cabin crew managed the passenger evacuation to the highest professional standard, in line with their training.



3.2.4 Findings relevant to flight operations

- (a) The flight was conducted in accordance with the Operator's operational procedures.
- (b) The trans-cockpit authority gradient was appropriate for the flight.
- (c) The operational flight plan (OFP) submitted for UAE521, the number of crewmembers, passengers and total persons on board information was blank. Information on persons on board was found in the loadsheet.
- (d) Approximately 60 minutes prior to landing, the Commander and the Copilot completed a briefing for the approach to runways 30L and 12L, which included a windshear escape maneuver brief.
- (e) An approach speed of 152 kt ($V_{REF} + 5$) was selected for a normal landing configuration, with a flaps 30 setting.
- (f) In the eight minutes prior to the attempted landing of UAE521, two aircraft performed go-arounds from beyond the runway threshold and two aircraft landed uneventful.
- (g) As the Aircraft descended through 930 ft radio altitude, the autopilot was disengaged and the approach continued with the A/T engaged.
- (h) The Aircraft passed over the threshold at approximately 54 ft radio altitude and airspeed 159 kt.
- (i) The Commander started to flare the Aircraft at approximately 40 ft radio altitude, approximately 100 m beyond the threshold. The *FCTM* recommends initiation of the flare when the main gear is approximately 20 to 30 ft above the runway surface.
- (j) At 25 ft radio altitude the engines started to spool down towards idle and the A/T mode changed to 'IDLE'. The airspeed started to decrease and reached 153 kt at 10 ft radio altitude.
- (k) Prior to activation of the inhibit logics, neither the Aircraft weather radar predictive windshear warning system nor the EGPWS immediate windshear warning system provided any windshear warning and/or alerts as the wind conditions that existed did not meet the windshear alerting design criteria.
- (l) For UAE521, the wind conditions that existed up to 10 ft radio altitude did not have a decreasing and/or increasing performance effect on the Aircraft.
- (m) Passing 7 ft radio altitude, the Aircraft floated over the runway and at 2 ft radio altitude, the IAS reached 165 kt. There was a 12 kt airspeed increase in approximately four seconds, during which time the descent rate decreased.
- (n) The flight crew did not notice the increase in airspeed as they were both focused outside the Aircraft.
- (o) Even though the Commander was not aware of the increasing airspeed, he had responded to the increasing performance and in an attempt to land, three times made small pitch attitude corrections to lower the nose of the Aircraft.
- (p) Ten seconds after initiation of the flare at approximately 1,090 m beyond the touchdown zone and at an airspeed of 161 kt IAS, the TO/GA switches became



inhibited, in accordance with TO/GA switch design logic, when the right main landing gear contacted the runway causing the gear to 'untilt'.

- (q) The Commander, who was the pilot flying decided to fly a go-around, as he was unable to land the Aircraft within the runway touchdown zone.
- (r) The go-around decision was based on the perception that the Aircraft would not land due to thermals and not due to a windshear encounter. For this reason, the Commander elected to fly a normal go-around and not the windshear escape maneuver.
- (s) When the Commander initiated the go-around, his perception was that the Aircraft was still airborne and had not touched down. The left TO/GA switch was pushed approximately 2.5 seconds after the Aircraft had touched down.
- (t) The flight crew did not observe that the speedbrake lever had partially deployed twice during the six seconds the Aircraft main landing gear had cycled between 'tilt' and 'untilt'.
- (u) During the attempted go-around, the Commander said that he became focused on the go-around maneuver and described his state as "tunnel visioned".
- (v) The Commander had stated that his right hand remained on the thrust levers during the attempted go-around. After pushing the left TO/GA switch, the Commander did not recognise that there was no tactile feedback of thrust lever movement.
- (w) The flight crew did not observe that the FMA modes did not change and that the flight director was not giving pitch guidance. They were not aware that the A/T mode had remained at 'IDLE'.
- (x) Contrary to the *FCOM – Go-around and Missed Approach Procedure*, after 'flaps 20', the Commander and the Copilot omitted the steps of engine thrust verification and continued to action the procedure from the 'positive climb' item.
- (y) From UAE521 CVR data (Appendix E of this Report), the timing between the Copilot's confirmation of 'Flaps 20' and the Commander's call for 'gear up' was 2.5 seconds.
- (z) No action was taken to increase engine thrust because both flight crewmembers were unaware that the engine thrust was not increasing automatically after the TO/GA switch had been pushed and neither flight crewmember checked the EPR indicators.
- (aa) The flight crew did not observe that the airspeed was decreasing as the Aircraft climbed.
- (bb) Four seconds after the Aircraft became airborne passing 58 ft radio altitude, ATC communicated with the flight crew just after the Commander called 'gear up'.
- (cc) The Copilot responded to the ATC communication after selecting the landing gear to 'up'. The Copilot did not check that the flight director was 'on' after selecting the landing gear lever to 'up' as required by the *FCOM – Missed Approach and Go-Around Procedure*.
- (dd) The Aircraft reached 85 ft radio altitude and then started to sink back onto the runway.



- (ee) As the Aircraft sank, at approximately 67 ft radio altitude, three seconds before impact, the Aircraft loss of airspeed was perceived by the Commander as a windshear effect, which prompted him to call “Windshear TOGA”.
- (ff) The Commander pushed the TO/GA switch and manually advanced both thrust levers fully forward, as per the Operator's *windshear escape maneuver* procedure. Only at this time did the Commander realize that the engines were not producing sufficient thrust.
- (gg) The Aircraft impacted the runway 18 seconds after the go around command and with the landing gear transitioning to the up position.

3.2.5 Findings relevant to the Operator

- (a) The Operator's OM-A policy required the A/T to be engaged for engine thrust management for all phases of flight including approach and landing. This policy did not consider pilot actions that would be necessary during a normal go-around initiated while the TO/GA switches were inhibited.
- (b) The Operator's training program for the B777 was based on the Aircraft manufacturer and FAA approved training program, which did not include the TO/GA inhibition logic.
- (c) The Operator's procedure, as per *FCOM – Flight Mode Annunciations (FMA)*, except for landing when the aircraft is below 200 ft, FMA changes are required to be announced by the pilot flying and checked by the pilot monitoring.
- (d) In developing the training for a go-around after touchdown as referenced in the Operator's *B777 training manual*, scenarios for a go-around in automatic flight and in manual flight with the A/T armed and active were not considered. The TO/GA switches inhibit logic was also not considered, and as a result was not part of the training syllabus.
- (e) The training program implemented by the Operator during the *manual handling phase 2* training was accepted as a training standard for a go-around executed after touchdown.
- (f) Not all information related to the TO/GA switches inhibit logic was available either in the *FCOM* or in the *FCTM*. No reference was contained in these manuals as to why the A/T mode will not change when the TO/GA switches become inhibited.
- (g) The flight crew were not made aware that the TO/GA switches become inhibited when the aircraft is below 2 ft radio altitude for a period of time greater than three seconds.
- (h) Similar to the TO/GA inhibit logic below 2 ft, the enabling of the TO/GA switch and availability of the A/T for mode change above 2 ft radio altitude was not referred to in the *FCOM* and *FCTM*.
- (i) The Operator's normal go-around training did not contain information with regards to the time it would take for the engines to achieve TO/GA thrust either by manual advancement of the thrust levers or by use of the A/T after the TO/GA switch is pushed.



- (j) The Operator's normal go-around training did not contain guidance on how to perform a normal go-around when the TO/GA switches become inhibited prior to and after touchdown.
- (k) During Operator simulator sessions the Investigation observed that, the pilot flying keeps his hand on the thrust levers during approach and landing. There was no reference to this technique in either the Operator's or Manufacturer's manuals.
- (l) The Operator had a single procedure for all normal go-arounds and missed approaches. Even though it is stated in the *FCOM Appendix 1 – Standard Calls*, the Operator's *FCOM –Go-Around and Missed Approach Procedure* does not require the pilot flying to call out 'GO AROUND'.
- (m) The *FCOM and FCTM* did not require monitoring and callout of FMA changes on initiation of a go-around.
- (n) The *FCOM normal procedure* did not require a callout of thrust setting when the pilot flying pushed the TO/GA switch for a normal go-around.
- (o) The flight training records on pilot performance during training and during assessment were maintained on electronic online grading system (OGS) forms.
- (p) The Operator did not have a requirement to review comments made on the OGS forms when a pilot assessment marker (PAM) grading meets the Operator's acceptable proficient standard.
- (q) There was no specific technique employed by the Operator to train and measure the effectiveness of pilot instrument scan and pilot identification of abnormal indications.
- (r) In case of a missed approach, the *OM-A – Missed Approach* flight procedures requires that the pilots shall advise air traffic control as soon as practicable. There was no guidance in the *OM-A* on what should be reported in case of a go-around.
- (s) The Operator had established a safety management system (SMS) and a flight data monitoring (FDM) program in compliance with *Civil Aviation Regulations* of the United Arab Emirates, *CAR-OPS 1*.
- (t) The Operator's training and operational systems did not identify hazards associated with normal go-arounds performed close to the runway or after touchdown.
- (u) As stated in the alternative training and qualification program (ATQP) reports, between 2013 and 2015 a number of inaccurately executed all-engines-operating go-around events which was highlighted by flight data monitoring.
- (v) After touchdown, with manual advancement of the thrust levers to the TO/GA position, and without pushing the TO/GA switch, an AUTOTHROTTLE DISC message appears on the EICAS. Under this condition, the display of this message was not mentioned in the Operator's *B777 training manual* including the *FCTM* and the *FCOM*.



3.2.6 Findings relevant to air traffic control

- (a) At 0830, a warning of moderate windshear for all runways was broadcast on the ATIS information Zulu 37 minutes before UAE521 attempt to land.
- (b) At 0824, a Boeing 737, flight number IAW123, landed on runway 12L and the flight crew advised the Tower that there was an indication of light to moderate windshear on short final.
- (c) Except for one aircraft, AIC933, the next four aircraft, including UAE521, that were cleared to land by the Tower before the Accident, were not informed that there was a pilot report of windshear on short final during the landing.
- (d) Two aircraft performed a missed approach after crossing the threshold, however, the next three aircraft, including UAE521, were not informed by the Tower about the go-arounds. Neither was the reason for the go-arounds reported to air traffic control nor was it reported by the flight crews.
- (e) After 0830, even though runway 12L had an acceptable recorded surface tailwind for landing, only runway 12R had a surface headwind component.
- (f) A number of essential information was not communicated to UAE521 flight crew. These included missed approaches, the reported windshear on short final by flight IAW123, the continued gusting and windshear conditions, and the wind shift at runway 12L threshold from headwind to tailwind starting from 0829.
- (g) The Tower instructions to UAE521, which occurred seven seconds after initiation of the go-around, did not contribute to the flight crew omitting the procedural verification of engine thrust increase.
- (h) The Tower instructions occurred at a critical phase of the go-around four seconds after the Aircraft became airborne and coincided with the landing gear selection to the 'up' position.
- (i) The modification of the go-around procedure by the Tower added to the flight crews' workload as they attentively listened and responded to the instructions, which required a new missed approach altitude to be set. The flight crews' concentration on their primary task of flying the Aircraft and monitoring was momentarily affected as both the FMA verification and the flight director status were missed.
- (j) Other than for a high-speed rejected takeoff, no guidance was included in the *DMATS* directing air traffic controllers to avoid distracting the flight crew with unwarranted radio calls during high flight crew workload situations, such as go-arounds, especially those initiated at low altitudes, or from the runway.
- (k) The Tower issued a missed approach instruction for UAE521 to climb straight ahead to 4,000 ft, which was a modification to the missed approach as stated in the *aeronautical information publication (AIP)* of the United Arab Emirates.
- (l) The *DMATS missed approach procedure* and the letter of agreement established between the OMD Tower and Approach was not aligned with the *AIP*. The *AIP* required aircraft flying a missed approach from runway 12L, "Climb direct to DAMOR, hold at 3000 ft".



3.2.7 Findings relevant to Airport weather information

- (a) The combined effects of two low pressure areas delayed the onset of the regular sea breeze at the Airport which crossed the aerodrome unusually slowly and extended the period of windshear conditions on the runways.
- (b) At OMDB, windshear due to the onset of the sea breeze is a known weather phenomenon.
- (c) The weather stations fitted outside OMDB and within the Airport did not indicate windshear conditions.
- (d) The windshear warning with information Zulu on the day of the Accident was based on an analyses of the synoptic weather conditions over Dubai.
- (e) The Hyatt aviation weather station was not functional at the time of the Accident as it was removed from service in 2014 for safety reasons.
- (f) At the time of the Accident, there was no agreement between the NCMS and the Aircraft Operator to provide additional automated wind information generated by the aircraft.
- (g) Except for the anemometers fitted at locations close to the threshold of runways 12L/30R and 12R/30L, and the wind profiler, the Airport was not equipped with a low-level windshear system to detect localized windshear near the runways.
- (h) At approximately 0829, the wind started to shift to a tailwind component at the threshold of runway 12L. At 0830, except for runway 12R, runways 30R and 30L also had tailwind component.
- (i) Neither the flight crew nor the Tower was aware that the wind shift along runway 12L was after the runway aiming point and before the end of the runway touchdown zone.
- (j) At OMDB, the aerodrome weather office had no ability to create, issue or distribute automated windshear alerts.

3.2.8 Findings relevant to Airport rescue and firefighting service (ARFFS)

- (a) The ARFFS capabilities were compliant with the requirements of the *Civil Aviation Regulations* for a Category 10 airport.
- (b) The response time of the first responding fire vehicles was within the regulatory requirements, however, the first two responding major foam vehicles (MFV) were positioned behind the trailing edge of the right wing and obstructed the escape paths of the evacuating passengers.
- (c) The fire commander did not correctly establish incident sectors and did not cover the area that extended from the right wing leading edge to the Aircraft nose. His view of the Accident site was limited because he positioned his vehicle inappropriately.
- (d) No dynamic risk assessment was conducted and sideline firefighters were moving very close to fuel tanks where there was a potential explosion hazard. Crew managers did not communicate details of the firefighting actions to the fire commander.



- (e) The monitors and sideline firefighters were targeting the upper surface of the fuselage and the right side wing root area without positively identifying the smoke source. No available unique capabilities were utilized in firefighting tactics.
- (f) The firefighting agent was applied from a non-aspirating (jets) main and bumper monitors against the Aircraft structure at near right angles causing the foam bubbles to breakdown on impact.
- (g) The fire from the retracted right landing gear continuously heated the right side of the center wing fuel tank.
- (h) The resulting fuel vapor explosion tore a large section of the upper right wing skin away from the wing, fatally injuring one firefighter.
- (i) The tactic of the post-explosion firefighting was changed to defensive mode, where more attention was paid to the safety of the ARFFS personnel since the prospect of saving the Aircraft was considered lost. During this mode, large volumes of water were used in applying uncoordinated tactics that prolonged the time taken to gain control of the fire.
- (j) The ARFFS training system could not detect the lack of knowledge, understanding, and experience in aircraft incident command and firefighting tactics. Exercises were limited to simple fire scenarios and no appropriate simulated techniques were developed to challenge the fire commanders, sector commanders, crew managers, and firefighters to assess fire dynamics and develop appropriate tactics.
- (k) The most recent pre-Accident audit carried out by the GCAA included findings that were not appropriately addressed by the Airport management.
- (l) The most recent Airport emergency exercise, carried out in June 2015, revealed deficiencies that were repeated during the Accident response.
- (m) The tests that were carried out on samples collected from the fire extinguishing agent used during the Accident determined that the extinguishing agent met International Civil Aviation Organization (ICAO) *level B* standards.

3.2.9 Findings relevant to medical aspects

- (a) There was no evidence that incapacitation or physiological factors affected flight crew performance.
- (b) The flight crew were not fatigued.
- (c) The results of toxicological tests of the flight crewmembers for common drugs, alcohol, or any psychoactive substance were negative.
- (d) Of the 300 Aircraft occupants, 21 passengers and seven crewmembers sustained minor injuries. Four cabin crewmembers suffered serious injuries.
- (e) One firefighter suffered fatal injuries. Five firefighters and two police officers sustained minor injuries.

3.2.10 Findings relevant to survivability

- (a) All passenger doors were armed in accordance with the Operator's procedures.



- (b) The Commander initiated the evacuation approximately one minute after the Aircraft came to rest. Part of this time was used to locate the evacuation checklist amongst the items that had been scattered around the cockpit during the impact.
- (c) The cabin crewmembers promptly followed the Commander's instruction to initiate the evacuation of the Aircraft.
- (d) The Copilot exited the Aircraft from door R2 to direct evacuated passengers away from the Aircraft.
- (e) The cabin crewmembers were challenged by difficult situations when assessing the outside conditions and when deciding the escape slide status to either block an exit, or commence the evacuation.
- (f) Some passengers disregarded cabin crewmember instructions and left their seats while the seat belt sign was still illuminated.
- (g) No passenger reported any problems with their seatbelt function.
- (h) The impact caused damage to the L1 cabin crew seat, resulting in the seat base folding down.
- (i) During the evacuation, smoke filled the center cabin, separating the forward evacuation process from the evacuation in the aft cabin.
- (j) For most of the evacuation, only one exit was usable in the forward cabin, while two exits were usable in the aft cabin. Five slides were affected by wind and these exits were permanently or temporarily blocked.
- (k) The cabin crew attempted to convince passengers to leave their carry-on baggage behind, but a number of passengers evacuated with one or more pieces of carry-on baggage which prolonged the evacuation.
- (l) Out of 282 passengers, 69 percent evacuated the Aircraft from usable exits on the right side, where firefighting activities were ongoing. The remaining passengers evacuated from the L5 door.
- (m) The passenger evacuation lasted 6 minutes 40 seconds. The Commander and the senior cabin crewmember were still onboard the Aircraft at the time of the explosion of the center wing fuel tank and they evacuated from the L1 door, jumping onto the detached escape slide.
- (n) The Airport passenger evacuation management system (PEMS) did not control the evacuated passengers.
- (o) The Operator's hangar G was used as an assembly area and for triage. Passengers walked, some without shoes, approximately 580 m to the assembly area. Some passengers were transported using available airside vehicles.
- (p) The MICC was deployed sometime after the Accident and was not utilized as per procedure.
- (q) As recorded by the ARFFS watchroom log, 18 minutes after the Accident, the fire commander was informed that a total number of persons on board the Accident flight was 290.



- (r) Approximately 2 hours and 40 minutes after the Accident the fire commander had passed information to the ARFFS watchroom confirming that there was no one left on the Aircraft.

3.2.11 Findings relevant to GCAA safety oversight

- (a) The *Civil Aviation Regulations, CAR-OPS 1*, did not specify that training was required for rejected landing, bounced landing recovery, go-around below 50 ft, or go-around after touchdown under normal engine power, or after the loss of an engine.
- (b) The GCAA clarified that as the *Regulations* are not prescriptive in nature, the inspector's audit checklist *FOF-CHK-002*, contained rejected landing as a check item option.
- (c) The GCAA conducted annual audits on the Operator based on progressive audit and the audits were supervised by the principal inspector designated for the oversight functions, which included the operations, safety, and flight crew training.
- (d) A review of the records of the GCAA audits over a 6-year period prior to the Accident showed that there were no significant findings against the Operator's B777 go-around training standards, the OGS review system, and the Operator's hazard identification for go-around procedures and training.
- (e) The Operator's FDM program was under the responsibility of the Operator's Flight Operations instead of the safety management system post holder. The GCAA accepted this as an alternate means of compliance in accordance with *AC OPS 1.037*.
- (f) The *Civil Aviation Regulations, CAR Part VIII, Subpart 7 – Meteorological Services*, does not give guidance with regards to aviation meteorology including forecasting and reporting of windshear.
- (g) The GCAA safety oversight related to aviation meteorology is performed by air traffic service inspector(s), as there are no trained, qualified and experienced meteorology subject matter experts employed to fill this role.
- (h) The *Civil Aviation Regulations Part VIII, subpart 4 – ATS Organizations*, Appendix 6.6.17.7 – *Windshears*, requires that "Descriptions of Windshears notified by aircraft should be relayed to following arriving aircraft and to departing aircraft."
- (i) There was no guidance in the GCAA civil aviation system on what is required to be broadcasted in the windshear warnings.
- (j) The *Civil Aviation Regulations* did not require an item in the *passenger briefings* for passengers to leave behind their carry-on baggage.
- (k) The *Civil Aviation Regulations CAR-OPS 1* does not stipulate that persons on board is required information in the flight plan as well as there was no guidance in the *Civil Aviation Regulations* on a model flight plan form similar to what is in *ICAO Doc 4444*.



3.2.12 Findings relevant to the certification specifications issued by the Federal Aviation Administration (FAA) of the United States

- (a) The *FAR* certification specifications did not contain a requirement to alert pilots when the autothrottle was armed and active but becomes unavailable due to the TO/GA switches inhibit logic.
- (b) The *FAR* certification specifications did not contain a requirement to alert pilots when the go-around configuration conflicts with the engine thrust setting.
- (c) *TSO-C69b* issued by the FAA does not define criteria for the 'most critical angle' of the wind direction, or where the person providing assistance originates from. *TSO-C69c* does address both criteria.

3.3 Causes

The Air Accident Investigation Sector determines that the causes of the Accident are:

- (a) During the attempted go-around, except for the last three seconds prior to impact, both engine thrust levers, and therefore engine thrust, remained at idle. Consequently, the Aircraft's energy state was insufficient to sustain flight.
- (b) The flight crew did not effectively scan and monitor the primary flight instrumentation parameters during the landing and the attempted go-around.
- (c) The flight crew were unaware that the autothrottle (A/T) had not responded to move the engine thrust levers to the TO/GA position after the Commander pushed the TO/GA switch at the initiation of the *FCOM – Go-around and Missed Approach Procedure*.
- (d) The flight crew did not take corrective action to increase engine thrust because they omitted the engine thrust verification steps of the *FCOM – Go-around and Missed Approach Procedure*.

3.4 Contributing Factors

The Investigation determines that the following were contributory factors to the Accident:

- (a) The flight crew were unable to land the Aircraft within the touchdown zone during the attempted tailwind landing because of an early flare initiation, and increased airspeed due to a shift in wind direction, which took place approximately 650 m beyond the runway threshold.
- (b) When the Commander decided to fly a go-around, his perception was that the Aircraft was still airborne. In pushing the TO/GA switch, he expected that the autothrottle (A/T) would respond and automatically manage the engine thrust during the go-around.
- (c) Based on the flight crew's inaccurate situation awareness of the Aircraft state, and situational stress related to the increased workload involved in flying the go-around maneuver, they were unaware that the Aircraft's main gear had touched down which caused the TO/GA switches to become inhibited. Additionally, the flight crew were unaware that the A/T mode had remained at 'IDLE' after the TO/GA switch was pushed.



- (d) The flight crew reliance on automation and lack of training in flying go-arounds from close to the runway surface and with the TO/GA switches inhibited, significantly affected the flight crew performance in a critical flight situation which was different to that experienced by them during their simulated training flights.
- (e) The flight crew did not monitor the flight mode annunciations (FMA) changes after the TO/GA switch was pushed because:
 - 1. According to the Operator's procedure, as per *FCOM – Flight Mode Annunciations (FMA)*, FMA changes are not required to be announced for landing when the aircraft is below 200 ft;
 - 2. Callouts of FMA changes were not included in the Operator's *FCOM – Go-Around and Missed Approach Procedures*.
 - 3. Callouts of FMA changes were not included in the Operator's *FCTM Go-Around and Missed Approach* training.
- (f) The Operator's *OM-A* policy required the use of the A/T for engine thrust management for all phases of flight. This policy did not consider pilot actions that would be necessary during a go-around initiated while the A/T was armed and active and the TO/GA switches were inhibited.
- (g) The *FCOM – Go-Around and Missed Approach Procedure* did not contain steps for verbal verification callouts of engine thrust state.
- (h) The Aircraft systems, as designed, did not alert the flight crew that the TO/GA switches were inhibited at the time when the Commander pushed the TO/GA switch with the A/T armed and active.
- (i) The Aircraft systems, as designed, did not alert the flight crew to the inconsistency between the Aircraft configuration and the thrust setting necessary to perform a successful go-around.
- (j) Air traffic control did not pass essential information about windshear reported by a preceding landing flight crew and that two flights performed go-arounds after passing over the runway threshold. The flight crew decision-making process, during the approach and landing, was deprived of this critical information.
- (k) The modification of the go-around procedure by air traffic control four seconds after the Aircraft became airborne coincided with the landing gear selection to the 'up' position. This added to the flight crew workload as they attentively listened and the Copilot responded to the air traffic control instruction which required a change of missed approach altitude from 3,000 ft to 4,000 ft to be set. The flight crews' concentration on their primary task of flying the Aircraft and monitoring was momentarily affected as both the FMA verification and the flight director status were missed.



4. Safety Recommendations

4.1 General

The safety recommendations listed in this Report are proposed according to paragraph 6.8 of *Annex 13 to the Convention on International Civil Aviation*, and are based on the conclusions listed in part 3 of this Report. The Air Accident Investigation Sector (AAIS) expects that all safety issues identified by the Investigation will be addressed by the receiving States and organizations.

4.2 Safety Actions Taken

4.2.1 Safety actions taken by the General Civil Aviation Authority (GCAA) of the United Arab Emirates

- (a) Publication of *Safety Alert 09/2016 – Reporting of windshear by Air Traffic Services Unit*, which required the Air Traffic Control Units (ATCUs):
 - To maintain pilot awareness and alertness of possible windshear and to ensure that information about the operational effect of the windshear (speed loss or gain) in an area is effectively relayed to assist other pilots flying in the same area; and
 - Ensure training of air traffic services personnel includes a windshear program.

- (b) Publication of *Safety Alert 12/2016 – Operational Readiness of the Rescue and Fire Fighting Services (RFFS)*.

The safety alert addressed safety concerns relating to operational readiness of RFFS and the need to review the Structured Learning Program and Maintenance of Competency (MoC) of RFFS personnel.

- (c) Publication of *Safety Alert 14/2016 – Review of Aerodrome Crisis Management Framework and Emergency Planning Procedures*.

The safety alert required Aerodrome certificate holders to review aerodrome crisis management framework and procedures for Silver Command and Disabled Aircraft Recovery operations with emphasis on management of health, safety and environmental impact.

- (d) In April 2018 a revised *Civil Aviation Regulation CAR-OPS 1 – Commercial and Private Air Transportation Aeroplanes* was issued. The regulation became effective from 01 August 2018.

The changes to *CAR-OPS 1* included *Go-Arounds From Various Stages During the Approach*, and stated:

“Operators should conduct the go-around exercises from various altitudes during the approach with all engines operating, taking into account the following considerations:

- a) Un-planned go-arounds expose the crew to the surprise and startle effect;
- b) Go-arounds with various aeroplane configurations and different weights; and
- c) Balked landings (between Decision Altitude and touchdown or after touchdown unless thrust reversers have been activated).”



4.2.2 Safety actions taken by Emirates

The Operator has implemented the following safety actions:

- (a) Introduction of Evidence Based Training (EBT) into conversion, upgrade and recurrent training with the focus on risks and threats to the operation such as go-around scenarios with the TOGA switches inhibited;
- (b) Training for go-around after touchdown;
- (c) In Seat Instruction (ISI) in the simulator where the trainer makes subtle errors requiring the pilot monitoring to alert the pilot flying and if necessary use the intervention techniques;
- (d) Inclusion of information relating to TO/GA switch inhibit logics in various training modules;
- (e) Introduction of a pre-simulator briefing requirement for the flight crewmembers to verbalise the go-around procedure;
- (f) Promoting the tactile feedback of the moving thrust levers during critical stages of flight;
- (g) Simulation of the Accident flight [UAE521] wind effect in the simulator to expose flight crews to the effects of a performance increasing shear;
- (h) Flight crew training has introduced an enhanced trend monitoring process for pilots whose average competencies are less than 3.33 [pilot assessment marker] over the last 18 months;
- (i) Flight crew training has initiated a project to enhance scanning techniques using “Seeing Machines” and eye tracking functionality;
- (j) The Operator is evaluating the display of the evacuation checklist on the control wheel chart holder;
- (k) Following the Operator’s internal investigation recommendations, the Operator has introduced evacuations with winds adversely impacting slides in training courses;
- (l) See Appendix F of this Report for additional safety actions taken by the Operator.

4.2.3 Safety actions taken by ‘dans’

Dubai Air Navigation Services, ‘dans’, conducted a review of go-arounds at OMDB and have undertaken work to improve the management of go-arounds by the air traffic controllers. ‘dans’ has included appropriate information and guidance in the *Air Traffic Services Operational and Training Manuals* and added modules in the air traffic controller’s annual contingency training programs.

4.2.4 Safety actions taken by Dubai Airports

Dubai Airports Airport Fire Service and Aerodrome Emergency Planning (AEP), in consultation with the GCAA, undertook a review with planned changes to:

- Fire fighters and fire command training systems
- Fire services Infrastructure and technology investments
- AEP thorough examination and improvement.



4.3 Final Report Safety Recommendations

4.3.1 Safety recommendations addressed to Emirates

Emirates is recommended to:

SR01/2020

disseminate, to its pilots, knowledge and information about factors affecting landing distance and flare duration, such as aircraft height and airspeed over the threshold, early flare initiation and weather conditions that may affect aircraft performance during the landing.

SR02/2020

enhance the normal go-around and missed approach training standards which should include simulated scenarios for a normal go-around initiated close to the runway and after touchdown when the takeoff/go-around (TO/GA) switches are inhibited. This should also include information on engine response time to achieve go-around thrust.

SR03/2020

enhance training standards regarding TO/GA switch inhibiting so that pilots are aware of the effect on FMA annunciations and the flight director, and the availability of the autothrottle after the aircraft becomes airborne during a go-around.

SR04/2020

enhance the flight crew training and assessment system to include procedures for managing evaluator comments on pilot performance including pilots who have met the competency standard.

SR05/2020

review and enhance the go-around training standards taking into consideration the available analytical flight monitoring data as well as the recommendations made within the industry. For example, the recommendations contained in United Kingdom Civil Aviation Authority *Information Notice No. IN-2013/198 – Go-around Training for Aeroplanes* may be consulted.

SR06/2020

implement changes to crew resource management training taking into consideration the lessons of the UAE521 Accident.

SR07/2020

reiterate to flight crew the effects on aircraft performance due to wind changes that can affect landing, and the importance of effective monitoring of the flight instrumentation during a windshear warning.



SR08/2020

examine the training system to assess its adequacy in enhancing the cockpit instrumentation monitoring skills of flight crew.

SR09/2020

enhance the simulated training scenarios for a normal go-around before and after touchdown. The training and simulator sessions should emphasize the importance of performing and verifying each procedural step.

SR10/2020

include, in cabin crew training, evacuation scenarios where the escape slides are affected by wind.

SR11/2020

for quick access, ensure that the evacuation checklist is displayed securely in a position in the cockpit easily visible to the flight crew.

4.3.2 Safety recommendations addressed to Dubai Air Navigation Services ('dans')

Dubai Air Navigation Services is recommended to:

SR12/2020

ensure that best practice guidelines for the transmission of air traffic control instructions to flight crew be reviewed and included in unit procedures and continuation training for all current and future air traffic controllers. These guidelines should include, consideration of appropriate times and conditions when air traffic controllers may establish communication and issue instructions, with particular emphasis regarding critical phases of flight.

Note: Further reference may be found in EASA Safety Information Bulletin 2014-06 and GCAA *Safety Alert 09/2016*.

SR13/2020

implement procedures to ensure that the air traffic control *missed approach procedure* in the *Dubai manual of air traffic service (DMATS)* is consistent and aligned with the *aeronautical information publication (AIP)* of the United Arab Emirates.

Note: Reference should be made to European Aviation Safety Agency (EASA) *Safety Information Bulletin (SIB) No. 2014-06*.

SR14/2020

implement procedures and guidance that would limit the air traffic controller, to the maximum extent, from distracting the flight crew by issuing instructions modifying the published missed approach procedures in case of a missed approach.

Note: Reference should be made to European Aviation Safety Agency (EASA) *Safety Information Bulletin (SIB) No. 2014-06*.



SR15/2020

enhance the procedures, and air traffic controllers training, so that whenever windshear warnings are in effect at an aerodrome, essential safety information, such as go-arounds, long/deep landings when reported, wind gust and wind shift, is always transmitted to the flight crew at an appropriate time during the approach.

SR16/2020

enhance the procedures, and air traffic controllers training, so that whenever windshear warnings are in effect at an aerodrome, when safe to do so, the reason for an aircraft go-around, including wind conditions for aircraft that landed, should be requested by the air traffic controller if the information is not passed by the flight crew.

SR17/2020

as the GCAA-certificated meteorological service provider at Dubai Airports, install the required meteorological equipment necessary for detection and alerting of low-level windshear, that will enhance the accuracy and conciseness of the weather information broadcasted from the National Center of Meteorology (NCM) aviation meteorological forecasters and air traffic controllers.

SR18/2020

implement changes to the procedures so that following an aircraft emergency, and the flight crew is not available, there are effective means of obtaining and transmitting to the search and rescue and firefighting services, information related to persons on board and dangerous goods within an acceptable time. This should be aligned with recommended practices as stated in the International Civil Aviation Organization (ICAO) *Doc 4444* chapter on *Emergency Procedures* and ICAO *Doc 9137 – Airport Services Manual, Part 7 – Airport Emergency Planning*.

4.3.3 Safety recommendations addressed to Dubai Airports

Dubai Airports is recommended to:

SR19/2020

enhance training for the Airport rescue and firefighting service (ARFFS) personnel to enable them to identify confined heat sources based on indicators and smoke traces. This training should enable the fire commander to understand the fire dynamic and determine the appropriate tactics, depending on the site circumstances and considering utilization of unique capabilities of the fire vehicles. This should be supported by sufficient training in incident command.

SR20/2020

enhance the ARFFS personnel practical training exercises by including new scenarios based on appropriate simulated techniques, that challenge the firefighters, crew managers, and fire commanders to assess fire dynamics and develop tactics. The scenarios should replicate the circumstances of actual accidents, with various aircraft states. Different weather and environmental conditions should also be considered.



SR21/2020

periodically test the Airport passenger evacuation management system (PEMS) using properly-developed exercises, to ensure that the system is effective in providing a high level of safety to the evacuees from the time of evacuation to the time of assembly in the survivors reception center (SRC).

4.3.4 Safety recommendations addressed to The Boeing Company

The Boeing Company is recommended to:

SR22/2020

enhance the Boeing 777 crew alerting system to include aircraft configuration inconsistency when a go-around maneuver is commanded and the engine thrust is insufficient for the maneuver.

SR23/2020

enhance the Boeing 777 *flight crew operations manual (FCOM)* and *flight crew training manual (FCTM)* for consistency in TO/GA switches inhibiting information. In addition, it is recommended to appropriately highlight, in the *FCOM* and *FCTM*, the significance of the effects on the A/T due to the TO/GA switches inhibit logic.

SR24/2020

include in the Boeing 777 *Go-Around and Missed Approach Procedure*, and amend the *FCOM* and *FCTM* accordingly, requirements for the pilot flying to give call outs for thrust setting with verbal verifications of thrust increase being made by the pilot monitoring. In addition, emphasis should be made on the importance of guarding the thrust levers. The existing thrust setting callout in the *take-off procedure* could be referred to.

SR25/2020

study the benefits of adding callouts to the Boeing 777 flight mode annunciations (FMA) changes at the initiation of the *Go-Around and Missed Approach Procedure*, and amend the *FCOM* and *FCTM* accordingly.

SR26/2020

conduct a safety study to determine the benefits of developing a common procedure for the Boeing 777 normal go around and missed approach. This procedure should consider manual advancement of the thrust levers at low altitude and after touchdown, and the requirements for go-around after touchdown including flap position, aircraft rotation speed and crew awareness of associated warning/alert messages.



4.3.5 Safety recommendations addressed to the General Civil Aviation Authority (GCAA) of the United Arab Emirates

The GCAA is recommended to:

SR27/2020

implement measures that could improve the audit program and checklist used by the inspectors so that the effectiveness of the oversight function related to flight crew training and flight operations is enhanced.

SR28/2020

establish a position within the GCAA and induct a subject matter expert in aviation meteorology who is appropriately trained, qualified and experienced inspectorate.

SR29/2020

publish recommendations for air navigation service providers:

- (a) to implement procedures and guidance that would limit the air traffic controller, to the maximum extent, from issuing instructions to flight crews that would modify the published missed approach procedures in case of go around with the sole exception of transmitting essential instructions to ensure air safety;
- (b) to emphasize the benefits of consistently applying the published missed approach procedure and the risks associated with modifications to such procedure at a time of high flight crew workload when potential for distraction must be minimized;
- (c) to emphasize, during all phases of air traffic controller training, the importance of correctly timed, concise and effective communication to flight crew performing a missed approach;
- (d) to incorporate appropriate details of the accident described in this report and the lessons learned into air traffic controller training;

SR30/2020

enhance the *Civil Aviation Regulations* for the provision of flight information services related to information regarding significant changes (see *Note*) in the meteorological conditions, in particular the latest information, if any, on windshear and/or turbulence in the final approach area or in the takeoff or climb-out area, to be transmitted to the aircraft without delay, except when it is known that the aircraft already has received the information.

Note.— Significant changes in this context include those relating to surface wind direction or speed, visibility, runway visual range or air temperature (for turbine-engined aircraft), and the occurrence of thunderstorm or cumulonimbus, moderate or severe turbulence, windshear, hail, moderate or severe icing, severe squall line, freezing precipitation, severe mountain waves, sandstorm, dust storm, blowing snow, tornado or waterspout.



SR31/2020

study the benefit of specifying, and incorporating changes to the *Civil Aviation Regulations*, the required meteorological equipment used for detection of low-level windshear and alerts; placement of anemometers along the runways; and receiving current aircraft wind information, that will enhance the accuracy and conciseness of the weather information broadcasted from the aviation meteorological forecasters and air traffic controllers.

SR32/2020

revise the *CAR-OPS* so that it is aligned with the requirements of ICAO *Annex 2* and *ICAO Doc 4444* with regarding submission of the operational flight plan and for the GCAA to specify what information is considered relevant in the flight plan.

SR33/2020

provide guidance to the air traffic service providers in the United Arab Emirates, aircraft operators and airport operators, so that following an aircraft emergency where the flight crew is not available, there are effective means of obtaining and transmitting to the search and rescue and firefighting services, information related to persons on board and dangerous goods for flights departing and arriving at United Arab Emirates airports within an acceptable time. This should be aligned with recommended practices as stated in ICAO *Doc 4444* chapter on *Emergency Procedures* and ICAO *Doc 9137 – Airport Services Manual, Part 7– Airport Emergency Planning*.

SR34/2020

perform a safety study, which should include a review of the *Civil Aviation Regulations*, to determine the effectiveness to include the requirement that passenger safety briefings and passenger safety cards have clear instructions and illustrations that carry-on baggage must not be taken during an emergency situation and to leave carry-on baggage during an evacuation.

The Investigation recommends that the GCAA refer to ICAO *Document 10086 – Manual on Information and Instructions for Passenger Safety*.

4.3.6 Safety recommendations addressed to Federal Aviation Administration (FAA) of the United States

The FAA is recommended to:

SR35/2020

perform a safety study in consultation with the Aircraft manufacturer for the purpose of enhancing the Boeing 777 windshear alerting system. This study should encompass both 'predictive' and 'immediate', *TSO-C117a/b* windshear systems.

SR36/2020

perform a safety study in consultation with the Aircraft manufacturer, for the purpose of enhancing the Boeing 777 autothrottle system and TO/GA switches inhibit logic that will avoid pilot errors due to overreliance on automation. The study should also include improvement with crew procedures and training of the autothrottle system



and TO/GA switches inhibit logic, with consideration of manual advancement of the thrust levers for a go-around initiated at low altitude and for a go-around initiated after touchdown.

SR37/2020

require Essex Industries (the manufacturer of the protective breathing equipment 'PBE'), to evaluate the current design features of the PBE container (stowage compartment) and pouch, and develop modifications to prove compliance with *TSO-C116a* and *TSO-C99a* regarding easy access.

SR38/2020

review the current *Federal Aviation Regulations* and relevant guidance material to address inadequate performance of escape slides during evacuations with collapsed landing gear. The review should consider the effect of wind on escape slide performance.

4.3.7 Safety recommendation addressed to the International Civil Aviation Organization (ICAO)

The ICAO is recommended to:

SR39/2020

to study the benefit of establishing a global, coordinated and structured data sharing within the industry, which derives the precursors to accidents and serious incidents. This initiative, together with participation of the aircraft manufacturers, should provide clear guidance on how these precursors can be identified through data analysis.

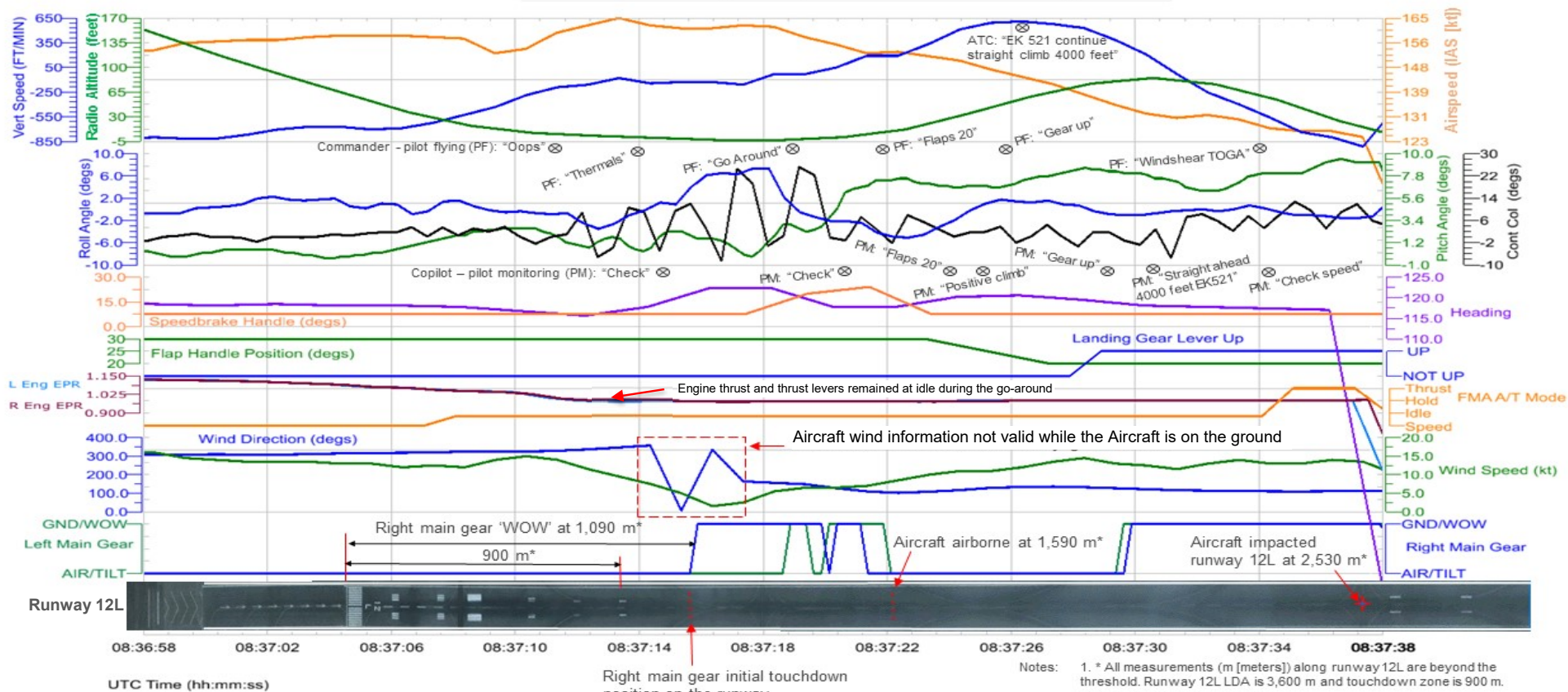
SR40/2020

to define Standards and Recommended Practices (SARPS) and procedures for air navigation services so that air traffic controllers, except where necessary for safety reasons are aware as to when it is safe to initiate communication with the flight crew during a go-around. Reference should be made to European Aviation Safety Agency (EASA) *Safety Information Bulletin (SIB) No. 2014-06*.



Appendix A. UAE521 Flight Data over the Last 100 Seconds

EK 521 path along runway 12L with the recorded flight data

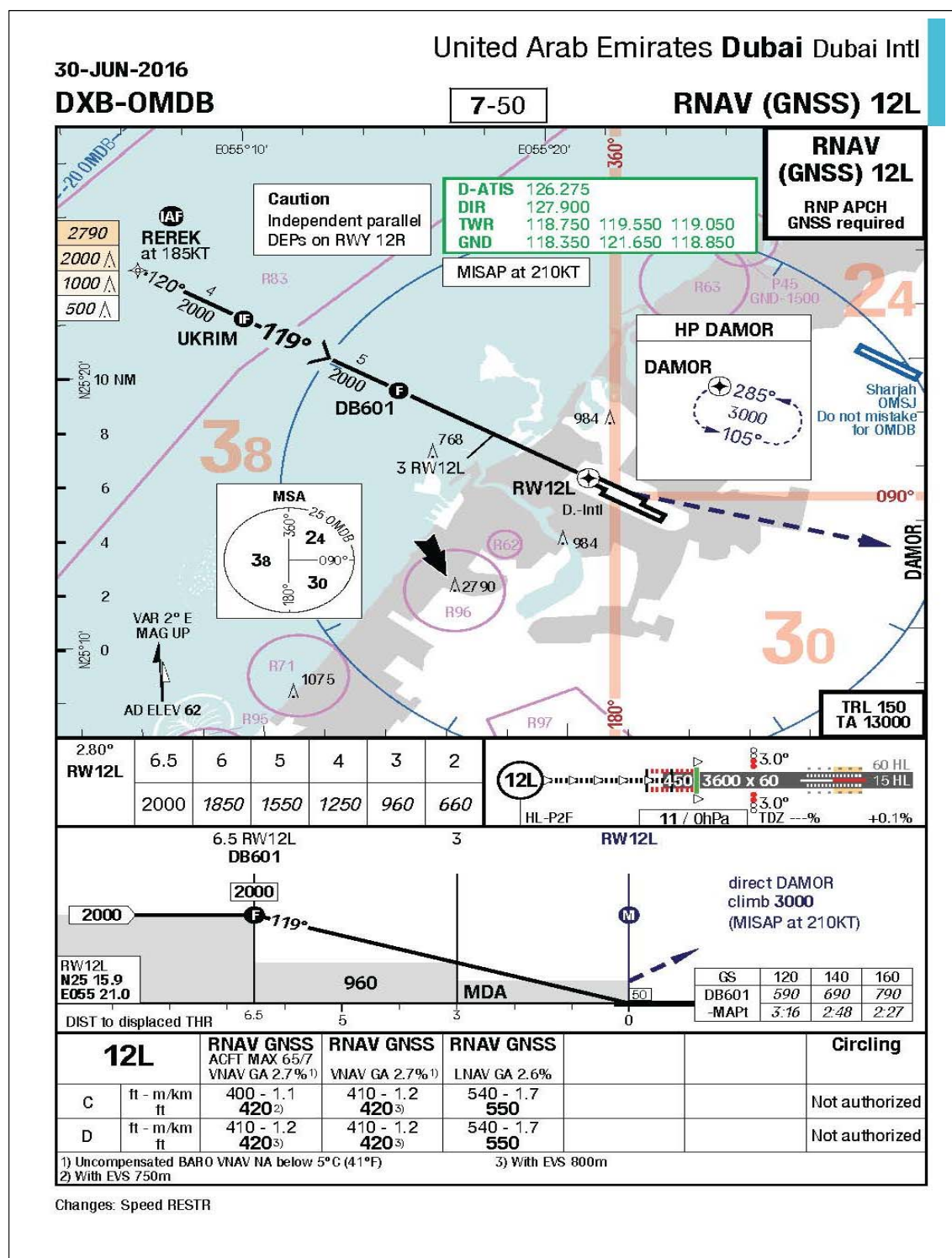




Appendix B. Operator's FCOM – Go-Around and Missed Approach Procedure (FCOM NP.21.56)

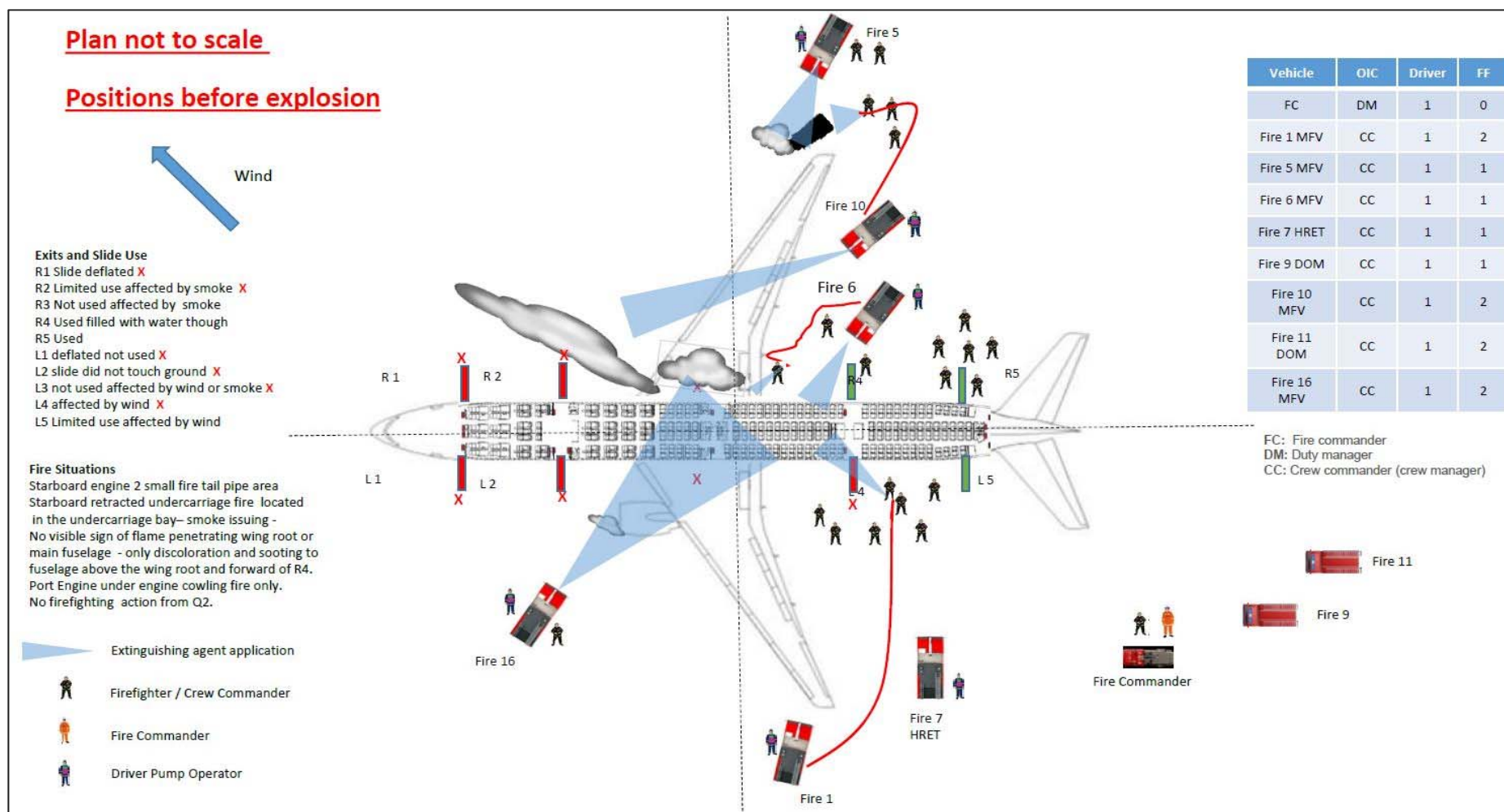
Go-Around and Missed Approach Procedure	
Pilot Flying	Pilot Monitoring
At the same time:	
- push the TO/GA switch - call "FLAPS 20".	
	Position the flap lever to 20.
Verify:	
- the rotation to go-around attitude - that the thrust increases.	
	Verify that the thrust is sufficient for the go-around or adjust as needed.
	Verify a positive rate of climb on the altimeter. Call "POSITIVE CLIMB."
Verify a positive rate of climb on the altimeter and call "GEAR UP."	
	Set the landing gear lever to UP and confirm the F/Ds are ON.
Limit bank angle to 15 degrees if airspeed is below minimum maneuver speed.	
Above 400 feet radio altitude, select or verify a roll mode.	Verify that the missed approach altitude is set.
Verify that the missed approach route is tracked. Note: If a go-around/missed approach is required, ensure LNAV is re-engaged immediately. - if an LNAV path is available, LNAV automatically arms and engages: - above 50 feet radio altitude when autopilot is not engaged, or - above 200 feet radio altitude when autopilot is engaged Note: Route discontinuities after the missed approach will prevent LNAV from engaging. - go-around remains the engaged roll mode until LNAV automatically engages or another mode is selected. "verify that the missed APP route is tracked"	
Verify that the missed approach altitude is captured.	
Set speed to the maneuver speed for the planned flap setting.	
Call "FLAPS ____" according to the flap retraction schedule.	Set the flap lever as directed. Checklist display switch PUSH.
After flaps are set to the planned flap setting and at or above flap maneuvering speed, select FLCH or VNAV as needed.	
Verify that climb thrust is set.	
Call "AFTER TAKEOFF CHECKLIST."	Do the AFTER TAKEOFF checklist.

Appendix C. LIDO Chart Dubai 12L





Appendix D. Firefighting vehicles position





Appendix E. Events – Threshold to Impact

Event	Elapsed time (seconds)	Distance beyond runway 12L threshold (meters)	Airspeed (kt IAS)	Ground speed (kt)	Radio altitude	Wind direction	Wind speed	Pitch angle
Aircraft passes over threshold	-1.85	Over threshold	159	180	54	315	13	-0.4
AUDIO: 'Fifty'	-0.6	50	159	179	50	317	13	0
Flare initiated (start point for elapsed time)	0.0	100	159	179	40	317	13	0.2
AUDIO: 'Twenty'	2.2	300	158	179	20	321	12	1.6
AUDIO: 'Ten'	3.5	485	153	177	10	324	14	2.6
Commander: "Oops"	5.5	650	160	176	5	329	14	2.1
Commander: "Thermals"	7.7	840	165	172	2	Aircraft wind information not valid while the Aircraft is on the ground. During this period, the wind over the runway shifted to a head wind.		1.8
Right main landing gear 'untilt'	10.2	1,090	161	167	-2			2.3
Go around initiated (Sound of TO/GA switch click). This was followed by left main gear 'untilt'	12.7		162	161	-3			1.9
Commander: "Go around" followed by AUDIO: 'Long Landing'	13	1,280	162	161	-3			1.9
Commander: "Flaps 20"	15.5		153	156	7	110	7	6.7
Aircraft airborne for the go-around (both main gear 'tilt')	16.4	1,590	153	153	12	102	8.5	7.4
Copilot: "Flaps 20"	17.9		152	150	22	108	10	7
Copilot: "Positive climb"	19.4		147	144	47	129	11	6.9
Commander: "Gear up". Soon after ATC: "Emirates five two one continue straight climb four thousand feet"	20.4		145	141	58	137	12	7
Copilot: "Gear up"	22.8		139	136	77	132	14.5	8.4
Copilot to ATC: "Straight ahead four thousand feet emirates five two one"	25.2		131	130	83	116	11.5	7.4
Commander: "Windshear TOGA"	27.8		130	127	67	113	14	6.9
Aircraft Impact	31.2	2,530	124	123	6	111	14	9.2



Appendix F. Additional Safety Actions – Emirates

The following additional safety actions were taken based on the Operator's internal investigation:

- (a) Liaising with International Air Transport Association (IATA) to develop industry best practice for controlling passengers attempting to retrieve their hand luggage during evacuations based on the Flight Safety Foundation in the Cabin Crew Safety Bulletin – Attempts to retrieve carry-on baggage increase risks during evacuation, Volume 39 No 3, May-June 2004;
- (b) Notified the PBE manufacturer about the identified problems with the PBE container latch and seal bag tear strip, for the purpose of future product improvement;
- (c) Liaising with IATA to interact with slide raft manufacturers to improve future slide raft designs to achieve better stability in windy conditions, to address the discrepancy between aircraft wind limits and slide certification limits and to review whether future slide designs should change slide colour from the current grey colour;
- (d) Liaising with IATA to develop industry guidelines on how to stabilise evacuation slides in windy conditions;
- (e) Liaising with 'dans' to ensure that missed approach procedures are only modified for flight safety reasons, including that ATC should refrain from contacting an aircraft during the initial phases of a go-around unless necessary for flight safety and wait for contact to be initiated by the flight crew;
- (f) Liaising with IATA in order to review if the related ATC standards of ICAO DOC 4444 and 8168 should be amended to avoid unnecessary ATC involvement during a go-around;
- (g) Liaising with the OMDb authorities in order to install a low-level windshear alerting system (LLWAS);
- (h) Working with the meteorological office and 'dans' to conduct a study on dynamic environmental conditions, such as windshear and wind shift, wake turbulence and mechanical turbulence and how they affect the airport environment, and any technological methodologies for capturing this information, such as a digital 'aircraft to tower' data link;
- (i) Liaising with Aircraft and EGPWS manufacturers to explore the availability and introduction of engineered defences to alert flight crew to a performance increasing windshear;
- (j) Liaising with the Aircraft manufacturer to develop engineered defences that alert the flight crew when a TO/GA switch is pushed during an inhibited phase;
- (k) Liaising with the Aircraft and systems manufacturers to develop engineered defences that protect against insufficient aircraft energy states;
- (l) Liaising with the Aircraft manufacturer regarding the modification of the *FCOM– Go-Around and Missed Approach Procedure* in relation to the verification of engine thrust.