Descent Below Visual Glidepath and Impact With Seawall
Asiana Airlines Flight 214
Boeing 777-200ER, HL7742
San Francisco, California
July 6, 2013

Accident Report

NTSB/AAR-14/01
PB2014-105984

**National
Transportation
Safety Board**

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490 L'Enfant Plaza, SW
Washington, D.C. 20594

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Abstract: This report discusses the July 6, 2013, accident involving a Boeing 777-200ER, Korean registration HL7742, operating as Asiana Airlines flight 214, which was on approach to runway 28L when it struck a seawall at San Francisco International Airport (SFO), San Francisco, California. Three of the 291 passengers were fatally injured; 40 passengers, 8 of the 12 flight attendants, and 1 of the 4 flight crewmembers received serious injuries. The other 248 passengers, 4 flight attendants, and 3 flight crewmembers received minor injuries or were not injured. The airplane was destroyed.

Safety issues relate to the need for Asiana pilots to adhere to standard operating procedures regarding callouts; reduced design complexity and enhanced training on the airplane's autoflight system; opportunity at Asiana for new instructors to supervise trainee pilots in operational service during instructor training; guidance for Asiana pilots on use of flight directors during a visual approach; more manual flight for Asiana pilots; a context-dependent low energy alert; research that examines the injury potential from significant lateral forces in airplane crashes and the mechanism that produces high thoracic spinal injuries; evaluation of the adequacy of slide/raft inertia load certification testing; aircraft rescue and firefighting (ARFF) training for officers in command of an aircraft accident response; guidance on when to use a skin-piercing nozzle on a burning airplane fuselage; integration of the medical supply buses at SFO into the airport's preparation drills; guidance or protocols for ensuring the safety of passengers and crew at risk of a vehicle strike during ARFF operations; requirements for ARFF staffing; improvements in SFO emergency communications; and increased Federal Aviation Administration (FAA) oversight of SFO's emergency procedures manual. Safety recommendations are addressed to the FAA, Asiana Airlines, Boeing, the ARFF Working Group, and the City of San Francisco.

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Abbreviations

AC	advisory circular
ACARS	aircraft communications addressing and reporting system
ACRP	Airport Cooperative Research Program
AD	airworthiness directive
AFCS	automatic flight control system
AFDS	autopilot flight director system
AFE	above field elevation
AFFF	aqueous film forming foam
AFM	airplane flight manual
agl	above ground level
A/P	autopilot
ARAC	Aviation Rulemaking Advisory Committee
ARFF	aircraft rescue and firefighting
ASHWG	Avionics Systems Harmonization Working Group
ASO	airfield security officer
A/T	autothrottle
ATC	air traffic control
ATCT	air traffic control tower
ATIS	automatic terminal information service
BS	body station
CFR	*Code of Federal Regulations*
CG	center of gravity
CRM	crew resource management

CVR	cockpit voice recorder
DFW FTRC	Dallas/Fort Worth International Airport Fire Training Research Center
EASA	European Aviation Safety Agency
EFS	engineering flight simulator
EGPWS	enhanced ground proximity warning system
EICAS	engine indication and crew alerting system
EMS	emergency medical service
FAA	Federal Aviation Administration
FAF	final approach fix
FCOM	flight crew operating manual
FCTM	flight crew training manual
F/D	flight director
FDR	flight data recorder
FLCH SPD	flight level change speed
FMA	flight mode annunciator
FMC	flight management computer
FO	first officer
FOM	flight operations manual
fpm	ft per minute
FRMS	fatigue risk management system
g	ratio of a particular acceleration to the acceleration due to gravity at sea level
HDG SEL	heading select
HRET	high-reach extendable turret
ICAO	International Civil Aviation Organization

ICN	Incheon International Airport
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
IP	instructor pilot
KARAIB	The Republic of Korea Aviation and Railway Accident Investigation Board
KOCA	The Republic of Korea Office of Civil Aviation
L	left
LOC	localizer
MCP	mode control panel
MSAW	minimum safe altitude warning
msl	mean sea level
ND	navigation display
nm	nautical mile
NorCal	Northern California Terminal Radar Approach Control
NOTAM	notice to airmen
NTSB	National Transportation Safety Board
OE	operating experience
PAPI	precision approach path indicator
PF	pilot flying
PFD	primary flight display
PIC	pilot-in-command
PM	pilot monitoring
POI	principal operations inspector

POM	pilot operations manual
QAR	quick access recorder
QRH	quick reference handbook
R	right
RA	radio altitude
RI	response item
RSA	runway safety area
SAFO	safety alert for operators
SFFD	San Francisco Fire Department
SFFD-AB	San Francisco Fire Department-Airport Bureau
SFO	San Francisco International Airport
SFPD	San Francisco Police Department
SOP	standard operating procedure
SPD	speed
START	simple triage and rapid treatment
THR	thrust
TO/GA	takeoff/go-around
$\mathbf{V_{ref}}$	reference landing speed
VMC	visual meteorological conditions
VNAV	vertical navigation
VPI	vertical path indicator
V/S	vertical speed

Executive Summary

On July 6, 2013, about 1128 Pacific daylight time, a Boeing 777-200ER, Korean registration HL7742, operating as Asiana Airlines flight 214, was on approach to runway 28L when it struck a seawall at San Francisco International Airport (SFO), San Francisco, California. Three of the 291 passengers were fatally injured; 40 passengers, 8 of the 12 flight attendants, and 1 of the 4 flight crewmembers received serious injuries. The other 248 passengers, 4 flight attendants, and 3 flight crewmembers received minor injuries or were not injured. The airplane was destroyed by impact forces and a postcrash fire. Flight 214 was a regularly scheduled international passenger flight from Incheon International Airport, Seoul, Korea, operating under the provisions of 14 *Code of Federal Regulations* Part 129. Visual meteorological conditions prevailed, and an instrument flight rules flight plan was filed.

The flight was vectored for a visual approach to runway 28L and intercepted the final approach course about 14 nautical miles (nm) from the threshold at an altitude slightly above the desired 3° glidepath. This set the flight crew up for a straight-in visual approach; however, after the flight crew accepted an air traffic control instruction to maintain 180 knots to 5 nm from the runway, the flight crew mismanaged the airplane's descent, which resulted in the airplane being well above the desired 3° glidepath when it reached the 5 nm point. The flight crew's difficulty in managing the airplane's descent continued as the approach continued. In an attempt to increase the airplane's descent rate and capture the desired glidepath, the pilot flying (PF) selected an autopilot (A/P) mode (flight level change speed [FLCH SPD]) that instead resulted in the autoflight system initiating a climb because the airplane was below the selected altitude. The PF disconnected the A/P and moved the thrust levers to idle, which caused the autothrottle (A/T) to change to the HOLD mode, a mode in which the A/T does not control airspeed. The PF then pitched the airplane down and increased the descent rate. Neither the PF, the pilot monitoring (PM), nor the observer noted the change in A/T mode to HOLD.

As the airplane reached 500 ft above airport elevation, the point at which Asiana's procedures dictated that the approach must be stabilized, the precision approach path indicator (PAPI) would have shown the flight crew that the airplane was slightly above the desired glidepath. Also, the airspeed, which had been decreasing rapidly, had just reached the proper approach speed of 137 knots. However, the thrust levers were still at idle, and the descent rate was about 1,200 ft per minute, well above the descent rate of about 700 fpm needed to maintain the desired glidepath; these were two indications that the approach was not stabilized. Based on these two indications, the flight crew should have determined that the approach was unstabilized and initiated a go-around, but they did not do so. As the approach continued, it became increasingly unstabilized as the airplane descended below the desired glidepath; the PAPI displayed three and then four red lights, indicating the continuing descent below the glidepath. The decreasing trend in airspeed continued, and about 200 ft, the flight crew became aware of the low airspeed and low path conditions but did not initiate a go-around until the airplane was below 100 ft, at which point the airplane did not have the performance capability to accomplish a go-around. The flight crew's insufficient monitoring of airspeed indications during the approach resulted from expectancy, increased workload, fatigue, and automation reliance.

When the main landing gear and the aft fuselage struck the seawall, the tail of the airplane broke off at the aft pressure bulkhead. The airplane slid along the runway, lifted partially into the air, spun about 330°, and impacted the ground a final time. The impact forces, which exceeded certification limits, resulted in the inflation of two slide/rafts within the cabin, injuring and temporarily trapping two flight attendants. Six occupants were ejected from the airplane during the impact sequence: two of the three fatally injured passengers and four of the seriously injured flight attendants. The four flight attendants were wearing their restraints but were ejected due to the destruction of the aft galley where they were seated. The two ejected passengers (one of whom was later rolled over by two firefighting vehicles) were not wearing their seatbelts and would likely have remained in the cabin and survived if they had been wearing their seatbelts.

After the airplane came to a stop, a fire initiated within the separated right engine, which came to rest adjacent to the right side of the fuselage. When one of the flight attendants became aware of the fire, he initiated an evacuation, and 98% of the passengers successfully self-evacuated. As the fire spread into the fuselage, firefighters entered the airplane and extricated five passengers (one of whom later died) who were injured and unable to evacuate. Overall, 99% of the airplane’s occupants survived.

The safety issues discussed in the report relate to the need for the following:

- **Adherence of Asiana pilots to standard operating procedures (SOP) regarding callouts.** The flight crew did not consistently adhere to Asiana’s SOPs involving selections and callouts pertaining to the autoflight system’s mode control panel. This lack of adherence is likely the reason that the PF did not call out “flight level change” when he selected FLCH SPD. As a result, and because the PM’s attention was likely on changing the flap setting at that time, the PM did not notice that FLCH SPD was engaged.
- **Reduced design complexity and enhanced training on the airplane’s autoflight system.** The PF had an inaccurate understanding of how the Boeing 777 A/P and A/T systems interact to control airspeed in FLCH SPD mode, what happens when the A/T is overridden and the throttles transition to HOLD in a FLCH SPD descent, and how the A/T automatic engagement feature operates. The PF’s faulty mental model of the airplane’s automation logic led to his inadvertent deactivation of automatic airspeed control. Both reduced design complexity and improved systems training can help reduce the type of error that the PF made.
- **Opportunity at Asiana for new instructors to supervise trainee pilots in operational service during instructor training.** The PM was an experienced 777 captain who was on his first flight as an instructor pilot supervising a trainee captain gaining operating experience. The PM did not have the opportunity during his instructor training to supervise and instruct a trainee during line operations while being observed by an experienced instructor. Such an opportunity would have improved the PM’s awareness of the dynamic and often unpredictable challenges that an instructor must deal with when supervising a trainee during line operations.

- **Guidance for Asiana pilots on use of flight directors during a visual approach.** During the accident flight, after the A/P was disconnected, the PM loosely followed Asiana's informal practice, which was to turn both flight directors (F/Ds) off and then turn the PM's F/D back on when conducting a visual approach. However, the two F/D switches were not both in the off position at the same time. If they had been, the A/T mode would have changed to speed mode and maintained the approach speed of 137 knots. In addition, during a visual approach, F/D pitch and roll guidance is not needed and can be a distraction.
- **More manual flight for Asiana pilots.** Asiana's automation policy emphasized the full use of all automation and did not encourage manual flight during line operations. If the PF had been provided with more opportunity to manually fly the 777 during training, he would most likely have better used pitch trim, recognized that the airspeed was decaying, and taken the appropriate corrective action of adding power. Federal Aviation Administration (FAA) guidance and a recent US regulatory change support the need for pilots to regularly perform manual flight so that their airplane handling skills do not degrade.
- **A context-dependent low energy alert.** The airplane was equipped with a low airspeed alerting system that was designed to alert flight crews to low airspeed in the cruise phase of flight for the purpose of stall avoidance. However, this accident demonstrates that existing low airspeed alert systems that are designed to provide pilots with redundant aural and visual warning of impending hazardous low airspeed conditions may be ineffective when they are developed for one phase of flight (e.g., cruise) and are not adequately tailored to reflect conditions that may be important in another phase of flight (e.g., approach). During the approach phase of flight, a low airspeed alert may need to be designed so that its activation threshold takes airspeed (kinetic energy), altitude (potential energy), and engine response time into account.
- **Research that examines the injury potential from significant lateral forces in airplane crashes and the mechanism that produces high thoracic spinal injuries.** In this accident, the dynamics were such that occupants were thrown forward and experienced a significant lateral force to the left during the impact sequence. One passenger sustained serious head injuries as a result of striking the arm rest of the seat that was in front of and to his left. While current FAA dynamic seat certification requirements do include testing row/row seat interactions with seats positioned slightly off the longitudinal axis, they would not likely approximate the forces encountered in this accident. Further, there was a high number of serious injuries to the high thoracic spine in this accident, and the mechanism that produces these injuries is poorly understood.
- **Evaluation of the adequacy of slide/raft inertia load certification testing.** The forces experienced by the slide/rafts during the impact sequence far exceeded their certification limits, leading to overload failures of the slide/raft release mechanisms on the 1R and 2R slide/rafts. Given the critical nature of these evacuation devices and their proximity to essential crewmembers, slides and slide/rafts must be certified to sufficient loads so that they will likely function in a survivable accident. Although this exact accident scenario is unlikely to occur again, the data obtained during this accident investigation could prove useful for future slide/raft design.

- **Aircraft rescue and firefighting (ARFF) training for officers placed in command of an aircraft accident.** The arriving incident commander placed an officer in charge of the fire attack who had not received ARFF training, and this individual made decisions that reflected his lack of ARFF training. Although no additional injuries or loss of life could be attributed to the fire attack supervisor's lack of ARFF training, it demonstrates the potential strategic and tactical challenges associated with having nonARFF trained personnel in positions of command at an airplane accident.
- **Guidance on when to pierce the fuselage of a burning airplane with a skin-piercing nozzle.** The airport's fire department had two vehicles equipped with high-reach extendable turrets (HRETs) that were not used to the best of their capabilities in the initial attack. This was partially the result of departmental guidance that discouraged penetration of the fuselage using the skin-piercing nozzles on the HRETs until all of the occupants were known to have evacuated the airplane. Current FAA guidance provides information on how to pierce but does not include any guidance on when to pierce.
- **Integration of the medical supply buses at SFO into the airport's preparation drills.** Although the airport's emergency procedures manual called for airport operations personnel to deliver the airport's two emergency medical buses to the accident site, neither of the medical buses arrived. Further, the monthly emergency drills conducted by the airport did not include deployment of the buses either as a matter of routine or as part of the unique scenario being evaluated. This lack of integration of the medical buses into the airport's preparation drills likely played a part in their lack of use in the initial response to the accident.
- **Guidance or protocols for ensuring the safety of passengers and crew at risk of being struck or rolled over by a vehicle during ARFF operations.** In this case, only one passenger was at significant risk for a vehicle strike due to her close proximity to the burning airplane; however, there are other accident scenarios in which many injured or deceased persons could be located near an accident airplane. There is currently no guidance or any recommended protocols for ensuring the safety of passengers and crew at risk of being struck or rolled over by a vehicle during ARFF operations.
- **Requirements for ARFF staffing.** Seven ARFF vehicles and 23 ARFF personnel from SFO's fire department were involved in the initial response to the accident. This equipment level exceeded the FAA-required minimum of three vehicles, and there is currently no FAA-required minimum staffing level. Because of the amount of available ARFF vehicles and personnel, the airport firefighters were able to perform exterior firefighting and send firefighters into the airplane who rescued five passengers who were unable to self-evacuate amid rapidly deteriorating cabin conditions. Due to the lack of an FAA-required minimum staffing level, passengers involved in an aviation accident at a smaller airport may not be afforded the same level of protection that the passengers of flight 214 had.
- **Improvements in emergency communications at SFO.** Numerous problems with communications occurred during the emergency response, the most critical being the inability for responding mutual aid units to speak directly with units from the airport on a common radio frequency. Although some of the communications difficulties encountered during the emergency response, including the lack of radio

interoperability, have been remedied, others, such as the breakdown in communications between the airport and city dispatch centers, should be addressed.

- **Increased FAA oversight of SFO's emergency procedures manual.** Although the airport had submitted, and the FAA had approved in December 2012, an updated emergency procedures manual, the airport had not yet distributed or trained personnel on the updated manual when the accident occurred and was still actively operating with the manual approved by the FAA in December 2008.

The National Transportation Safety Board (NTSB) determined that the probable cause of this accident was the flight crew's mismanagement of the airplane's descent during the visual approach, the PF's unintended deactivation of automatic airspeed control, the flight crew's inadequate monitoring of airspeed, and the flight crew's delayed execution of a go-around after they became aware that the airplane was below acceptable glidepath and airspeed tolerances. Contributing to the accident were (1) the complexities of the autothrottle and autopilot flight director systems that were inadequately described in Boeing's documentation and Asiana's pilot training, which increased the likelihood of mode error; (2) the flight crew's nonstandard communication and coordination regarding the use of the autothrottle and autopilot flight director systems; (3) the PF's inadequate training on the planning and execution of visual approaches; (4) the PM/instructor pilot's inadequate supervision of the PF; and (5) flight crew fatigue, which likely degraded their performance.

As a result of this investigation, the NTSB makes safety recommendations to the FAA, Asiana Airlines, Boeing, the Aircraft Rescue and Firefighting Working Group, and the City and County of San Francisco.

1. Factual Information

1.1 History of Flight

On July 6, 2013, about 1128 Pacific daylight time,[1] a Boeing 777-200ER, Korean registration HL7742, operating as Asiana Airlines flight 214, was on approach to runway 28L when it struck a seawall at San Francisco International Airport (SFO), San Francisco, California. Three of the 291 passengers were fatally injured; 40 passengers, 8 of the 12 flight attendants, and 1 of the 4 flight crewmembers received serious injuries. The other 248 passengers, 4 flight attendants, and 3 flight crewmembers received minor injuries or were not injured. The airplane was destroyed by impact forces and a postcrash fire. Flight 214 was a regularly scheduled international passenger flight from Incheon International Airport (ICN), Seoul, Korea, operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 129. Visual meteorological conditions (VMC) prevailed, and an instrument flight rules (IFR) flight plan was filed. Figure 1 is a map showing the location of the accident.

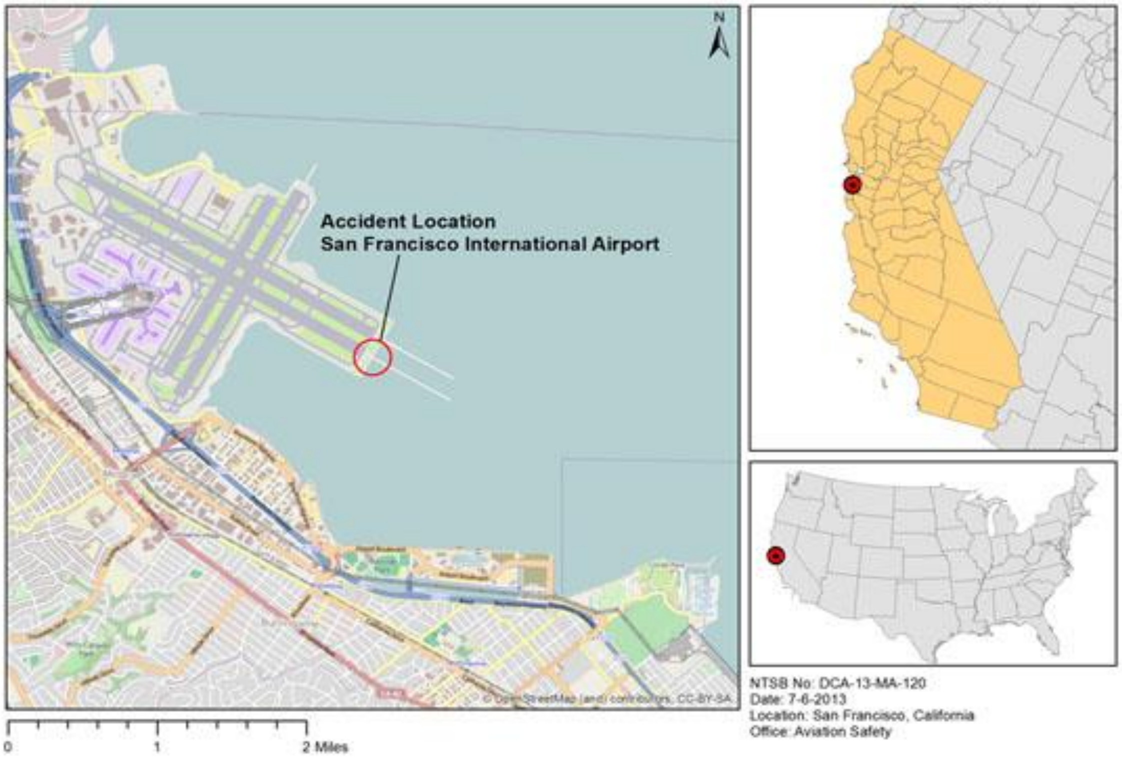

Figure 1. Map of the accident location.

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[1] All times in this report are Pacific daylight time (unless otherwise noted) and based on a 24-hour clock.

The flight and cabin crews were based at ICN. Two of the flight crewmembers, a trainee captain and an instructor pilot (IP), were the primary flight crew, and the other two flight crewmembers, a second captain and a first officer (FO), were relief pilots. The flight, which was the first of a scheduled 2-day trip with a scheduled layover in San Francisco, was an operating experience (OE) training flight for the trainee captain. The flight plan showed an estimated time en route of 10 hours 24 minutes.

As shown in figure 2, the trainee captain occupied the left seat and was the pilot flying (PF) for the takeoff and landing. The IP, who was the pilot-in-command (PIC), occupied the right seat and was the pilot monitoring (PM) for the takeoff and landing. The relief captain and FO occupied seats in the cabin for takeoff and during the initial part of the flight. About 4 hours 15 minutes after takeoff, they came forward to the cockpit and assumed flight crew duties for about the next 5 hours 15 minutes of the flight, allowing the primary flight crew to rest in the cabin.

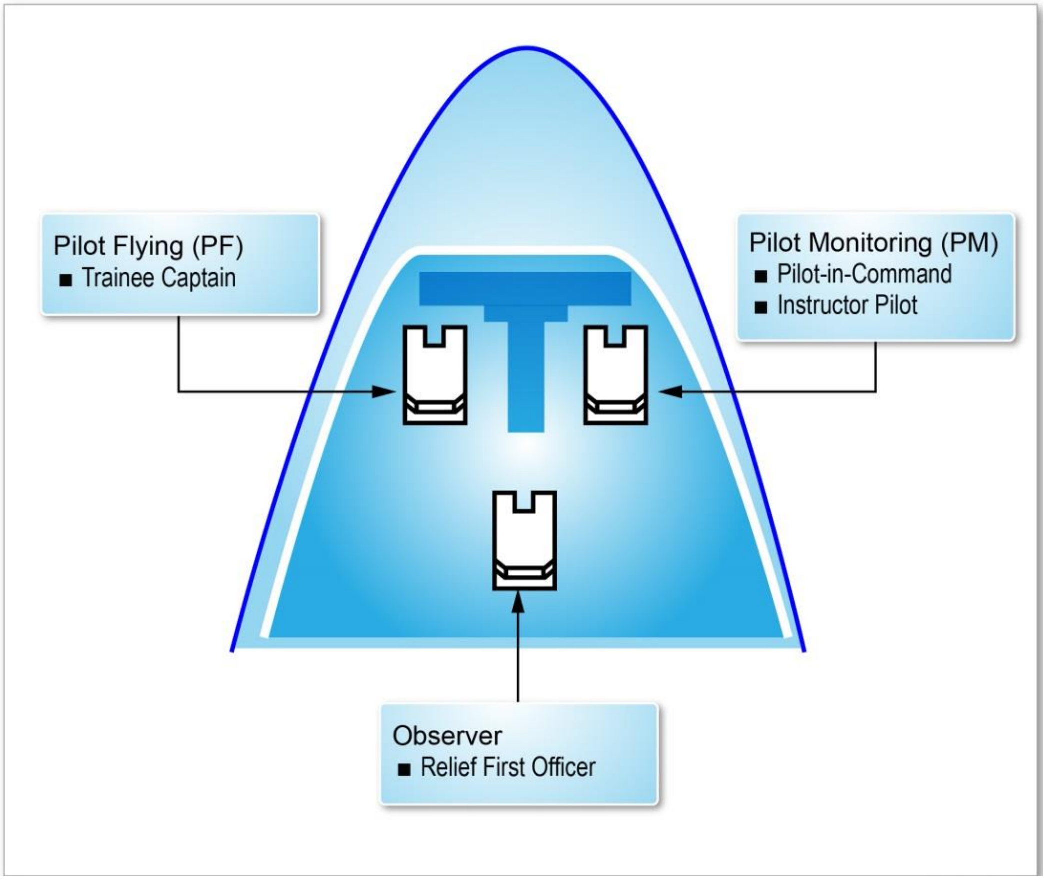

Figure 2. Diagram of cockpit showing flight crew roles.

The PF stated in an interview that he returned to the cockpit about 0938. According to the relief captain, he told the PF that he had programmed the flight management computer (FMC) with the instrument landing system (ILS)/localizer (LOC) 28L approach and advised him of the likelihood that the flight would be held at high altitude and/or high speed by air traffic control (ATC) for longer than normal during the approach to SFO. The relief captain stated that the PM returned to the cockpit about 10 minutes after the PF's return.

According to the cockpit voice recorder (CVR), at 0955:45, there was a transfer of aircraft control to the PF and the PM, and the relief captain and FO returned to the cabin. About 6 minutes later, the PF and the PM discussed expectations for receiving radar vectors for a visual approach.[2] At 1042:28, the PF began an approach briefing. During his briefing, the PF referred to automatic terminal information service (ATIS) Juliet,[3] which included the information that visual approaches to runways 28L and 28R were in progress, and the ILS glideslopes[4] for these runways were out of service. The PF stated that he expected vectors for a visual approach to runway 28L, would use the LOC to maintain lateral path, and, after capturing the LOC, would use the automatic flight control system (AFCS)[5] to manage the vertical profile. He said that the minimum descent altitude for the LOC approach was 460 ft mean sea level (msl) and that he would set a go-around altitude of 3,000 ft msl in case of a missed approach. Figure 3 is the instrument approach chart for the SFO runway 28L ILS or LOC Z procedure.

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[2] The Federal Aviation Administration defines a visual approach as an ATC authorization for an aircraft on an IFR flight plan to proceed visually to the airport of intended landing. It is not an instrument approach procedure, and there is no missed approach segment.

[3] Juliet was the assigned code for the ATIS broadcast given at 0956. The ATIS changed to information Kilo at 1056, but the content of the broadcast was not significantly different.

[4] The terms glideslope and glidepath are commonly used interchangeably. For the purposes of this report, glideslope refers to the electronic radio aid portion of the ILS that provides vertical guidance, and glidepath refers to a descent profile determined for vertical guidance during a final approach. When specific glidepaths are referenced, the method of determining the glidepath will be stated (for example, "PAPI [precision approach path indicator] glidepath").

[5] Specifically, the PF stated that he would use the vertical speed pitch mode of the autopilot flight director system (AFDS). Along with the autothrottle, the AFDS is a subsystem of the 777 AFCS. See section 1.6.3 for additional information about the functionality of these systems.

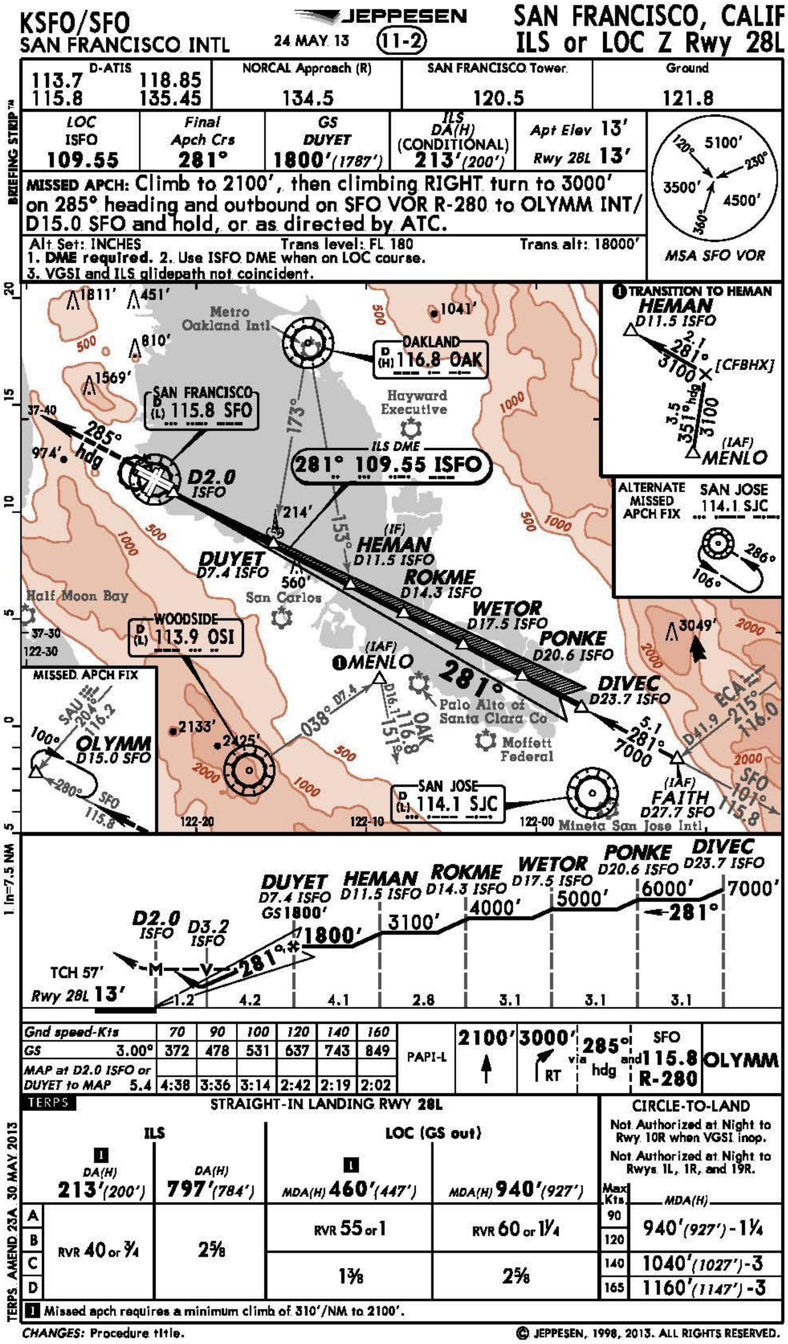

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Figure 3. Instrument approach chart for the SFO runway 28L ILS or LOC Z procedure.

At 1047:28, the PF called for the descent checklist. The PM acknowledged the callout and began to run the checklist, which included verification that the reference landing speed (V_{ref})[6] was 132 knots. At 1047:54, the PM stated, "checklist completed." At 1112:33, the relief

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[6] V_{ref} is 1.23 times the airplane's stalling speed in the landing configuration. It is the speed required on crossing the landing runway threshold at a 50-ft height to achieve calculated aircraft performance.

FO returned to the cockpit, occupied the center jumpseat, and acted as an observer during the approach and landing.[7] As the flight proceeded towards SFO, it was cleared to descend to lower altitudes and vectored to intercept a straight-in approach to runway 28L.

At 1121:49, a controller at Northern California Terminal Radar Approach Control (NorCal) asked if the flight crew had the airport in sight. The PM replied, "okay runway in sight," and the controller cleared the flight for a visual approach to runway 28L. According to flight data recorder (FDR) data, when the approach clearance was given, the airplane was descending through about 6,300 ft msl. The airplane's airspeed was about 211 knots; it was configured with the flaps and landing gear up; the autothrottle (A/T) was in hold (HOLD) mode; and the autopilot flight director system (AFDS) was in flight level change speed (FLCH SPD) pitch mode and heading select (HDG SEL) roll mode.[8]

At 1122:07, the PF stated, "I am intercepting localizer," and the PM responded, "yes." At 1122:11, the LOC[9] push-button switch on the AFCS's mode control panel (MCP) was pushed, arming the LOC mode, and the PM stated, "localizer armed," to which the PF replied, "check, cleared visual approach." At 1122:46, the PF stated, "next, three thousand one hundred" and then "cleared visual approach," and the PM replied "check." At 1122:48, the MCP-selected altitude changed to 3,100 ft. At 1122:52, LOC capture occurred, and the AFDS roll mode changed from HDG SEL to LOC, where it remained for the duration of the flight. At this time, the airplane was about 15.4 nautical miles (nm) from the runway threshold, descending through about 5,300 ft msl at an airspeed of about 210 knots.

At 1122:54, the PM stated, "let's descend slowly to one thousand eight hundred feet, and it's visual." The PF replied, "yes yes sir I will set to one thousand eight hundred." At 1123:02, the MCP-selected altitude was changed to 1,800 ft, which was the minimum altitude for the DUYET waypoint, located 5.4 nm from the runway and the final approach fix (FAF) for the ILS/LOC 28L approach.[10] At 1123:05, the PM stated, "localizer capture." The PF replied, "check, flaps one sir," and the PM stated, "speed check flaps one set." At 1123:11, the flap lever was moved to the flaps 1 position as the airplane was descending through about 4,900 ft msl at an airspeed of about 214 knots. At 1123:16, the PF stated, "speed one nine two set," and the MCP-selected airspeed changed from 212 to 192 knots.

At 1123:17, when the airplane was about 14.1 nm from the runway, descending through about 4,800 ft msl at an airspeed of about 215 knots and a descent rate of about 900 ft per minute (fpm), the NorCal controller instructed the flight to reduce airspeed to 180 knots and to maintain that speed until 5 miles from the airport; the PM acknowledged the instruction. At 1123:31, the PF stated, "speed one eight zero," and the PM replied, "check." At 1123:33, the PF stated, "flaps

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[7] The relief captain remained in the cabin for the descent, approach, and landing.

[8] In HOLD mode, the A/T will not move the thrust levers; FLCH SPD pitch mode moves the elevator to maintain the selected airspeed; and HDG SEL roll mode maintains the selected heading. See section 1.6.3 for further description of the airplane's AFCS.

[9] The LOC roll mode captures and tracks the localizer centerline.

[10] Because flight 214 was conducting a visual approach, there was no requirement for the flight to cross DUYET at 1,800 ft. The flight crew chose to use this altitude as a reference.

five." About 3 seconds later, the PM made an unintelligible comment, and the MCP-selected airspeed changed to 180 knots. At 1123:42, the PF stated, "flaps five sir," and the PM replied, "speed check" and then "flaps five." At 1123:45, the flap lever was moved to the flaps 5 position.

By 1123:50, the airplane's descent rate had decreased to about 300 fpm, and the PM made an unintelligible comment. About 2 seconds later, the MCP-selected airspeed changed to 172 knots. At 1123:53, the PF stated, "yeah, I am descending now," and the PM replied, "yeah." At 1123:57, the AFDS pitch mode changed to vertical speed (V/S);[11] the A/T mode changed to speed (SPD) mode;[12] and the MCP-selected vertical speed was set to -900 fpm. At 1123:58, the PM called out the pitch mode change by stating, "V/S," and the PF replied, "one thousand." About 1 second later, the MCP-selected vertical speed changed to -1,000 fpm, and the PM stated, "check." There was no communication between the flight crew for about the next 31 seconds.

At 1124:32, when the airplane was about 9.5 nm from the runway, descending through about 3,900 ft msl at an airspeed of about 185 knots and a descent rate of about 1,000 fpm, the relief FO who was observing (hereafter referred to as the observer) commented that the flight was to maintain 180 knots until 5 miles from the airport by stating, "to one eight zero five miles." The PM responded, "ah ah ah one eight zero," and the observer repeated, "one eight zero five miles." At 1124:36, the PF stated, "huh?" The observer again repeated the speed to be maintained as instructed by the NorCal controller, and the PF stated, "okay one eight zero five miles." There was no communication between the flight crew for about the next 12 seconds.

At 1124:51, when the airplane was about 8.5 nm from the runway, descending through about 3,500 ft msl at an airspeed of about 188 knots and a descent rate of about 1,000 fpm, the PF called for the landing gear to be extended. At 1124:53, the gear handle was moved to the down position, and the PM stated, "this seems a little high." About 2 seconds later, the PF stated, "yeah," and the PM repeated, "this should be a bit high." About 3 seconds later, the PF stated, "do you mean it's too high?" The PM made an unintelligible reply. At 1125:02, the PF stated, "I will descend more," and at 1125:04, the MCP-selected vertical speed changed to -1,500 fpm. There was no communication between the flight crew for about the next 21 seconds.

At 1125:23, the PM made an unintelligible comment, followed about 6 seconds later by his comment, "ok." At 1125:31, the PM stated, "one thousand," and the MCP-selected vertical speed changed to -1,000 fpm. At this time, the airplane was about 6.3 nm from the runway, descending through about 2,600 ft msl at an airspeed of about 178 knots and a descent rate of about 1,500 fpm.

At 1125:36, the NorCal controller instructed the flight to contact the SFO air traffic control tower (ATCT), and the PM acknowledged the instruction. At 1125:43, the PF stated that the missed approach altitude was 3,000 ft, and about 2 seconds later, the MCP-selected altitude changed to 3,000 ft.

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[11] V/S pitch mode maintains the selected vertical speed until the selected altitude is captured.

[12] SPD A/T mode commands thrust to maintain the selected airspeed.

The airplane crossed DUYET at 1125:46, while descending through about 2,250 ft msl at an airspeed of about 176 knots and a descent rate of about 1,100 fpm. When it reached DUYET, the airplane was about 450 ft above the 1,800-ft minimum altitude depicted on the approach chart. The airplane reached a point about 5 nm from the runway at 1125:55, while descending through about 2,085 ft msl at an airspeed of about 174 knots and a descent rate of about 1,000 fpm. When it reached the 5.0 nm point, the airplane was about 400 ft above the altitude for the desired glidepath[13] of 3°.

At 1125:56, the PM radioed the tower controller stating the flight's position but did not receive an immediate response. About 5 seconds later, the PF called out "flaps twenty," and the PM replied, "flaps five ahh" and then "flaps twenty." At 1126:06, the flap lever was moved to the flaps 20 position as the airplane was descending through about 1,900 ft msl at an airspeed of about 175 knots and a descent rate of about 1,000 fpm, and the PF stated, "yeah." At 1126:10, the MCP-selected speed changed to 152 knots. About 2 seconds later, the PF called out "flaps thirty," and the PM replied, "speed check flaps thirty sir." At this time, the airplane's airspeed was about 174 knots, which was above the flaps 30 limit speed of 170 knots.

At 1126:25.7, the AFDS pitch mode changed to FLCH SPD, and the A/T mode changed to thrust (THR) mode.[14] The AFCS responded to the mode change by starting to slow the airplane to the MCP-selected speed of 152 knots and initiating a climb toward the MCP-selected target altitude of 3,000 ft, as seen in FDR-recorded AFDS pitch commands, a slight increase in thrust lever angles, and a slight pitch up. At 1126:28.3, the PM stated "flaps thirty," and at 1126:29.5, the PF made an unintelligible statement that included the word "sir." Between these two remarks, at 1126:28.8, the flap lever was moved to the flaps 30 position, and simultaneously, the autopilot (A/P) was disconnected. At this time, the airplane was about 3.5 nm from the runway, descending through about 1,500 ft msl at an airspeed of about 169 knots and a descent rate of about 1,000 fpm.

According to FDR data, the AFCS-initiated forward movement of the thrust levers that began when the A/T mode changed to THR was manually overridden, and the thrust levers were moved aft. At 1126:33, the thrust levers reached the idle position, and the A/T mode changed to HOLD. Immediately before the A/T mode change occurred, at 1126:32.5, the PM stated, "flight director," and immediately after the change, at 1126:34.0, the PF replied, "check."[15]

During a postaccident interview, the PF stated that he considered pressing the FLCH push-button to obtain a higher descent rate but could not recall whether he did so or not. When interviewed, none of the three flight crewmembers recalled seeing the changes to the A/T mode displayed on each primary flight display's (PFD) flight mode annunciator (FMA) that resulted from the selection of FLCH.

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[13] For purposes of this report, the term "desired glidepath" refers to a descent profile extending out from the 28L touchdown zone at an angle of 3° and approximately conforming to the PAPI glidepath, the ILS glideslope, and an imaginary line drawn through the ILS/LOC 28L approach step-down waypoints.

[14] THR A/T mode commands thrust to maintain the climb/descent rate required by the pitch mode.

[15] As a result of disconnecting the A/P, the status indication for the AFDS displayed near the top of both pilots' primary flight displays would have changed from "A/P" to "FLT DIR."

At 1126:36, the PM stated, “speed,” and the PF replied, “target speed one three seven.”[16] At 1126:38, the MCP-selected airspeed changed to 137 knots. At this time, the airplane was about 2.9 miles from the runway, descending through 1,300 ft msl at an airspeed of about 165 knots and a descent rate of about 1,000 fpm. By this point, the flight crew should have been able to clearly see the precision approach path indicator (PAPI)[17] lights; the PAPI indication would have been four white lights, showing that the airplane was significantly above the PAPI glidepath angle of 2.98°.

At 1126:40, the PF called out “flight director off,” and the PM replied, “okay.” According to quick access recorder (QAR) data,[18] at 1126:43, the left (PF’s) flight director (F/D) switch was turned off, and the right (PM’s) F/D switch remained on.[19] There were no further changes in the F/D switch positions for the duration of the recording. At 1126:44, the PM stated, “it’s high,” and over the next 8 seconds, the airplane’s descent rate increased from about 1,000 to 1,500 fpm. At 1126:52, the PM stated, “one thousand,” and the PF replied, “check.” At 1126:54.9, the airplane was about 2.1 nm from the runway when it descended through 1,000 ft radio altitude[20] (RA) at an airspeed of about 151 knots with a descent rate of about 1,500 fpm. When it descended through 1,000 ft RA, the airplane was 243 ft above the altitude for a 3° glidepath, and the PAPI indication was four white lights. Table 1 lists selected events during the last 1,000 ft of the approach.

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[16] Target speed for the approach was 132 knots (V_{ref}) plus 5 knots, or 137 knots.

[17] A PAPI system consists of a row of four light units installed on the side of the runway that provide visual glidepath indications. The on-glidepath angle (typically about 3°) indication is two red and two white lights. Other light combinations indicate when an airplane’s position is above the glidepath (four white), slightly above (three white and one red), slightly below (three red and one white), and below (four red). According to the Federal Aviation Administration’s (FAA) *Aeronautical Information Manual,* PAPI lights are visible from about 5 miles during the day and up to 20 miles at night.

[18] The QAR data were used to determine the flight director switch positions because it recorded the switch positions once per second while the FDR recorded them once every 4 seconds.

[19] It is also possible that the PM rapidly (in less than 1 second) cycled his F/D switch off and then back on before he turned off the PF’s F/D switch.

[20] Radio altitude is the height of an airplane above terrain immediately below the airplane as measured by a radio altimeter.

Table 1. Timeline of selected events during last 1,000 ft of approach.

With respect to the PAPI lights, W=white and R=red.

Local Time	Time to impact (seconds)	Radio altitude (feet)	Airspeed (knots)	Event
1126:54.9	-55.3	1000	150.5	PAPI displaying WWWW
1126:58.6	-51.7	917	146.7	Observer: "sink rate sir"
1126:59.1	-51.2	904	147.2	PF: "yes sir"
1126:59.5	-50.8	891	147.6	PM (radio): "tower asiana two one four short final"
1127:05.1	-45.2	723	146.0	Observer: "sink rate sir"
1127:07.5	-42.8	658	144.4	Controller issues landing clearance
1127:10.8	-39.5	581	141.3	PM (radio): "cleared to land two eight left"
1127:14.8	-35.4	500	136.7	PAPI displaying WWWR
1127:15.1	-35.2	495	135.9	Airspeed drops below MCP-speed (137 knots)
1127:16.6	-33.7	465	133.8	PF: "landing checklist"
1127:17.5	-32.8	447	134.4	PM: "landing checklist complete cleared to land"
1127:19.8	-30.5	404	134.0	PM: "on glide path sir" / PAPI WWRR
1127:21.2	-29.1	378	132.8	PF: "check"
1127:23.3	-27.0	344	130.5	Airspeed drops below V_{REF} (132 knots)
1127:24.1	-26.2	331	129.7	PAPI changes to WRRR
1127:31.0	-19.3	219	121.9	PAPI changes to RRRR
1127:32.3	-18.0	198	120.4	Electronic voice: "two hundred"
1127:33.6	-16.7	180	117.6	PM: "it's low"
1127:34.8	-15.5	165	119.2	PF: "yeah"
1127:39.3	-11.0	124	113.9	Sound of quadruple chime
1127:41.6	-8.7	102	111.8	Electronic voice: "one hundred"
1127:42.8	-7.5	90	109.8	PM: "speed"
1127:43.2	-7.1	86	109.1	Right engine thrust lever advanced
1127:43.7	-6.6	81	108.4	Left engine thrust lever advanced
1127:44.7	-5.6	68	106.9	A/T mode transition from HOLD to THR
1127:46.4	-3.9	46	103.6	Stick shaker engaged
1127:47.8	-2.5	29	103.8	PM: “go around”
1127:48.6	-1.7	21	104.7	Stick shaker disengaged
1127:50.3	0	5	105.5	Impact

At 1126:59, the observer stated, “sink rate sir,” and the PF replied, “yes sir.” At 1127:00, the PM radioed the tower controller that the flight was on short final. At 1127:05, the observer stated, “sink rate sir” for the second time. About this time, the airplane’s descent rate momentarily reached about 1,800 fpm. Then the descent rate began to decrease, and the pitch attitude began to increase. At 1127:06, the PM stated, “cleared to land?” About 1 second later, one of the flight crewmembers stated, “sink rate.” Simultaneously, the tower controller cleared the flight to land on runway 28L. At 1127:11, the PM radioed acknowledgment of the landing clearance, and simultaneously, one of the other flight crewmembers said something unintelligible. At 1127:14.3, the PM stated, “okay.”

At 1127:14.8, the airplane was about 1.3 nm from the runway when it descended through 500 ft RA at an airspeed of about 137 knots with a descent rate of about 1,200 fpm. As shown in figure 4, which depicts a profile view of the last 40 seconds of the flight, the PAPI indication was three white lights and one red light—a slightly above glidepath indication—when the airplane descended through 500 ft RA. The thrust levers were at the idle position, and the engines’ N_1 speeds[21] were about 24%. At 1127:15.5, an electronic voice[22] announced “five hundred,” and about 1 second later, the PF called out “landing checklist.”

At 1127:16.8, an electronic voice announced “minimums, minimums.” At 1127:17.5, the PM stated, “landing checklist complete cleared to land.” At 1127:19.8, the PM stated, “on glidepath sir,” as the PAPI indication changed to two white and two red lights, showing the airplane’s on-glidepath position. At this time, the airplane was descending through about 400 ft RA at an airspeed of about 134 knots (where it remained for about 4 seconds) and a descent rate of about 1,100 fpm, which was above the descent rate of about 700 fpm needed to remain on glidepath. At 1127:21.2, the PF responded, “check.” There was no communication between the flight crew for about the next 11 seconds.

At 1127:23.3, the airplane’s airspeed dropped below 132 knots (V_{ref}). At 1127:24.1, the airplane was about 1 nm from the runway at 331 ft RA, the airspeed was about 130 knots, the descent rate was about 1,000 fpm, and the PAPI indication changed to one white light and three red lights, showing the airplane’s slightly below-glidepath position. Over the next 5 seconds, the airplane’s pitch attitude increased from about 2° to 4° nose up, where it remained for about 3 seconds. At 1127:31.0, the airplane was about 0.7 nm from the runway at 219 ft RA, the airspeed was about 122 knots, the descent rate was about 900 fpm, and the PAPI indication changed to four red lights, showing the airplane’s significantly below-glidepath position. Over the next 5 seconds, the airplane’s pitch attitude increased to about 7° nose up, where it remained for about 3 seconds before continuing to increase.

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[21] N_1 speed is the rotational speed of the engine’s low pressure spool, which includes the fan, low pressure compressor, and low pressure turbine.

[22] The airplane was equipped with an enhanced ground proximity warning system (EGPWS) that included an advisory callout feature that generated radio-altitude-based callouts at 500, 200, 100, 50, 40, 30, 20, and 10 ft. In addition, a callout was generated when the airplane reached the minimum descent altitude for the approach, in this case 460 ft. For more information about the EGPWS, see section 1.16.4.

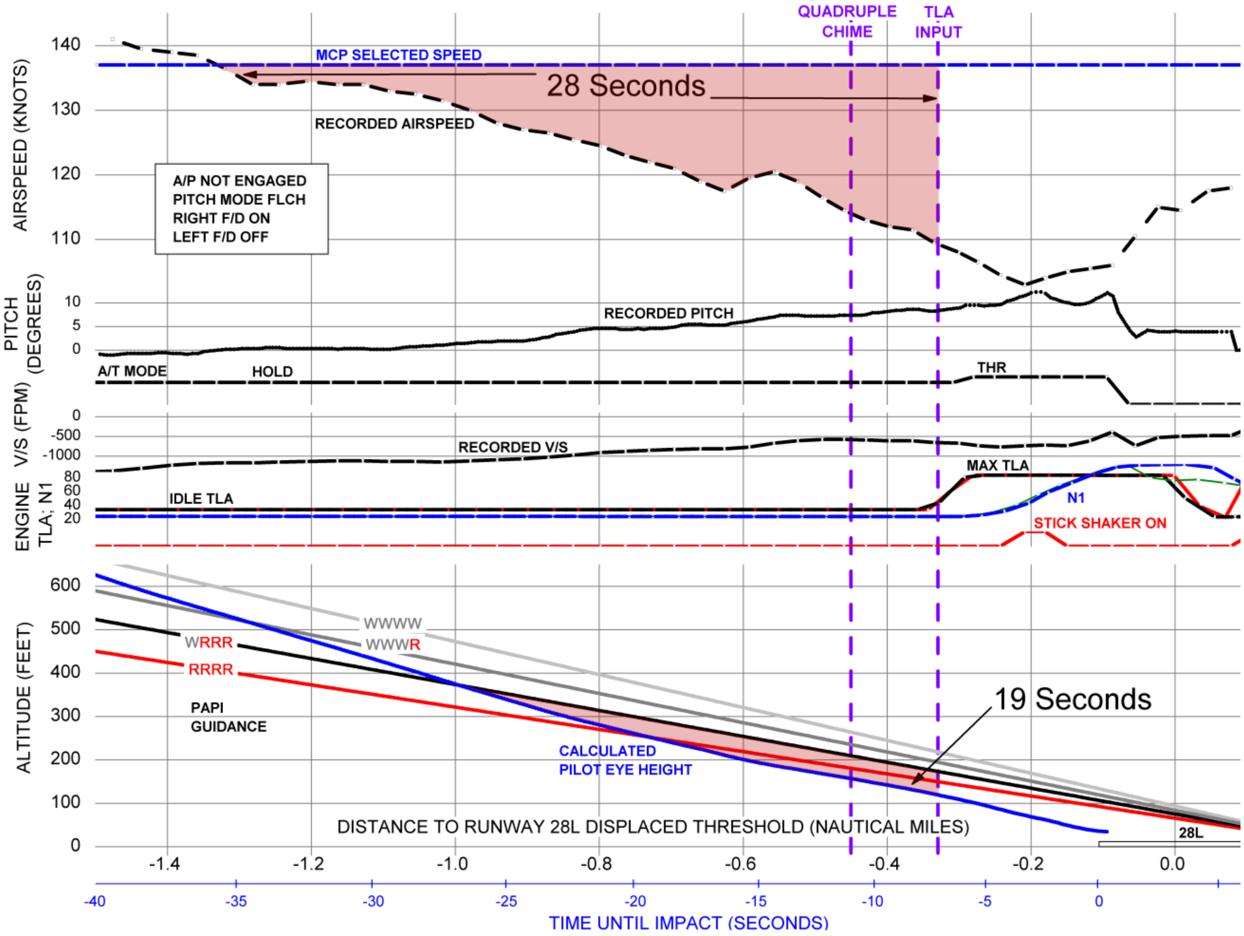

Figure 4. Profile view of the last 40 seconds of flight 214.

During a postaccident interview, the observer stated that he saw two white lights and two red lights on the PAPI as the flight descended through 500 ft RA. He recalled that beginning sometime after the airplane descended below 500 ft, he could no longer see the runway or the PAPI lights through the windscreen. The PM stated that at 500 ft RA, the airplane was slightly low, and he saw one white light and three red lights on the PAPI. The PF stated that he began to see one white light and three red lights on the PAPI at 500 ft RA and recalled thinking that if he allowed the PAPI indication to go to four red lights, he would fail his flight and would be embarrassed.[23] The PF pitched the airplane up to avoid going low. He stated that about that time, he “saw some light and was in blindness for a second.” The light prompted him to stop looking outside and instead look down at the instrument panel. He stated that the blindness was only momentary, and he could see the airspeed tape and noticed that the airspeed was low. The PM stated that he did not see any bright light. The PM further stated that about 200 ft RA, the airspeed was about 120 knots; he saw four red lights on the PAPI and thought perhaps the A/T was not working.

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[23] Although the OE training flight was not a check flight, one of the PF’s previous Asiana OE instructors told investigators that a four-red PAPI indication that occurred during an OE training approach would probably be reported to Asiana training managers.

At 1127:32.3, an electronic voice announced “two hundred.” At 1127:33.6, the PM stated, “it’s low,” and the PF replied, “yeah.” At 1127:36.0, one of the flight crewmembers made an unintelligible comment. At 1127:39.3, the quadruple chime master caution alert sounded. When the alert sounded, the airplane was about 0.45 nm from the runway at 124 ft RA, the airspeed was about 114 knots, and the descent rate was about 600 fpm. At 1127:41.6, an electronic voice announced “one hundred.” At 1127:42.8, the PM stated, “speed.” Less than a second later, both thrust levers were advanced by the PM.[24] At 1127:44.7, the A/T mode changed from HOLD to THR. At 1127:46.4, the CVR recorded the stick shaker activating, and the lowest airspeed during the approach of about 103 knots was recorded by the FDR at 1127:46.9. At this time, the airplane was about 0.35 nm from the runway at 39 ft RA, the descent rate was about 700 fpm, the N_1 speeds for both engines were increasing through about 50%, and the pitch attitude reached about 12° nose up. The airspeed then began to increase. At 1127:47.8, the PM called out, “go around,” and at 1127:48.6, the airspeed was about 105 knots, and the stick shaker stopped. The initial impact with the seawall occurred at 1127:50. At that time, the N_1 speeds for both engines were increasing through about 92%, and the airspeed was about 106 knots.[25]

Video from airport surveillance cameras showed that following the initial impact, the tail of the airplane separated, the airplane slid along the runway, and the rear of the fuselage lifted up, tilting the airplane into about a 30° nose-down angle. The airplane pivoted counterclockwise about 330° before impacting a second time and coming to rest off the left side of the runway, about 2,400 ft from the initial seawall impact point. The airplane came to a stop about 1128:06.[26] Figure 5 is an aerial view of the approach end of runway 28L and the location of the wreckage. (See sections 1.15.3 and 1.15.4 for information about the evacuation and emergency response, respectively.)

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[24] All three flight crewmembers recalled that it was the PM who performed this action.

[25] When the thrust levers were fully advanced, 90% N_1 compressor speeds were reached in about 6 seconds by the left engine and about 7 seconds by the right engine. The acceleration time for both engines met the 8-second performance requirement stated in the design specification.

[26] Because the airplane was enveloped in a cloud of dust between 1128:02 and 1128:28, it was not possible to determine from the video footage exactly when the airplane came to a stop.

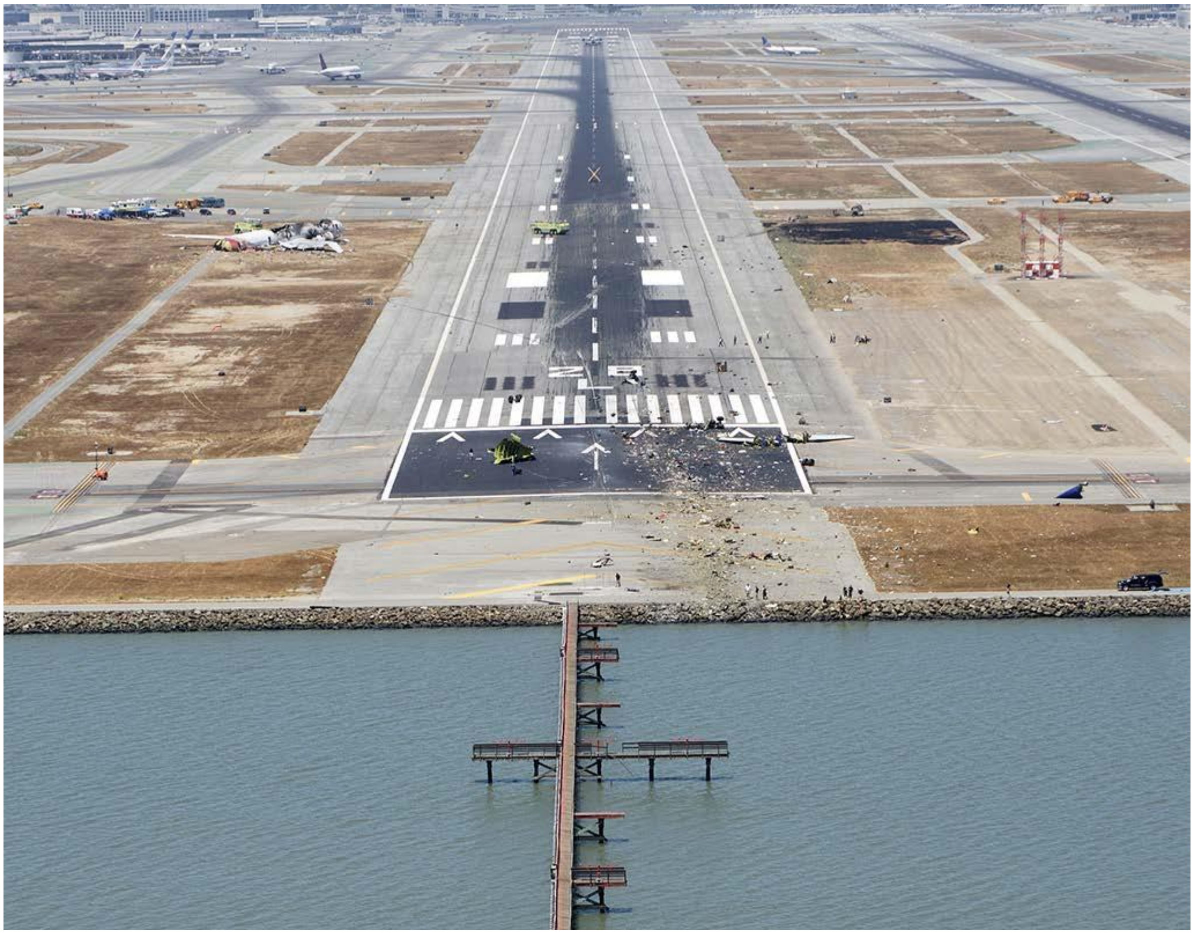

Figure 5. Aerial view of the flight 214 wreckage.

1.2 Injuries to Persons

Table 2. Injury chart.

Injuries	Flight Crew	Cabin Crew	Passengers	Total
Fatal	0	0	3	3
Serious	1	8	40	49
Minor	2	2	134	138
None	1	2	114	117
Total	4	12	291	307

1.3 Damage to Airplane

The airplane was destroyed by the impact forces and postcrash fire.

1.4 Other Damage

The PAPI and the runway were damaged during the accident sequence.

1.5 Personnel Information

1.5.1 The Pilot Flying

The PF, age 45, held an airline transport pilot certificate issued by the Republic of Korea Office of Civil Aviation (KOCA)[27] with a multiengine land airplane rating and type ratings in the Airbus A320 and the Boeing 737, 747-400, and 777. His most recent KOCA medical certificate was issued on July 4, 2013, with no limitations and an expiration date of September 30, 2014. Asiana records did not indicate any previous accidents, incidents, violations, or company disciplinary actions. The records indicated that the PF had accumulated 9,684 total flight hours, including 3,729 hours as PIC. He had 33 hours of 777 flight time and 24 hours of 777 simulator time. In the 90 days, 30 days, and 7 days before the accident, the PF accumulated about 33, 33, and 5 flight hours, respectively.

The PF was hired by Asiana Airlines on March 2, 1994, as a cadet pilot with no previous flight experience, and he received *ab initio* (from the beginning) flight training at a flight school in Florida from 1994 to 1996. He began FO training on the 737 in 1996 and served as a 737 FO and a 747-400 FO before upgrading to 737 captain on December 15, 2005. He transitioned to A320 captain on October 22, 2007.

The PF began transition training to 777 captain on March 25, 2013. He completed ground training, full flight simulator training, a simulator check, and OE ground school. He completed his 777 simulator proficiency check on May 18, 2013, and his line-oriented flight training check on May 30, 2013. Training records indicated that during the simulator stage of his 777 transition training, the PF performed six visual approaches, two without an ILS glideslope, receiving a grade of "good" each time. In addition, the PF performed one circling approach and one sidestep maneuver[28] in the simulator. The record for the PF's sixth simulator period noted that the instructor "reviewed high-energy[29] landing technique to achieve planned performance runway required" but did not indicate whether the instruction was a discussion only or an approach was flown. According to the Asiana 777 captain transition training syllabus in use at the time, a high-energy approach was not required.

The PF began 777 observation flights on June 14, 2013, and logged 9 hours 35 minutes of observer time. He began flying the 777 with an IP as part of his required initial OE on June 16,

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[27] The KOCA is similar in function to the US FAA. For more information on the KOCA, see section 1.17.3.

[28] A sidestep maneuver is a visual maneuver performed to execute a landing on a runway parallel to the one an instrument approach has been made to.

[29] The level of energy of an airplane is a function of primary flight parameters (airspeed, thrust, configuration, and flightpath) and their rate of change. The pilot controls energy level by controlling these parameters and trading one parameter for another. A low-energy airplane is too slow and/or too low; a high-energy airplane is too fast and/or too high.

2013. Of the 20 flight legs and 60 hours flight time required by Korean regulations, the PF had completed 8 flight legs and 33 hours 31 minutes before the accident flight.[30] All of the approaches the PF had previously flown during OE were ILS approaches, and there was no requirement to perform visual approaches during OE. On one approach, the PF made an automated landing, and on several approaches, he disengaged the A/P about 1,000 ft before landing.

Three IPs who had flown with the PF during his OE training were interviewed. The first IP, who conducted two flights with the PF, told investigators the PF made errors that were normal for his stage of training, like not flaring soon enough when landing, and that the PF's overall performance was above average. The second IP, who conducted four flights with the PF, told investigators that nothing stood out about the PF's performance.

A third IP, who conducted two flights with the PF 2 days before the accident, told investigators he was not sure if the PF was making normal progress because the PF did not perform well during their trip together. He said the PF was not well organized or prepared, conducted inadequate briefings, poorly monitored the operation, and deviated from multiple standard operating procedures (SOP). He said that the PF allowed the descent rate to get a little high on short final and allowed the nose to drop at an altitude of 200 to 100 ft. This had caused the airplane to go below the desired glidepath and forced the PF to initiate the flare early. The IP counseled the PF extensively on these and other issues but worried that the PF was not taking his feedback seriously enough. The IP was not overly concerned, however, because he knew that the PF had to complete more OE flights.

The PM said that during the takeoff, climb, and cruise portions of the flight, he did not find any problems with the PF's proficiency. He also said that the PF communicated well, notifying him before doing something, after which, the PM would confirm it. The PM said that the callouts and responses seemed to be working well.

Asiana records showed that the PF flew 29 trips that transited SFO as a 747 FO from July 24, 1997, to April 29, 2004. On those 29 trips, he made 4 landings at SFO. His most recent prior landing at SFO was on July 30, 2002, and his most recent prior flight into SFO was on April 29, 2004.

1.5.1.1 The Pilot Flying's Preaccident Activities

The PF reported no recent stressors in his personal life. He stated, however, that life was generally stressful and that performing 777 OE flights was stressful. He reported that he normally went to sleep about 2300 and needed 6 to 8 hours of sleep per night to feel rested.[31]

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[30] The PF's previous OE flights originated from and returned to ICN, and the destination airports were Narita (NRT), Los Angeles (LAX), and London (LHR).

[31] The times in this section are expressed in Korea local time, based on a 24-hour clock.

On Thursday, July 4, the PF woke at an unknown time. He served as PF on a roundtrip from ICN to Narita and back, departing ICN about 1500, returning to ICN about 2200, and arriving at his residence about midnight. He could not recall when he fell asleep. On Friday, July 5, the PF woke at an unknown time. He was off duty and engaged in routine activities at home. He went to sleep about 2200 or 2300 and slept 8 or more hours.

On Saturday, July 6, the PF woke about 0700 feeling rested. He went jogging, returned about 0800, and ate breakfast. He took a bus to ICN about 0930, arrived about 1030, and began preparing for the flight. The official show time was 1510, but he met his instructor (the PM) about 1440, and they began briefing for the flight. The PF had a cup of coffee when he arrived at the airplane.

The PF was in the cockpit for the first 4 hours 15 minutes of flight. After reaching the initial cruising altitude, he ate a crew meal and drank a second cup of coffee. About 2108, he left the cockpit, went to a business class seat that reclined flat, and began a 5-hour rest break. He recalled being asleep for the first 2 hours of the break and "half-asleep" for the rest of it. He recalled feeling tired but finding it difficult to sleep. Near the end of the break, he ate a small meal and drank a third cup of coffee.

The PF was scheduled to reenter the cockpit about 0208 but returned about 0138 instead.[32] He decided to do this because it was a training flight. The PM joined him at the scheduled time, and they resumed control of the flight. The PF recalled feeling excited because he had not flown into SFO in 10 years but feeling stressed that the runway 28L glideslope was out of service. He was concerned about his ability to conduct a stable visual approach without the electronic glideslope. There was no CVR evidence that the PF discussed his concern with the PM.

1.5.2 The Pilot Monitoring

The PM, age 49, held an airline transport pilot certificate issued by the KOCA with a multiengine land airplane rating and type ratings in the Boeing 757/767 and 777. His most recent KOCA medical certificate was issued on September 5, 2012, with no limitations and an expiration date of September 30, 2013. Asiana records did not indicate any previous accidents, incidents, violations, or company disciplinary actions. The records indicated that the PM had accumulated 12,307 total flight hours, including 9,045 hours as PIC. He had a total time of 3,208 hours in the 777. In the 90 days, 30 days, and 7 days before the accident, the PM accumulated about 211, 71, and 0 hours, respectively.

After serving as a pilot in the Republic of Korea Air Force, the PM was hired by Asiana Airlines on February 1, 1996. He was initially qualified as a 767 FO and upgraded to 767 captain on March 21, 2001. He transitioned to 777 captain on January 16, 2008. He underwent 777 IP

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[32] During the flight from ICN to SFO, the airplane crossed the International Date Line and 8 time zones. The PF's reported return to the cockpit occurred about 0138 on July 7 Korean standard time, which was equivalent to about 0938 on July 6 Pacific daylight time.

training in May and June 2013 and became qualified as an IP on June 12, 2013. The accident flight was his first time acting as an IP.

The PM had attended Asiana's 777 recurrent training every year since 2008. A review of Asiana's 777 recurrent simulator training guides from 2010 to 2013 showed that visual approach training had been conducted each year. Specifically, the 2010 recurrent training included a visual approach at night with no ILS or PAPI, and the 2011 recurrent training included a visual approach to runway 28L at SFO with no PAPI.

The PM's IP training included ground school, simulator training, and OE. A review of the PM's instructor training records showed that typical comments were "good performance" or "very good performance." Records indicate that he performed a visual approach three times during the simulator stage of his IP training in 2013, receiving a grade of "good" on each occasion.

One of the instructors who provided training to the PM during the simulator stage of his IP training stated that he performed "well enough" in the simulator. The instructor said that he told new IPs that when they were in the right seat, they were chosen because of a higher level of proficiency. They had to do the FO's job and do it well, and, at the same time, they had to supervise the new captain in training. He advised the PM to let the trainee do his job as much as possible but never go beyond their own comfort level.

One of the instructors who had flown with the PM during the OE stage of his IP training stated that the PM had a good character and personality and that he could be a very good instructor. He discussed common errors instructors see in transitioning pilots. The captain who conducted the PM's OE final check flight stated that he was very calm, followed the procedures correctly, had professional knowledge of the flight, and had good capability and skill as an instructor.

The PF said some Asiana IPs were very energetic and active, pointing at and touching the instruments, and he sometimes found their behavior stressful. The PM was more relaxed by comparison. The PF thought the PM had been adequately supporting him.

Asiana records showed that the PM flew 33 trips that transited SFO as a 777 captain from December 12, 2007, to May 10, 2013. On those 33 trips, he made 17 landings at SFO. His most recent prior landing at SFO was on May 8, 2013.

1.5.2.1 The Pilot Monitoring's Preaccident Activities

The PM reported that he normally went to sleep about 2400, needed 6 to 7 hours of sleep per night to feel rested, and typically slept 7 hours per night when off duty for an extended period.[33] He reported no recent personal stressors.

On Thursday, July 4, the PM woke about 0600 and went to the Asiana Airlines training facility in Seoul. He participated in joint crew resource management (CRM) training from 0800 to 1600, returned home about 1700, and went to sleep about midnight. On Friday, July 5, the PM woke about 0700 or 0800. He spent the day engaging in routine activities at home and went to sleep about midnight. He recalled that his quality of sleep was "okay."

On Saturday, July 6, the PM woke about 0800. He ate breakfast, visited with family, and watched television. He recalled taking a 15-minute nap while watching television. He reported leaving home about 1310 or 1315 and taking a 1330 bus to the airport. He reported napping for 20 minutes on the bus. He arrived at the airport about 1420 and changed into his uniform. He recalled feeling rested as he went on duty. He began briefing flight 214 with the PF about 1440.

He was in the cockpit for the first 4 hours 15 minutes of the flight. During this time, he ate a crew meal and drank a cup of coffee. He was relieved about 2108 and took a rest break. He went to a business class seat that reclined flat and slept from about 2128 to 0028. When he woke, he ate some soup, drank a second cup of coffee, and watched movies. He returned to the cockpit about 0208 feeling "normal" as he and the PF resumed control of the flight.

1.5.3 The Observer

The observer (relief FO), age 40, held an airline transport pilot certificate issued by the KOCA with a multiengine land airplane rating and type ratings in the Airbus A320 and the Boeing 777. His most recent KOCA medical certificate was issued on July 4, 2013, with no limitations and an expiration date of July 31, 2014. Asiana records indicated that the observer had accumulated 4,557 total flight hours, including 1,445 hours as PIC. He had a total time in the 777 of 715 hours. In the 90 days, 30 days, and 7 days before the accident, the observer accumulated about 232, 57, and 0 hours, respectively.

After serving as a pilot in the Republic of Korea Air Force, the observer was hired by Asiana Airlines on December 12, 2007. He was initially qualified as an A320 FO and transitioned to the 777 on March 3, 2012. Asiana records showed that the observer flew seven trips that transited SFO as a 777 FO from May 29, 2012, to April 10, 2013, and made no landings at SFO during those trips. The observer's most recent flight into SFO before the accident was on May 10, 2013.

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[33] The times in this section are expressed in Korea local time, based on a 24-hour clock.

1.5.3.1 The Observer's Preaccident Activities

The observer said he normally went to sleep between 0200 and 0300 and woke between about 0930 and 1000, sleeping 6.5 to 8 hours.[34] He reported no recent personal stressors.

On Thursday, July 4, the observer was off duty. He went to sleep and woke in keeping with this normal schedule. He reported spending the day at home reading books. On Friday, July 5, the observer was off duty. He went to sleep between about 0200 and 0300 and woke between about 0930 and 1000. He was home until about 1600, then ate dinner at a restaurant. He returned home about 2000 and read books.

On Saturday, July 6, the observer went to sleep about 0200 and woke about 1130. He recalled that his quality of sleep was "good." He ate lunch and left home about 1250 to catch a 1310 bus to the airport. He reported that he arrived at the airport about 1420 feeling "okay."

During the initial portion of the flight, the observer rested in a business class seat that reclined flat. He ate dinner and drank a cup of coffee about 2 hours into the flight and then took what he described as a good-quality 2-hour nap. About 2108, he went to the cockpit and began operating the flight with the reserve captain. While he was in the cockpit, he consumed four more cups of coffee and had a snack. About 0208, he was relieved by the PM and returned to his seat in business class. He took a nap, sleeping from about 0223 until 0243. When he woke, he felt tired. He tried to make himself feel more alert by going to the restroom and performing stretches. When he returned to the cockpit for the arrival at SFO, the airplane was descending through about 11,000 ft msl. He sat down in the center jumpseat and prepared to monitor the approach.

1.5.4 The Flight Attendants

Twelve flight attendants, ranging in age from 22 to 42, were working on the accident flight. The lead flight attendant (or cabin manager) completed initial training on March 13, 1995, and her most recent annual recurrent training was completed on January 24, 2013. Eight flight attendants completed initial training between November 1995 and October 2011, and their most recent annual recurrent training was completed between December 2012 and June 2013. The other three flight attendants completed initial training in June or July 2012 and had not received their first annual recurrent training as of the date of the accident.

1.6 Airplane Information

1.6.1 General

The Boeing Airplane Company completed the manufacture of the accident airplane (model 777-200ER, serial number 29171) on February 6, 2006. The airplane was delivered new to Asiana Airlines on March 7, 2006, and it had since been continuously operated and

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[34] The times in this section are expressed in Korea local time, based on a 24-hour clock.

maintained by the company. The airplane was powered by two Pratt & Whitney PW4090 turbofan engines. At the time of the accident, the airplane had accumulated about 37,120 total hours and 5,388 total cycles.[35] Asiana Airlines maintained the airplane in accordance with the manufacturer's recommended continuing maintenance program, and the most recent scheduled maintenance was performed on June 28, 2013, when the airplane had accumulated 36,992 total hours.

According to the Asiana 777 Flight Crew Operating Manual (FCOM), the V_{ref} speed for a flaps 30 landing at the airplane's landing weight was 132 knots. The flap limit speeds given in the FCOM were 255 knots for flaps 1, 235 knots for flaps 5, 195 knots for flaps 20, and 170 knots for flaps 30.

1.6.2 Instrument Panel Displays

The 777 instrument panel is equipped with five flat panel liquid crystal display units that supply information to the flight crew. As shown in figure 6, the engine indication and crew alerting system (EICAS) is located in the center of the panel, two navigation displays (ND) are located on either side of the EICAS, and two PFDs are located on the far left and far right sides of the panel. The EICAS displays engine parameters and provides a single, central location for alert messages. Each PFD presents a color display of the parameters necessary for flightpath[36] control, including flight mode annunciations (see section 1.6.3.3), airspeed (see section 1.6.4.1), altitude, radio altitude, vertical speed, and attitude.

Each ND provides a mode-selectable[37] color flight progress display. Recommended for most phases of flight, the MAP mode was in use during the accident approach (figure 7 shows an exemplar ND with the indications and parameters that the flight crew would have seen during the approach to SFO). The MAP mode is presented track up and shows airplane position relative to the route of flight (represented by a magenta line) against a moving map background. A green altitude range arc shows the map position where the airplane will reach the MCP target altitude[38] based on current vertical speed and groundspeed.

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[35] An airplane cycle is one complete takeoff and landing sequence.

[36] Flightpath refers to the precise route taken or due to be taken by the airplane; it is the combination of the airplane's vertical and lateral paths.

[37] The modes are MAP (map), VOR (very high frequency omnidirectional range), APP (approach), and PLN (plan).

[38] See section 1.6.3 for more information about the MCP.

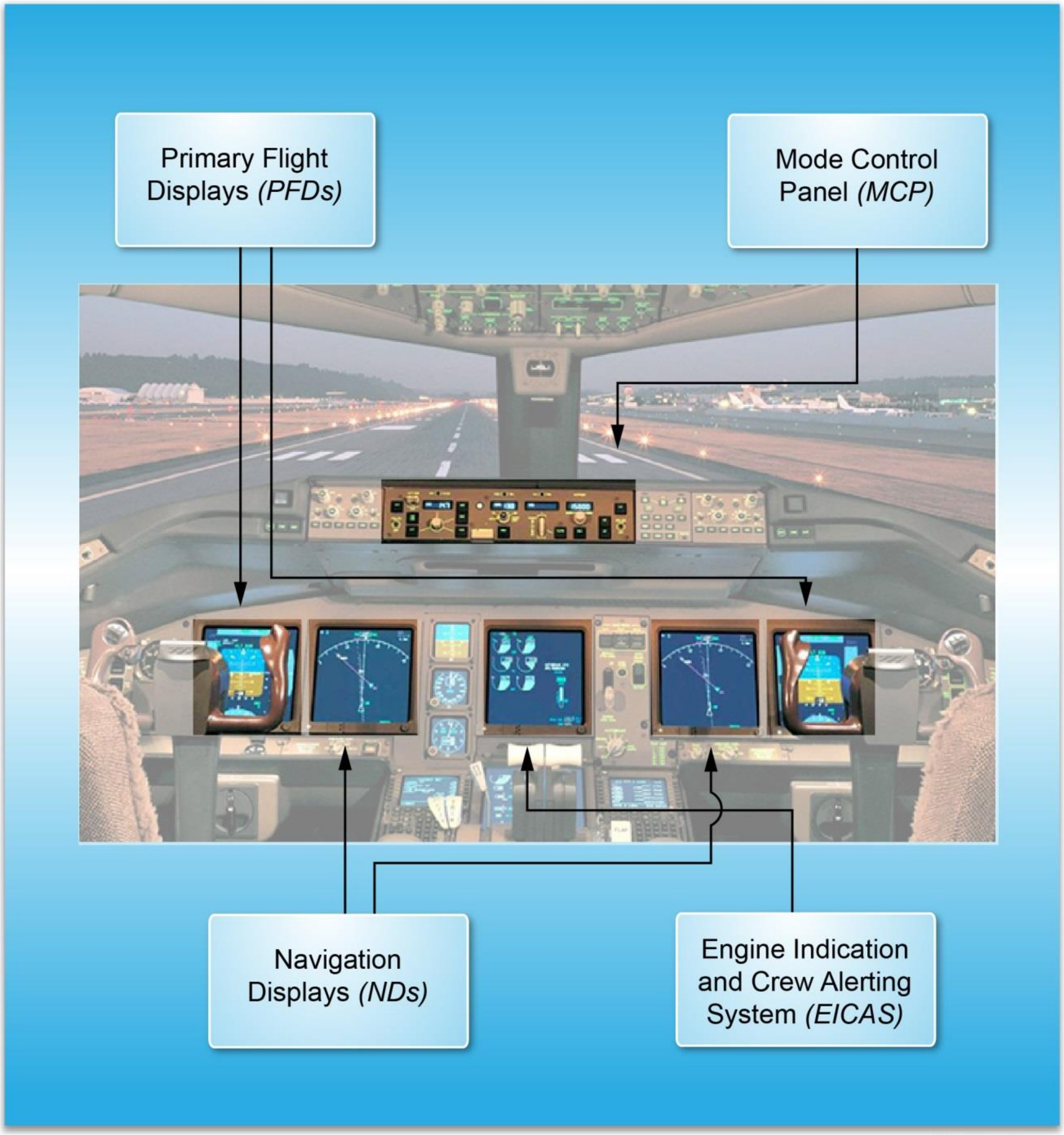

Figure 6. 777 instrument panel.

The FMC computes a performance-optimized descent path, assuming idle thrust from the top of descent, that meets all airspeed and altitude constraints and the end of descent point in the flight plan. During descent, once the top of descent has been passed, a vertical path indicator (VPI), consisting of a path pointer and deviation scale, is displayed on the lower right side of the ND (see figure 7). The VPI shows the airplane’s vertical distance above or below the computed descent path. If the FMC has been programmed for a LOC procedure, the airplane’s vertical navigation (VNAV) system computes a vertical path from the FAF to the runway threshold. From the FAF to the runway, the VPI shows the airplane's vertical distance above or below the computed glidepath for the approach regardless of whether or not the ILS glideslope is functional.

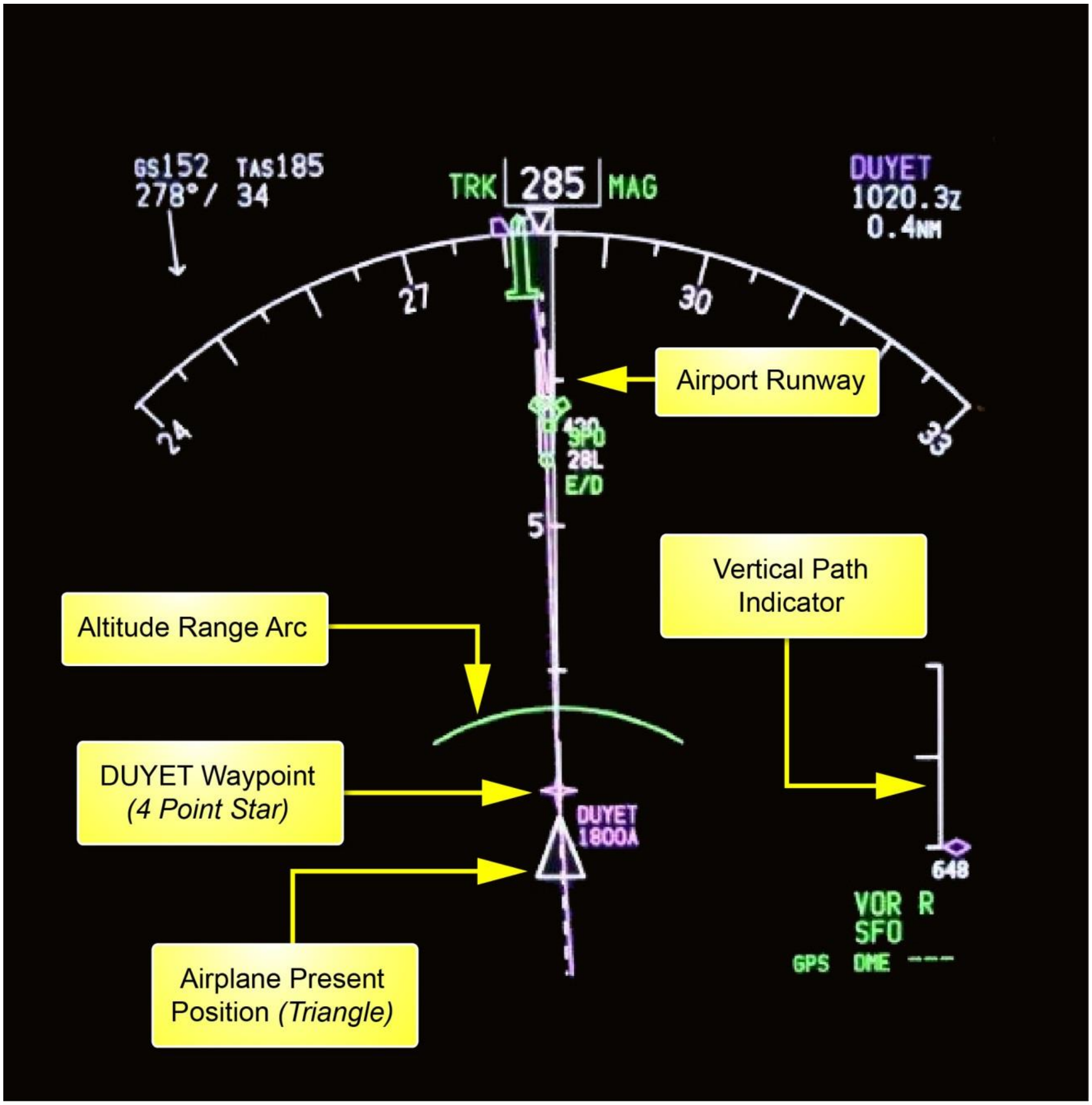

Figure 7. 777 navigation display depicting information for the approach to SFO.

1.6.3 Automatic Flight Control System

The 777 AFCS consists of the AFDS and the A/T. The flight crew configures the AFDS and A/T to perform climb, cruise, descent, and approach through the FMC and the MCP. The MCP, located above the center of the instrument panel and accessible to either pilot (see figure 6), is the primary interface between the flight crew and the AFDS and A/T. Through the MCP, which is shown in figure 8, the flight crew arms or engages the AFDS and the A/T, makes mode selections, and sets target values. Four liquid crystal displays on the MCP show the target values for indicated airspeed, heading or track, vertical speed or flightpath angle, and altitude.

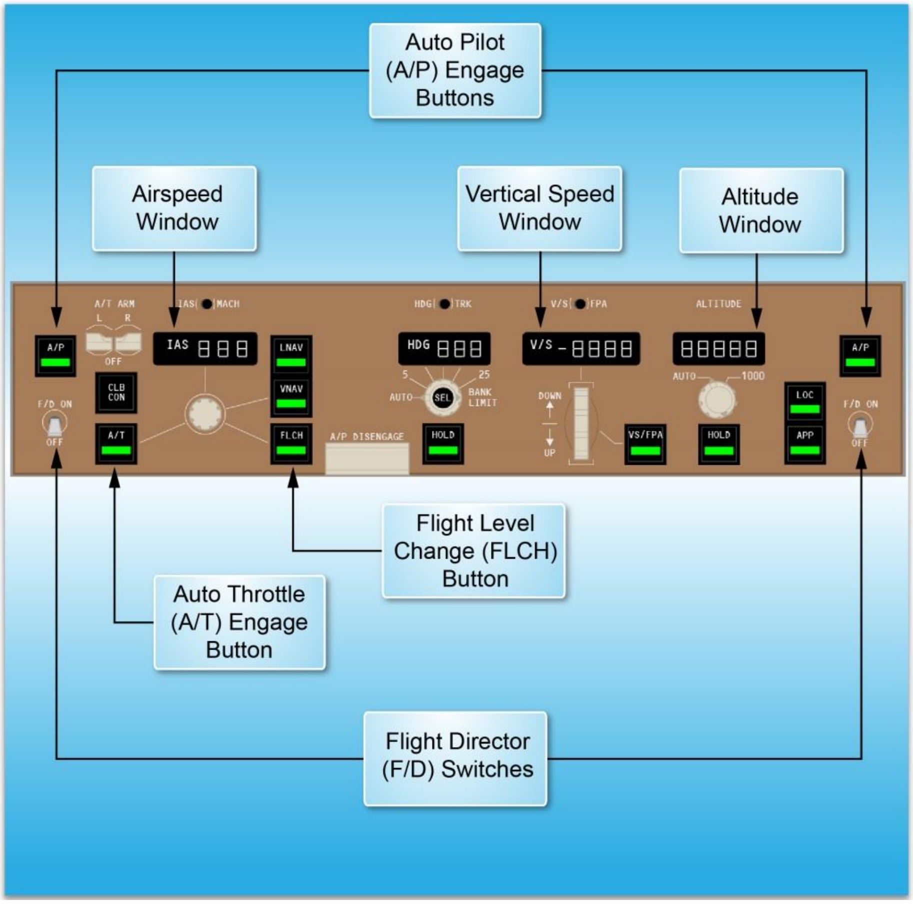

Figure 8. 777 mode control panel.

1.6.3.1 Autopilot Flight Director System

The AFDS can provide A/P pitch, roll, and yaw commands to the airplane's flight control surfaces through the fly-by-wire control system,[39] and it can provide F/D guidance to the flight crew on the PFDs. Left and right F/D switches on the MCP (shown in figure 8) activate the F/D steering indications on the respective PFDs.

The A/P is engaged by pushing either of the two MCP A/P engage buttons. The A/P can be disengaged by pressing the control wheel A/P disengage switch, pulling the MCP A/P disengage bar down, or by overriding the control column, control wheel, or rudder pedals.

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[39] In a fly-by-wire control system, pilot control inputs are processed by flight control computers that then send electrical signals to actuators that move the flight control surfaces.

Disconnecting the A/P generates a warning level alert.[40] The master warning lights on the glareshield illuminate, the message "AUTOPILOT DISC" displays on the EICAS, and the siren, which is the aural cue for all warning level alerts, sounds. The first push of a control wheel disengage switch triggers the alert, and the second push cancels the alert.

Numerous AFDS pitch and roll modes are available and can be activated or armed by pushing the appropriate buttons on the MCP or programming the FMC. When an MCP mode button is pushed, a light in the lower half of the button illuminates. The AFDS pitch and roll modes that are relevant to this report are summarized in tables 3 and 4, respectively.

Table 3. Selected AFDS pitch modes.

AFDS Pitch Mode	AFDS Annunciation	AFDS Mode Description
Flight level change speed	FLCH SPD	Acquires and maintains an MCP airspeed target.
Vertical speed	V/S	Acquires and maintains an MCP vertical speed target.
Takeoff/Go-around—Pitch	TO/GA	Acquires and maintains takeoff speed reference after liftoff, or go-around speed reference after initial go-around rotation.
Vertical navigation speed	VNAV SPD	Follows vertical steering commands from the FMC. VNAV SPD acquires and maintains an FMC or MCP speed target.

Table 4. Selected AFDS roll modes.

AFDS Roll Mode	AFDS Annunciation	AFDS Mode Description
Heading select	HDG SEL	Acquires and maintains an MCP heading target.
Takeoff/Go-around—Roll	TO/GA	Maintains ground track after liftoff or at go-around.
Lateral navigation	LNAV	Follows lateral steering commands from the FMC.
Localizer	LOC	Captures and tracks the localizer centerline.

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[40] The 777 has three levels of alerts: advisory, caution, and warning. Advisory alerts require routine pilot awareness, caution level alerts require immediate crew awareness and action may be required, and warning level alerts require immediate crew action.

1.6.3.2 Autothrottle

The A/T is armed by moving the left and right engine A/T arm switches on the MCP to the ARM position. Once armed, the A/T will engage when certain AFDS pitch modes (including FLCH SPD) are selected or the MCP A/T engage button is pushed. The A/T may be overridden manually at any time by taking control of the thrust levers and placing them at a desired position. The A/T can be disconnected by turning off the A/T arm switches on the MCP or by pushing the A/T disconnect switches located on the thrust levers. Disconnecting the A/T generates a caution level alert. The master caution lights illuminate, the message "AUTOTHROTTLE DISC" displays on the EICAS, and the quadruple chime, which is the aural cue for all caution level alerts, sounds. The first push of an A/T disconnect switch triggers the alert, and the second push cancels the alert.

Table 5 summarizes the A/T modes that may be active under normal operating conditions.

Table 5. A/T mode summary.

A/T Mode	**A/T Annunciation**	**A/T Mode Description**
Thrust reference	THR REF	Thrust set to the reference thrust limit displayed on EICAS.
Speed	SPD	Thrust applied to maintain target airspeed set using the MCP or FMC.
Thrust	THR	Thrust applied to maintain the climb/descent rate required by AFDS pitch mode.
Idle	IDLE	Occurs when A/T controls the thrust levers to the aft stop.
Hold	HOLD	Occurs when A/T removes power from the servo motors. In this mode, A/T will not move the thrust levers.
No mode		A/T is armed but not engaged. This is the only state where the A/T automatic engagement function is potentially active.[41]

1.6.3.3 Flight Mode Annunciator

An FMA is located at the top of each PFD and displays flight mode annunciations and the AFDS status. As shown in figure 9, flight mode annunciations are above the AFDS status indication and show (from left to right) A/T mode, AFDS roll mode, and AFDS pitch mode. Active or captured modes are displayed in green letters, and armed modes are displayed in smaller white letters. A green box surrounds the mode annunciation for 10 seconds when a mode first becomes active.

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[41] See section 1.6.3.5 for a description of the A/T automatic engagement function.

The AFDS status is displayed on each PFD just above the attitude display. When the A/P is engaged, the message "A/P" displays on both PFDs. When the A/P is disengaged and the left or right F/D switch is turned on, the message "FLT DIR" displays on the respective PFD. When the A/P is disengaged and both F/D switches are turned off, no message is displayed on either PFD.

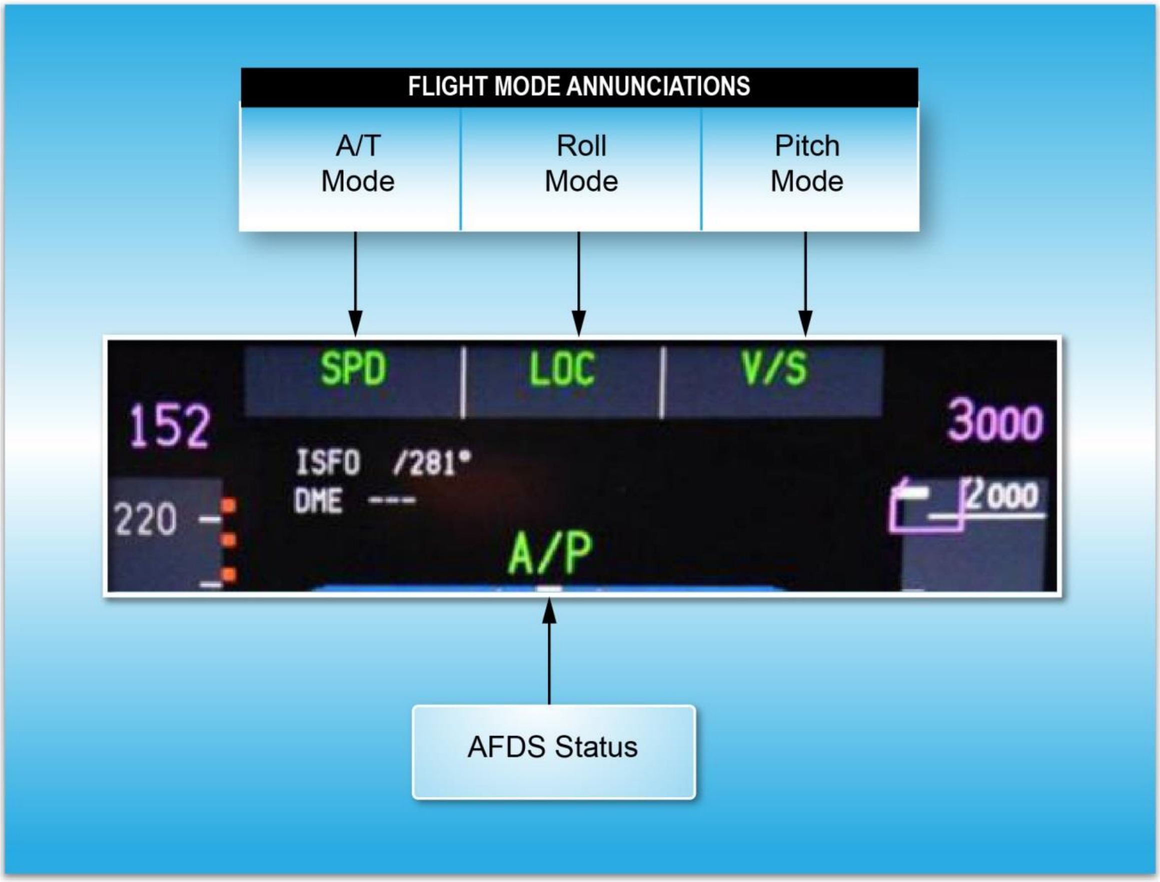

Figure 9. 777 flight mode annunciator.

1.6.3.4 Autopilot and Autothrottle Pairing

Airplane speed can be controlled by the AFDS or the A/T. When the AFDS is controlling speed, this is informally called "speed-on-elevator," as the speed is controlled by modifying the pitch of the airplane through elevator movement. When the A/T is controlling speed, this is informally called "speed-on-throttle," as the speed is controlled by movement of the thrust levers. The A/T controls speed only when it is in SPD mode.

An example of "speed-on-throttle" is the pairing of V/S pitch mode with the SPD A/T mode. In the V/S pitch mode, the AFDS issues elevator commands to achieve the MCP vertical speed target, while the airspeed is controlled by an increase or decrease in thrust through A/T control or manual pilot control. The pilot may use this mode to climb or descend to the altitude set in the MCP. The V/S mode is selected by setting the target vertical speed on the MCP and pushing the V/S button. To maintain the target airspeed, the pilot must set the engine thrust manually or engage the A/T by pushing the MCP A/T engage button, which will activate the A/T in the SPD mode. With the V/S mode active and the A/T engaged, the lights on the V/S and A/T buttons on the MCP will illuminate, and the FMA will display “V/S” for pitch mode and “SPD” for A/T mode. The annunciations “V/S” and “SPD” will be surrounded by green boxes for 10 seconds after being activated.

An example of “speed-on-elevator” is the pairing of FLCH SPD pitch mode with the THR or HOLD A/T modes. The FLCH SPD pitch mode is used to change flight level, and, just as with the V/S mode, the pilot may use this mode to climb or descend to the altitude set in the MCP. However, in this mode, the elevator commands from the AFDS maintain the MCP target speed, while the climb or descent rate (vertical speed) is controlled by an increase or decrease in thrust through A/T control or manual pilot control. To use the FLCH SPD mode, the pilot sets an MCP target altitude and pushes the FLCH button on the MCP. If armed, the A/T will activate in the THR mode and advance the thrust levers if the target altitude is above the airplane’s current position or retard the thrust levers if the target altitude is below the airplane’s current position. With the FLCH SPD pitch mode active and the A/T engaged, the lights on the FLCH and A/T buttons on the MCP will illuminate, and the FMA will display “FLCH SPD” for pitch mode and “THR” for A/T mode. The annunciations “FLCH SPD” and “THR” will be surrounded by green boxes for 10 seconds after being activated.

In FLCH SPD mode, the rate at which the thrust levers move depends on the difference between the current altitude and the target altitude. The A/T is limited by the thrust limit at the forward range of thrust lever travel and by idle at the back range of travel. During a FLCH descent, HOLD mode will engage when the thrust levers reach the aft stop or if the pilot manually overrides the A/T. During a FLCH climb, HOLD mode will engage only if the pilot manually overrides the A/T. When the HOLD mode engages, the annunciation for the A/T mode will change from “THR” to “HOLD,” and the annunciation will be surrounded by a green box for 10 seconds. The A/T will remain in HOLD mode until one of the following conditions is met:

(1) The airplane reaches the MCP target altitude.
(2) The pilot engages a new AFDS pitch mode or new A/T mode.
(3) The A/T arm switches are turned off.
(4) The thrust is manually commanded to increase past the thrust limit.
(5) The A/P is disconnected, and both F/D switches are turned off.

1.6.3.5 Autothrottle Automatic Engagement

The A/T system has an automatic engagement feature (commonly referred to as “A/T wakeup”). Automatic engagement functions when the AFDS is in a compatible pitch mode or no mode, as long as the A/T is armed but not activated in any of its modes, the engine thrust is not already at its maximum limit, and the aircraft is above 100 ft on approach or 400 ft on takeoff. Compatible AFDS pitch modes are all modes except FLCH SPD and Takeoff/Go-Around. The feature will engage the A/T automatically if the airspeed is detected to be below a minimum threshold for 1 second. According to Boeing, at flaps 30, the minimum threshold is 8 knots below V_{ref}.[42] When the system automatically engages, the A/T will respond with the same functionality as it would if the A/T engage button was manually selected.

The A/T automatic engagement feature was described in the Asiana 777 FCOM, chapter 4, "Automatic Flight," page 4.20.9, as follows:

> The autothrottle can support stall protection when armed and not activated. If speed decreases to near stick shaker activation, the autothrottle automatically activates in the appropriate mode (SPD or THR REF) and advances thrust to maintain minimum maneuvering speed (approximately the top of the amber band) or the speed set in the mode control speed window, whichever is greater. The EICAS message AIRSPEED LOW displays.
>
> Note: When the pitch mode is FLCH or TOGA, or the airplane is below 400 feet above the airport on takeoff, or below 100 feet radio altitude on approach, the autothrottle will not automatically activate.
>
> Note: During a descent in VNAV SPD, the autothrottle may activate in HOLD mode and will not support stall protection.

1.6.4 Airspeed Awareness and Low Airspeed Alerting Features

The primary means of airspeed awareness for flight crews is through indications on the left and right PFDs. If airspeed decreases below the minimum maneuver speed, additional visual, aural, and tactile cues are provided by low airspeed alerting features.

1.6.4.1 Airspeed Awareness

Each PFD includes a speed tape that displays the current airspeed (normally in a white box), an airspeed trend vector, and the MCP-selected airspeed on a continuous basis (see figure 10). The airspeed trend vector (an upward- or downward-pointing green arrow) indicates whether the airspeed is increasing or decreasing. According to Boeing, the airspeed trend vector indicates the predicted airspeed at which the airplane will be flying in 10 seconds based on current acceleration or deceleration. The MCP-selected airspeed is represented on the tape by a magenta pointer and is also displayed in a box above the speed tape. V_{ref} is represented on the speed tape by a green line with the letters "REF" beside it. For low speed operations, an amber band is displayed on the speed tape, which indicates the speed range between the minimum maneuvering speed[43] (the top of the amber band) and the speed at which the stick shaker will activate (the bottom of the amber band). A red and black barber pole is displayed below the amber band, and the top of this barber pole indicates the speed at which the stick shaker will

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[42] For flight 214, the minimum threshold was 132 knots (V_{ref}) minus 8 knots, or 124 knots.

[43] When flaps are extended, minimum maneuvering speed is the airspeed that provides 1.3*g* maneuver capability to stick shaker activation.

activate. The pitch angle at which the stick shaker will activate is indicated on the PFD by an amber pitch limit indicator.

If airspeed decreases below the minimum maneuvering speed, further nose-up pitch trim is inhibited. As speed decreases within the amber band's range, the force required to pull back on the control column increases. The pilot may still override the force with increased effort. These features are designed to provide a tactile cue that the airspeed is dropping below the minimum maneuvering speed.

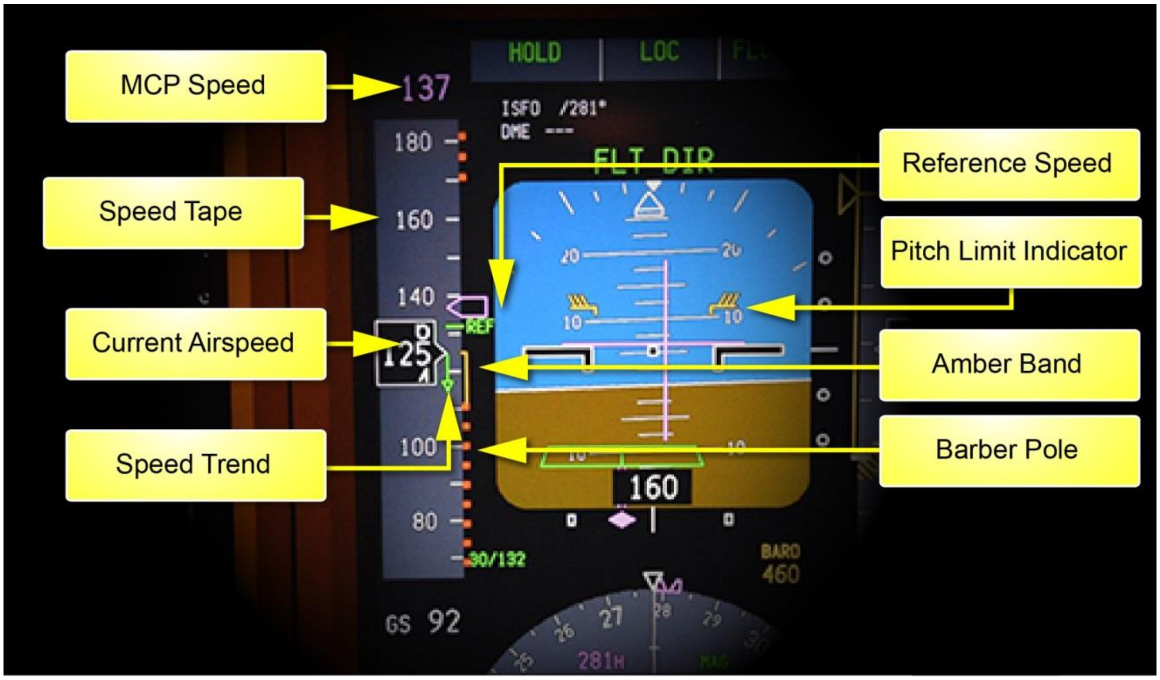

Figure 10. 777 indicated airspeed display.

1.6.4.2 Low Airspeed Alerting Systems

The 777 low airspeed alerting systems include a low airspeed alert and a stick shaker. The low airspeed alert is a caution-level alert and occurs when airspeed decreases about 30% below the top of the amber band. The visual cues that accompany a low airspeed alert include changing the color of the airspeed box on the PFD to amber, displaying an "AIRSPEED LOW" caution message on the EICAS, and illuminating the master caution lights. The caution-level aural alert (quadruple chime) will also sound.

The stick shaker is a warning-level alert designed to warn the flight crew that the aircraft is approaching an aerodynamic stall. The noise of the stick shaker motor shaking the columns provides an aural cue, and the physical shaking of the column provides a tactile cue. The stick shaker activation point is the top of the barber pole. When the flaps are not retracted, or at slow speeds with the flaps retracted, the stick shaker activation point is also shown by the pitch limit indicator, an amber visual indication on the PFD's attitude indicator.

1.7 Meteorological Information

The SFO weather observation about 1056 reported wind from 210° at 6 knots, 10 miles visibility, few clouds at 1,600 ft above ground level (agl), temperature of 18°C, dew point temperature of 10°C, and an altimeter setting of 29.82 inches of mercury. The SFO weather observation about 1156 reported wind from 210° at 7 knots, wind variable between 170° and 240°, 10 miles visibility, few clouds at 1,600 ft agl, temperature of 18°C, dew point temperature of 10°C, and an altimeter setting of 29.82 inches of mercury.

1.8 Aids to Navigation

No problems with any navigational aids were reported. At the time of the accident, the runway 28L ILS glideslope was out of service due to a construction project.

1.9 Communications

No problems with any communications equipment during the flight were reported. See section 1.15.4.3 for information about communications problems during the emergency response.

1.10 Airport Information

SFO, located about 13 miles south of downtown San Francisco, is owned and operated by the City and County of San Francisco. The field elevation is 13 ft msl. For the 12-month period ending December 12, 2012, SFO had about 430,812 total aircraft operations.

SFO is served by four paved runways. Two parallel runways are oriented east/west (runway 10L/28R and runway 10R/28L), and two parallel runways are oriented north/south (runway 01L/19R and runway 01R/19L).

At the time of the accident, runway 28L had a grooved asphalt surface that was 11,381 ft long and 200 ft wide. It was marked as a precision instrument approach runway and equipped with high-intensity runway edge and centerline lights.

In July 2012, SFO began a construction project to comply with a congressional mandate (Public Law 109-115) to bring the runway safety areas (RSA) of all its runways into compliance with Federal Aviation Administration (FAA) design standards.[44] Part of the project involved moving the runway 28L threshold west to expand the RSA. Runway 28L was closed for repaving/remarking on June 24, 2013, and reopened on June 29, 2013. The threshold was

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[44] An RSA is a clear area around a runway, centered on the runway centerline, that is free of objects and structures. According to FAA Advisory Circular 150/5300-13, "Airport Design," the RSA standards applicable to SFO are a width of 500 ft, a length prior to landing of 600 ft, and a length beyond the runway of 1,000 ft.

displaced west 300 ft, providing a 600-ft RSA between the seawall and the threshold. Also, the runway 28L ILS glideslope antenna, portions of the approach lighting system, and the PAPI lights had to be relocated as a result of the threshold movement. At the time of the accident, the ILS glideslope and the approach lighting system were out of service. A notice to airmen (NOTAM) published by the FAA on June 1, 2013, indicated that the ILS glideslope would remain out of service until August 22, 2013.

An FAA flight check conducted on July 2, 2013, certified the relocated PAPI lights serving runway 28L with a 2.98° glidepath.[45] The 28L LOC was operational at the time of the accident. On July 7, 2013, an FAA after-accident flight check of the LOC found that it was functioning properly.

The FAA certified SFO as a 14 CFR Part 139 airport with Index E aircraft rescue and firefighting (ARFF) capabilities.[46] At the time of the accident, the San Francisco Fire Department-Airport Bureau (SFFD-AB) had three fire stations on airport property dedicated to ARFF. ARFF services were continuously available, and the stations were staffed by a minimum of 23 firefighters and paramedic personnel.[47]

According to 14 CFR 139.317, an Index E airport is required to have three ARFF vehicles.[48] The SFFD-AB fire stations had a total of seven firefighting vehicles: three structural firefighting vehicles (Rescue 44 and Engine 33 and 56) and four ARFF vehicles. Three of the ARFF vehicles were Oshkosh Striker 4500s (Rescue 9, 10, and 11), two of which (Rescue 9 and 10) were equipped with 65-ft high-reach extendable turrets (HRET) with piercing nozzles. Each of the three Strikers had a capacity of 4,500 gallons of water, 630 gallons of foam, 460 lbs of dry chemical, and 500 lbs of Halotron. Each Striker was staffed with two firefighters.

The fourth ARFF vehicle (Rescue 88) was an Oshkosh T3000 that had a capacity of 3,000 gallons of water, 420 gallons of foam, and 460 lbs of dry chemical. This unit was staffed with two firefighters and a lieutenant. SFFD maintained three additional ARFF vehicles (Rescue 34, 37, and 49) as reserve vehicles. In addition to the firefighting vehicles, two SFFD

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[45] On the flight inspection report for the PAPI check, the box labeled “G[lide].S[lope]. Angle” contained the entry “2.85/2.98 Sat[isfactory].” According to the FAA, the entry indicated that the intended PAPI glidepath angle was 2.85°, the as-inspected glidepath angle was 2.98°, and this result was satisfactory as it was within the required tolerance of +/-0.2°.

[46] SFO was certified as an Index E airport based on five or more average daily departures of aircraft at least 200 ft in length, as defined in 14 CFR 139.315.

[47] Title 14 CFR Part 139 does not address minimum ARFF staffing requirements.

[48] Of the three vehicles required by 14 CFR 139.317 for an Index E airport, one must carry either (1) 500 lbs of sodium-based dry chemical, halon 1211, or clean agent or (2) 450 lbs of potassium-based dry chemical and water with a commensurate quantity of aqueous film forming foam (AFFF) to total 100 gallons for simultaneous dry chemical and AFFF application. The other two vehicles must carry an amount of water and the commensurate quantity of AFFF such that the total quantity of water for foam production carried by all three vehicles is at least 6,000 gallons.

medical vehicles (Rescue 91 and 93) were based at SFO. Each medical vehicle was staffed with a driver/emergency medical technician and a paramedic.[49]

1.10.1 Emergency Plan and Drills

Title 14 CFR 139.325 requires that each certificated airport develop and maintain an airport emergency plan designed to minimize the possibility and extent of personal injury and property damage on the airport in an emergency. At the time of the accident, the airport was using an emergency procedures manual that had been approved by the FAA in December 2008. SFO had submitted, and the FAA had approved, an updated emergency procedures manual in December 2012; however, the airport had not yet distributed or trained personnel on the updated manual. There were no significant changes to the Alert 3 (which indicates an accident on or near the airport) section of the manual in the 2012 revision.

According to 14 CFR 139.325, SFO is required to hold a full-scale airport emergency plan exercise at least once every 36 consecutive calendar months. The airport conducted full-scale drills on an annual basis. In the 3 years before the accident, SFO conducted exercises responding to the following simulated scenarios: a water crash/water rescue incident (2012), an air crash involving San Mateo County mutual aid (2011), and a fire disaster involving an aircraft parked at an international terminal gate (2010).

In addition to these annual events, the Airport Operations and Security Division and SFFD-AB performed monthly “Redcap” drills, which were designed as “time trial” drills for ARFF personnel; they included exercises for basic strategy and tactics and for the positioning of ARFF units, initiating the incident command system, and establishing a unified command post with airport operations personnel.

1.10.2 Minimum Safe Altitude Warning System

NorCal and SFO ATCT used a minimum safe altitude warning (MSAW) system to alert controllers when an airplane was below, or was predicted by the radar system computer to go below, a predetermined minimum safe altitude. The SFO MSAW configuration consisted of two areas, a “Type 1” area and a “Type 2” area. The Type 1 area began at the approach end of the runway and extended out the approach path for 2 miles. MSAW alerts occurring within the Type 1 area were suppressed because an aircraft in this area was expected to be in close proximity to terrain. The Type 2 area extended from the end of the Type 1 area to a point 5 miles from the approach end of the runway. MSAW functions were enabled within the Type 2 area.

The Type 2 area contained a current warning slope and a predicted warning slope. The current warning slope started at the beginning of the Type 2 area and extended out the approach path at an angle of 0.68°. The predicted warning slope started at the beginning of the Type 2 area, 100 ft below the current warning slope, also at an angle of 0.68°. MSAW alerts are

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[49] Title 14 CFR 139.319(j)(4) requires that certificated airports have at least one individual, who has been trained and is current in basic emergency medical services, available during air carrier operations.

generated under two conditions: when an aircraft is radar-observed operating below the current warning slope, or when an aircraft is predicted to be operating below the predicted warning slope within the next 22 seconds.

Review of recorded radar data indicated that flight 214 remained well above the current and predicted warning slopes while operating in the SFO Type 2 area, and no MSAW alerts were generated. An MSAW simulation conducted at the FAA Technical Center indicated that with the SFO MSAW configuration changed so that the Type 2 area began at a point 1 mile from the approach end of the runway, no MSAW alerts would have been generated for flight 214.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a Honeywell 6022 solid-state CVR capable of recording 2 hours of 2-channel digital cockpit audio and 30 minutes of 3-channel digital cockpit audio.[50] An examination of the CVR at the National Transportation Safety Board's (NTSB) vehicle recorders laboratory found no evidence of structural or heat damage, and audio information was extracted without difficulty.

The extracted 2-hour, 5-minute, 33-second recording consisted of 5 channels of useable audio information. Excellent quality audio[51] was obtained from the channels for the cockpit area microphone and the three individual flight crew positions (right seat, left seat, and jump seat), and good quality audio was obtained from the channel that combined the audio information from all the individual flight crew positions.

The recording began at 0922:29 with the airplane in cruise flight and ended at 1128:02, about 12 seconds after the initial impact. A transcript was prepared starting at 1042:28 and is provided in Appendix B of this report.

1.11.2 Flight Data Recorder

The airplane was equipped with a Honeywell 4700 solid-state FDR that records airplane information in a digital format using solid-state flash memory as the recording medium. The FDR was sent to the NTSB's laboratory for readout and evaluation; it was received in good condition, and the data were extracted normally from the recorder. The FDR recorded about

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[50] One 2-hour-long channel contained audio information from the cockpit area microphone, one 2-hour-long channel contained audio information summed from all of the individual flight crew positions, and three 30-minute-long channels contained audio information from each of the individual flight crew positions.

[51] In an excellent quality recording, virtually all of the crew conversations can be accurately and easily understood, and only one or two words are not intelligible; any loss is usually attributed to simultaneous cockpit conversations and/or radio transmissions that obscure each other. In a good quality recording, most of the crew conversations can be accurately and easily understood, but several words or phrases are not intelligible; any loss can be attributed to minor technical deficiencies, momentary dropouts in the recording system, or a large number of simultaneous cockpit conversations and/or radio transmissions that obscure each other.

27 hours of data, and the accident flight was reflected in the final 10 hours 50 minutes of the recording. For this investigation, 260 parameters were verified.

At 1127:54, about 4 seconds after the initial impact, the values recorded for some parameters (including the acceleration parameters) became constant indicating they were no longer valid. The recording ended at 1128:01, about 11 seconds after the initial impact.

1.11.3 Quick Access Recorder

The airplane was equipped with a Teledyne Optical QAR that records airplane information in a digital format using an optical disc as the recording medium.[52] The QAR was sent to the NTSB's laboratory for readout and evaluation; it was received in good condition, and the data were extracted normally from the recorder. The QAR recording of the accident flight ended about 52 seconds earlier than the FDR data due to buffering of the QAR data stream. For this investigation, 16 parameters were verified to provide supplemental data to the FDR data.

1.12 Wreckage and Impact Information

Examination of the accident site showed that the airplane's main landing gear and the underside of the aft fuselage struck the seawall. The main landing gear, the first part of the airplane to hit the seawall, separated cleanly from the airplane as per design specifications.[53] The tail of the airplane separated at the aft pressure bulkhead. Ground scars and debris from the aft fuselage extended from the seawall to the main wreckage. The vertical stabilizer, the left and right horizontal stabilizers, and left and right main landing gear components were located between the seawall and the runway numbers.

The left and right engines separated cleanly from their respective wings during the impact sequence as per design specifications.[54] The left engine came to rest about 600 ft north of the main wreckage in the grass on the opposite side (right) of the runway. The engine exhibited fan blade airfoil fractures opposite the direction of rotation consistent with high speed fan rotation at the time of impact.

The right engine came to rest against the right side of the fuselage near door 2R, lying on its right side. The exterior surfaces of the left side of the engine, which was facing up, and the bottom of the engine, which was facing the fuselage, exhibited thermal damage and sooting. The oil tank located on the left side of the engine was partially melted, and the areas around the tank were heavily sooted and thermally damaged. The engine exhibited fan blade tip bending opposite

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[52] The primary function of a QAR is to provide the airplane's operator with a user-configurable set of flight data similar to that of the FDR. QARs are not crash hardened.

[53] The 777 main landing gear attachments to the wing rear spar are controlled by a series of fuse pins, which connect the landing gear to the wing fittings. These fuse pins are designed to fail under a prescribed load in the case of a landing gear breakaway event, thus protecting the wing fuel tank structure.

[54] The attachment of the 777 engines to the wing structure is controlled by a series of fuse pins, which connect the strut to the wing fittings. These fuse pins are designed to fail under a prescribed load in the case of an event that overloads the strut-to-wing attachment beyond design ultimate load, thus protecting the wing fuel tank structure.

the direction of rotation and hard object impact damage on the fan blade airfoil leading edges, consistent with foreign objects entering the fan when the engine was rotating at high speed.

1.13 Medical and Pathological Information

1.13.1 Fatalities

Passenger 41B,[55] a 16-year-old female, was found on the right side of the runway about midway between the seawall and the main wreckage. An autopsy was performed by the San Mateo County Coroner's office, and the cause of death was determined to be "multiple blunt injuries" and the manner of death to be "accident." The autopsy report described skull fractures, as well as extensive contusions and abrasions to the torso and extremities.

Passenger 41E, a 16-year-old female, was found about 30 ft in front of the airplane's left wing and about 50 ft from the left side of the fuselage. An autopsy was performed by the San Mateo County Coroner's office, and the cause of death was determined to be "multiple blunt injuries" and the manner of death to be "accident." The autopsy report noted that there was a moderate amount of dirt and plant material on the outside and inside of passenger 41E's clothing. The autopsy report described skull fractures, a lacerated aorta, a fractured pelvis, and extensive contusions and abrasions of the extremities and anterior torso as well as open fractures of the right humerus and left wrist and closed fractures of the left humerus and left femur.

Passenger 42A, a 15-year-old female, was taken to the hospital from the scene and died 6 days after the accident. The San Mateo County Coroner's Office performed an external examination and reviewed the patient's medical records. The cause of death was determined to be "multiple organ dysfunctions due to multiple traumatic injuries" and the manner of death to be "accident." Her injuries included a skull fracture, multiple traumatic brain injuries, a cervical spine fracture, and fractured ribs.

1.13.2 Survivors

Overall, 192 occupants (181 passengers, 10 flight attendants, and the observer) were treated at local area hospitals after the accident.[56] Additionally, the PF and the PM were treated at a hospital in Korea beginning on July 14, 2013.

Based on review of medical records and the definitions in 49 CFR 830.2, the severity of injuries to each of the 304 survivors was classified as serious, minor, or none. Forty-nine persons (40 passengers, 8 flight attendants, and the PF) sustained serious injuries; 138 persons

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[55] For purposes of this report, all passengers will be identified by the number of their assigned seat. Some passengers were known to have moved and were not seated in their assigned seats for landing. Specifically, passenger 41B was reported to be seated in 41D for landing.

[56] This total includes passenger 42A who died 6 days after the accident.

(134 passengers, 2 flight attendants, the PM, and the observer) sustained minor injuries; and 117 persons (114 passengers, 2 flight attendants, and the relief captain) were not injured.[57]

For additional information about the injuries sustained by the occupants, see section 1.15.5.

1.13.3 Flight Crew Toxicological Testing[58]

The NTSB's counterpart agency in Korea, the Republic of Korea Aviation and Railway Accident Investigation Board (KARAIB), collected scalp hair samples from the PF and the PM on August 4, 2013, and submitted them to the Korea National Forensic Service for toxicological tests, which found no evidence of drug use.[59]

The observer was transported to a local hospital where blood and urine samples were collected. Toxicological testing of the samples at the FAA's Civil Aerospace Medical Institute detected no evidence of alcohol or performance-impairing drugs.[60]

1.14 Fire

A fire erupted during the accident sequence and destroyed sections of the airplane before being suppressed by firefighting personnel. Portions of the fuselage crown structure above the window belt were burned through from about body station[61] (BS) 358 aft to about BS 1434. The cabin interior above the passenger floor from about the cockpit door aft to about BS 1434 was partially consumed by fire. Figure 11 shows fire damage to the airplane.

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[57] Passengers and crew who were not transported to a hospital after the accident and did not report an injury to the NTSB were considered to have no injury. Also considered to have no injury were 6 passengers who were examined at a local hospital and were found to have no injuries.

[58] See section 1.18.5 for information about postaccident flight crew toxicological testing requirements.

[59] Gas chromatography/mass spectrometry, gas chromatography/tandem mass spectrometry, and liquid chromatography/tandem mass spectrometry methods were used to look for evidence of 47 different substances, including amphetamine-type stimulants, cannabinoids, opioids, cocaine, and benzodiazepines.

[60] Specimens were screened using immunoassay and chromatography to detect alcohol and a variety of legal and illegal drugs, including amphetamines, opiates, marijuana, cocaine, phencyclidine, benzodiazepines, barbiturates, antidepressants, and antihistamines.

[61] On the 777, body station refers to the distance measured in inches from a point located 92.5 inches forward of the tip of the airplane's nose to a point on the airplane's longitudinal axis.

Figure 11. Fire damage to the fuselage of flight 214.

Examination of the accident site and the airplane's fuel tanks showed no evidence of postcrash fire involving fuel. As previously noted, the right engine's oil tank was breached and partially melted; thermal damage signatures around the oil tank were consistent with an oil-fed fire. The fuselage in the area where the right engine came to rest (BS 825 to 867) showed severe heat damage but no penetrations other than rivet holes and minor cracks. The door 2R external skins were burned away, but the fire did not penetrate internal insulation and mechanisms into the cabin. However, below the cabin floor in the cargo bay, severely burned ducts, thermal acoustic insulation, and composite floor beams were found between BS 755.5 and 888 behind the cargo compartment liner. The path of the fire was traced from this area, up the environmental control system riser duct bay between BS 825 and 846 and into the overhead area.

1.15 Survival Aspects

1.15.1 General

The airplane was configured with 295 passenger seats, 2 flight deck crew seats, 2 flight deck observer seats, and 13 retractable flight attendant jumpseats. As shown in figure 12, the cabin was divided into three zones, which were separated by service areas (galleys and lavatories). A-zone was the forward section and contained 24 business-class seats in rows 1 to 6. B-zone was the middle section and contained 157 travel-class seats in rows 10 to 28. C-zone was the aft section and contained 114 travel-class seats in rows 29 to 42. The A-zone seats were equipped with lap belts and single-diagonal shoulder harnesses, and the B-zone and C-zone seats were equipped with lap belts only.

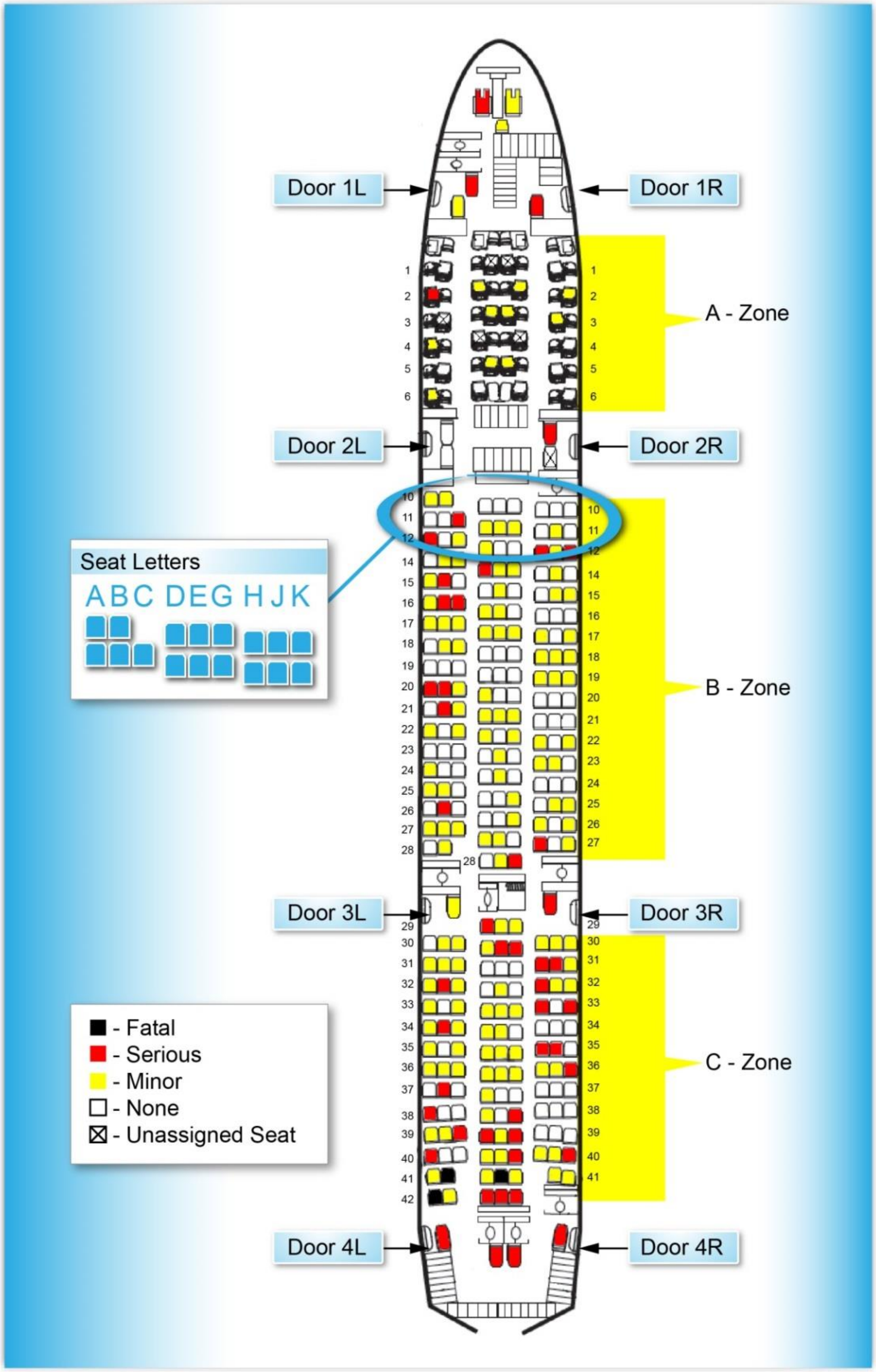

Figure 12. Diagram of flight 214's cabin configuration including injury classification based on assigned seat.

The airplane was equipped with eight doors that also served as emergency exits. There were no other cabin exits. The eight doors were paired along the airplane fuselage and numbered beginning at the front of the cabin and proceeding aft as 1 through 4 left (L) and 1 through 4 right (R). A window in each door allowed observation outside the airplane. Each door was equipped with an automatically inflating evacuation slide/raft, which was mounted on the lower face of the door and covered with a molded plastic cover.

As shown in figure 12, 11 of the 13 flight attendant jumpseats were located at cabin doors: 1 at door 1R; 2 each at doors 1L, 2R, and 2L; and 1 each at doors 3R, 3L, 4R, and 4L. If there were two jumpseats at the same door, the jumpseat on the forward side of the door was designated A, and the jumpseat on the aft side of the door was designated B. For example, the two jumpseats at door 1L were designated as L1A and L1B. Additionally, there were two aft-facing jumpseats in the aft galley between doors 4R and 4L that were designated as M4A and M4B. During the approach, all of the flight attendant jumpseats were occupied except the R2B jumpseat.[62]

1.15.2 Seatbelt Compliance

Following the accident, NTSB investigators interviewed and/or obtained written statements from 8 of the 12 flight attendants.[63] These flight attendants described a normal flight until the final approach for landing. They reported that they performed their seatbelt compliance checks and that at least two flight attendants (the cabin manager and flight attendant L2A) checked C-zone.[64]

The three passengers who sustained fatal injuries were part of a school group traveling from China to the United States to attend summer camp. Following the accident, an NTSB investigator interviewed three students from the school group. The students, passengers 41G, 41J, and 41D (who was seated in 41B for landing), were interviewed together and stated that their school group was seated throughout the cabin. All three students reported that they were wearing their seatbelts for landing. They reported that their fatally injured friend, passenger 41B, was seated in 41D and covered by a blanket at the time of landing. They did not know if she was wearing her seatbelt. They also reported that their fatally injured friend, passenger 41E, was seated in her assigned seat and was not wearing her seatbelt at the time of landing. The students made no seat location or seatbelt status observations regarding the other fatally injured student, passenger 42A. When asked if the flight attendants performed a seatbelt compliance check before landing, Passenger 41J stated that a male flight attendant[65] came through the cabin and that he specifically reminded her to fasten her seatbelt. Immediately after the impact,

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[62] For purposes of this report, with the exception of the cabin manager, who was seated in jumpseat L1A, the flight attendants will be identified by the number of their assigned jumpseat.

[63] Due to the extent of their injuries, the four aft flight attendants (seated in jumpseats L4, R4, M4A, and M4B) were not interviewed and were unable to provide written statements.

[64] Because they were not interviewed, it was not possible to determine whether the four aft flight attendants performed seatbelt compliance checks of C-zone; however, it would have been normal procedure for at least some of them to do so.

[65] L2A was the only male flight attendant.

passenger 41D (seated in 41B) noticed that the seats where her fatally injured friends had been sitting (41D and 41E) were empty. All three students believed that their friends, passengers 41B and 41E, were ejected from the airplane during the impact.

Other passengers from C-zone who were not members of the school group were interviewed. Passenger 37H stated that he believed many of students were inexperienced flyers. He stated that "they seemed pretty unfamiliar and the flight attendants did a pretty good job enforcing the safety measures." He reported that the first thing the students did after boarding was to put their tray tables down and get out iPads and other electronic devices. It was the same thing before landing. He stated that the flight attendants were "very diligent" in making sure seats and tray tables were up for takeoff and landing. He recalled flight attendants coming through the cabin before landing and checking seatbelt compliance and said "they had a lot of work to do," indicating there was significant noncompliance among passengers. Passenger 37B flew Asiana Airlines regularly and stated that they had always been good about safety and compliance checks. He felt they were very strict. He reported that the flight attendants even came through and checked seatbelts "a couple times" when there was turbulence during the accident flight.

1.15.3 Evacuation of Passengers and Crewmembers

Several flight attendants reported that as the airplane approached the runway, they felt a sensation that the airplane was traveling or descending too quickly. Flight attendant L2A was able to see out a window and felt they were going to impact the water and yelled for his colleague (flight attendant L2B) to brace herself. Some flight attendants reported that the airplane pitched up unusually. The flight attendants generally described the first impact as similar to a hard landing. One flight attendant reported a crushing sensation after the first impact. Some flight attendants stated that the first impact was followed by a sensation of lifting off again. Others reported being thrown against their restraints or that the airplane was shaking or rolling. The flight attendants reported a second impact that was much more severe than the first. Flight attendants R1 and R2A reported that the second impact caused the slide/rafts attached to their doors to come free and inflate inside the cabin, pinning them in their seats. Most of the flight attendants reported items flying throughout the cabin and oxygen masks and ceiling panels falling down.

According to the ATC transcript prepared by the SFO ATCT, at 1128:26, about 36 seconds after the initial impact and about 20 seconds after the airplane came to a stop, one of the pilots radioed the tower controller stating, "uh tower tower asiana two one four." The tower controller responded, "asiana two fourteen heavy emergency vehicles are responding." At 1128:33, the pilot again radioed the tower controller stating, "asiana two one four," and the tower controller responded, "emergency vehicles are responding." For about the next minute, radio calls from the pilot to the tower controller continued, but with the exception of a few words, the transmissions were unintelligible. The last transmission from the pilot was at 1129:37.

According to the PM, the airplane was enveloped in dust when it came to a stop, and he attempted to contact the tower controller to determine the airplane condition as seen by the tower. When the cabin manager came to the cockpit and asked if they should initiate an evacuation, the PM said "standby." When the PM understood emergency vehicles were responding, he read and accomplished the evacuation checklist. He was delayed in completing the 777 Quick Reference Handbook (QRH) evacuation procedure because he could not immediately find the QRH. Once the initial steps of the checklist were completed, he issued an evacuation order.

According to the cabin manager, after the airplane came to a stop, she ordered flight attendant L1B to check on the status of the pilots. Flight attendant L1B went to the cockpit and knocked on the door, which was immediately opened by one of the flight crew. She ascertained that they were okay and went back to door 1L. Upon hearing them say they were okay, the cabin manager immediately went to the cockpit and asked if the flight attendants should evacuate the airplane. She was told, "No, please wait." She went back to her jumpseat and made an announcement to passengers to remain seated. Immediately after her announcement, she heard "evacuate!" Although she was unsure of who the command came from, she went to door 1L, opened it, and began to command passengers to evacuate.

Flight attendant L2A reported that after the airplane came to a stop, he immediately realized the situation was an emergency. He made an announcement for passengers to wait while he assessed conditions and then heard flight attendant R2A screaming for help. Her legs had been pinned against the galley next to her jumpseat by the inflated slide/raft, and she could not free them. He went over to her to try to assist but was unsuccessful in freeing her. He saw fire and smoke outside the door 2R window and determined that they needed to evacuate. Before he could get back to his exit, he heard the cabin manager making her announcement for passengers to remain seated. He told flight attendant L2B to go to door 1L and stop her from making the announcement while simultaneously commanding the evacuation to begin in both Korean and English. He did not hear a command from a flight crewmember to evacuate; he initiated the evacuation entirely on his own.

Review of video from airport surveillance cameras indicated that doors 1L and 2L were opened nearly simultaneously at 1129:39, about 1 minute 33 seconds after the airplane came to a stop. Occupants began to evacuate down the 1L and 2L slide/rafts about 10 seconds later. The video footage showed the flow of passengers evacuating out of door 1L temporarily stopped after about 10 passengers evacuated in the first 30 seconds while the flow of passengers out of door 2L remained constant. At 1131:10, several occupants were seen evacuating door 1L, and by 1132:10, occupants were no longer evacuating from doors 1L and 2L.

Flight attendant L3 reported losing consciousness for a few seconds after impact. When she regained consciousness, she was still restrained in her jumpseat but recognized they were in a "very bad situation." She was confused because she heard the cabin manager make an announcement. She tried to use the interphone to independently command an evacuation but reported it did not work. She released her seatbelt and tried to open her door, but it would not open. She recognized flight attendant L2A's voice when he commanded an evacuation and shortly thereafter saw light coming from across the airplane at door 3R. Passenger 30K (who reported that he opened door 3R) was there directing passengers out the door. She stayed in the area of her jumpseat and began directing passengers to evacuate from both doors 2L and 3R. Flight attendant L3 was the only crewmember in the back half of the airplane who was capable of assisting with the evacuation. Flight attendant R3's statement indicated that despite fastening her seatbelt before landing, she was thrown to the floor and seriously injured during impact. She recalled being helped from the airplane through door 3R by passengers.

After most of the passengers had evacuated from the front of the airplane, the cabin manager and flight attendant L1B both realized that flight attendant R1 was trapped in her jumpseat by an inflated slide/raft and assisted her husband (who was traveling on the flight as a passenger) in extricating her. She was described as initially being unconscious, and she was helped down the 1L slide/raft by her husband and two flight attendants.

At the same time, flight attendant R2A's legs were still pinned against the galley across from her jumpseat. She remained conscious and had managed to unfasten her restraint and fall to the floor. Several flight attendants and at least one member of the flight crew helped her. When nothing could be immediately found to puncture the slide/raft, flight attendants who had evacuated asked for and retrieved knives from emergency responders who had arrived on scene. According to the cabin manager, she retrieved a knife from the galley between the doors 2R and 2L, and the observer (relief FO) punctured the slide/raft with it. She then retrieved a fire extinguisher, and the observer attempted to extinguish an interior fire. The remaining flight attendants and flight crew in the front of the airplane evacuated from either door 1L or door 2L.

When all of the ambulatory passengers in her area had evacuated, flight attendant L3 noticed that several passengers were not evacuating. She commanded them to evacuate but realized that some passengers were trapped. She went to the back of the airplane and tried to help extricate them until firefighters arrived, but she was forced to evacuate because of the smoke and difficulty breathing.

Once outside, the uninjured flight attendants performed various duties, such as gathering passengers together, attending to injured passengers and crewmembers, and notifying responders that the four flight attendants who had been seated in the aft galley area were missing.

1.15.4 Emergency Response

Most of the airport emergency responders learned of the accident via an Alert 3 notification from the ATCT about 10 seconds after the initial impact at 1128:00.

Review of video footage indicated that the first vehicle to arrive on scene was an airport operations pickup truck driven by an airfield security officer (ASO) at 1130:16. At that time, the evacuation at doors 1L and 2L had been underway for about 25 seconds. The first SFFD ARFF vehicle to arrive was Rescue 88 at 1131:11. It was positioned about the airplane's 1 o'clock position[66] and began to apply agent to the visible fire involving the right engine that was against

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[66] The positions of the ARFF vehicles are described by reference to a clock face overlaid on the airplane with the airplane's nose at 12 o'clock, the right wing at 3 o'clock, the tail at 6 o'clock, and the left wing at 9 o'clock.

the right side of the fuselage, near door 2R. Rescue 9 arrived and also began applying agent to the fire about 37 seconds later. Within about 20 seconds of Rescue 9's arrival, most passengers had finished evacuating from doors 1L and 2L.

By 1133:02, SFFD had seven firefighting vehicles on scene in various positions around the airplane. Additionally, two SFFD rescue vehicles had taken position on taxiway F in the location that would become the triage area. At 1136:53, Rescue 10 was repositioning to lay a foam blanket in front of the left wing near the missing left engine where fuel was leaking. On-vehicle camera footage showed several firefighters on the ground, one of whom directed Rescue 10 around a victim (later identified as passenger 41E) lying in the grass near a cart path forward of the left wing.

At 1138:37, three firefighters climbed the 2L slide/raft with a handline and entered the cabin. In their statements, these firefighters reported that one firefighter moved forward and searched the cockpit and forward cabin while the other two moved aft down the airplane's left aisle. Visibility was hazy, but one of these firefighters recalled seeing that the cockpit door was open when they entered the airplane. As he moved aft, he saw fire on the right side of the airplane spreading upward toward the overhead bins. He sprayed water on the fire to knock it down and continued aft past door 3L. He estimated four to six passengers remained in C-zone, and a flight attendant was attempting to assist them. Some passengers were pinned beneath seats, and others had stayed with them to try to help. Other firefighters and San Francisco Police Department (SFPD) officers entered C-zone through the hole in the back of the airplane and helped with extricating and removing these passengers from the airplane. Based on information from multiple sources, it is likely that the last passenger was extricated from the back of the airplane about 1147.

At 1149:41, video footage showed an individual walking across the runway from the debris field toward the airplane. Although the individual's path was partially hidden on the video by the smoke plume, the individual appeared to be walking from the general vicinity of where the R4 jumpseat was found. When the individual neared the edge of the runway in the vicinity of a runway distance-remaining marker behind the airplane, passengers ran to and began assisting the person.

The discovery of this individual prompted a search of the debris field between the seawall and the airplane, which had not yet been performed because all of the SFFD personnel on-scene were initially dealing with the airplane fire and interior search and rescue. Once the search of the debris field began, numerous SFPD officers and ASOs responded to assist. An SFPD officer provided a complete accounting for the occupants found on the runway stating that there were five total: one fatality (passenger 41B) and four who were seriously injured.

About the time the individual was seen walking across the runway, the Rescue 9 HRET began to rise, which was the first indication of an attempt to elevate that piece of equipment by the personnel of either Rescue 9 or Rescue 10 (the only two trucks equipped with an HRET). At the same time, Rescue 10 was positioned at 9 o'clock, and its personnel were dispensing foam from its roof turret onto the door 2L area from beyond the left wing tip. At 1148:34, Rescue 10 personnel began to slowly advance the truck perpendicular to the airplane while using its bumper turret intermittently. Rescue 10's in-vehicle video footage showed passenger 41E lying in a right lateral recumbent (fetal) position and covered by a layer of foam as Rescue 10 approached. Rescue 10 rolled over passenger 41E at 1150:46. The Rescue 10 HRET pierced the airplane in the area above and aft of door 2L at 1152:42, and the piercing tip was withdrawn about 50 seconds later. The tip was broken at that time and hung from the end of the HRET.

At 1158:37, Rescue 37 arrived in the area of the 1L slide/raft after Rescue 10 had departed. The fire attack supervisor directed the driver of Rescue 37 to dispense agent into door 2L, and she complied but ran out of water and departed the area by making a sweeping right turn in front of the left wing. During this turn, Rescue 37 rolled over passenger 41E at 1201:11. Shortly thereafter, passenger 41E (no longer covered due to the displacement of foam by the vehicle tires) was pointed out to the fire attack supervisor. He reported the victim over the radio and had the body covered with a blanket at 1206:29.

The heavy black smoke abated, and the fire was brought under control at 1218:30 after simultaneous, elevated attacks by both Rescue 9 and Rescue 10 using the burnthrough holes in the crown of the airplane as entry points for the application of water and foam.

1.15.4.1 Incident Command

The initial incident commander for the accident was the on-duty shift captain from the SFFD-AB. Mutual aid resources arrived from San Francisco within about 24 minutes of the accident. Upon arrival, an SFFD city assistant division chief assumed incident command. He assigned an SFFD city battalion chief as the fire attack supervisor, and the SFFD-AB shift captain remained at the incident command post as the liaison between SFFD city units and SFFD-AB units. Eventually, representatives from SFPD, airport operations, San Mateo County Fire, and AMR (an ambulance company) arrived at the command post.

Neither the SFFD city assistant division chief who served as incident commander nor the SFFD city battalion chief who served as fire attack supervisor had any previous experience working at an airport. When asked in interviews, both replied that they had never been involved in a disaster exercise at the airport. When asked why he had chosen to place the SFFD city battalion chief as fire attack supervisor, the incident commander stated that it was because he was the most knowledgeable about this type of fire. He knew that the fire attack supervisor was a pilot[67] and an instructor for tank fires in the Texas oil fields and that he knew about foam and ARFF operations.

Both audio and video of the fire attack supervisor's actions were recorded on a digital video camera installed on his helmet. Review of the video footage indicated that about 1200, the driver of Rescue 37 was applying agent through the airplane's windows near door 2L. The fire attack supervisor opened the vehicle's door and told the driver to discharge agent into the 2L

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[67] The fire attack supervisor stated that he was a commercial pilot with about 3,500 hours of flight time, the majority of which was in helicopters.

door rather than the windows. The driver briefly explained that there was a bulkhead inside the door that would limit the effectiveness of the agent but complied with his instructions for a short time before needing to depart and refill. The fire attack supervisor then directed city unit Engine 15 to position in that location and put agent into the 2L door.

Several minutes later, the fire attack supervisor was approached by members of a rescue squad who suggested a limited search in the back of the airplane. He advised them that he had been notified that everyone had already evacuated and not to proceed with a search saying, “anybody’s in there right now is dead.” The rescue squad persisted and the fire attack supervisor eventually relented, stating “okay. Don’t go too deep.”

About 1215, the fire attack supervisor was notified that four “cabin crew” were missing. He then instructed a rescue squad to place a ladder at the cockpit window and “try and break the window open.” When the rescue squad stated they preferred to use the open door 1L, he replied that the fire was “right there” and that they would have to deal with a secure cockpit door. Again the rescue squad persisted, and the fire attack supervisor eventually allowed them to use door 1L as their entry point.

1.15.4.2 Firefighting Tactics

Upon arrival, the driver of Rescue 88 observed the evacuation taking place on the left side of the airplane and took the 1 o’clock position. He immediately began to engage the visible fire in the right engine, which appeared to be spreading under the fuselage. Initially, he used the roof turret and then the bumper turret to knock down the fire, and both the driver and rider stated that they used additional foam to try to cool the fuselage for the passengers who were evacuating. The driver stated that he hit the fire intermittently to make the agent last and also to assess the effectiveness of each blast. He reported that the fire did not completely extinguish but changed in character: the smoke went white, and the flames abated. He also tried to create a blanket of foam under the right wing due to the risk of leaking fuel.

Rescue 9 arrived immediately behind Rescue 88 and also took up a position near 1 o’clock. The driver stated that he shot foam from the bumper turret onto the top of the fuselage, aiming it just aft of the cockpit. Video footage indicated that Rescue 9 shot three blasts of agent (16, 2, and 11 seconds in length) in a 34-second period. The driver then decided to reposition around the left side of the airplane to take the 5 o’clock position.[68] Video footage showed that Rescue 9 began to reposition at 1132:44, about 1 minute after arriving on scene. While Rescue 9 was repositioning, numerous passengers were still in the area of the slide/rafts, including one occupant who was coming down the L1 slide/raft. When asked why they repositioned, Rescue 9’s rider stated that Rescue 88 had knocked down the fire; people were evacuating, and she was worried about hitting them with high pressure water. She stated that they thought they would be more effective at the rear of the airplane, so they repositioned. They went around the nose and down the left side of the airplane to the rear, assessing the situation.

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[68] The driver of Rescue 9 stated that after repositioning, he applied foam to the fuselage to keep it cool; however, video footage did not show evidence of this activity.

Rescue 10 arrived on scene about 1 minute after Rescue 9. It arrived directly behind Rescue 11 (a similarly sized vehicle but without a HRET). Rescue 11 turned left on taxiway N, took the 3 o'clock position, and began applying agent to the engine and fuselage. When he arrived on scene, the Rescue 10 driver noted that other ARFF vehicles had already arrived, and he saw passengers outside the airplane. Because of this, he chose to take the 10 o'clock position on the left side of the airplane. He said he selected his initial attack position based on his personal assessment and not as a result of command direction. Video footage showed that Rescue 10 continued straight on taxiway F and took a position facing the airplane beyond the left wing at 1133:42. By this time, the majority of passengers had evacuated, and a group of flight attendants in search of something sharp to puncture the 2R slide/raft approached the vehicle. While this was occurring, Engine 56 arrived on scene and eventually positioned next to Rescue 11 near the 3 o'clock position. Rescue 10 moved closer to the airplane and eventually took a position closer to the area of the missing left engine about 1137. Over the next 3 minutes, numerous short bursts of foam were applied to the left wing in the area of the missing left engine where fuel was leaking.

Rescue 10 then abandoned that position and performed a wide 360-degree circle, coming to a stop further from the fuselage, again near the left wing tip. About 1141, Rescue 10 personnel again discharged agent from the bumper turret onto the left engine area and fuselage. By this time, three firefighters had entered the airplane and begun the interior fire attack and rescue. Video footage showed that there was no longer activity with firefighters or crew around the slide/rafts, and gray smoke was visible coming from door 1L.

The driver of Rescue 10 indicated in his interview that he was waiting for an "all clear" from the firefighters inside the airplane before using the HRET to pierce the airplane. When an SFFD-AB lieutenant radioed that everyone was out of the airplane, both drivers commenced with piercing operations: Rescue 10 on the left side of the airplane above door 2L and Rescue 9 on the right side of the airplane near door 2R. Video footage of Rescue 10's piercing operation showed that the HRET was first raised at 1150:34. The airplane was pierced at 1152:51, and agent was discharged for about 41 seconds. The driver stated that during removal of the piercing tip, the angle of the tip changed, which he believed caused the tip to break and separate.[69]

Video footage showed Rescue 9's HRET was raised about 1148. Rescue 9 then quickly lowered the HRET, repositioned at 3 o'clock, and raised the HRET again about 1149. Due to the smoke plume and lack of onboard video, it could not be determined exactly when Rescue 9 pierced the fuselage. The driver stated that he pierced the airplane twice: once over the cockpit and once over the wing. He stated that he had no problems piercing the fuselage or dispensing the agent. Investigators found three circular-shaped holes on the airplane's right side: a hole near the 2R lavatory (BS 835), above row 14 (BS 972, even with the top of door frame), and above row 17 (BS 1108, on a stringer above the door frame).

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[69] At the NTSB's December 2013 investigative hearing for this accident, a witness explained that the piercing tip was designed to shear in the event forces are placed upon it that could potentially damage the boom.

In an interview, when asked about the HRET and SFFD's policy on when to pierce an airplane, the assistant deputy chief in charge of the SFFD-AB stated that there was no specific policy on the best time to use the piercing nozzle on the HRET.[70] At the NTSB's December 2013 investigative hearing for this accident, the assistant deputy chief provided the following testimony:

> Our personnel are trained from the beginning of their career to never conduct exterior fire attacks simultaneously with an interior fire attack. In this case, through the early part of the incident we had both trapped passengers and personnel inside the aircraft extricating those trapped passengers…I would say that it was a decision, a tactical decision made based upon their training and their experience, and good risk management to wait until…they had extricated the passengers from the aircraft and the personnel had evacuated the aircraft to go ahead and start piercing and employ an exterior attack.

1.15.4.3 Communication Problems

In postaccident interviews and statements, first responders reported numerous problems with communications during the emergency response. One of the reported problems was the inability for responding mutual aid units from the City of San Francisco to speak directly with units from the airport. According to the assistant deputy chief in charge of the SFFD-AB, the communication frequencies used at the airport were different than those used at the city, and the procedure was for the arriving SFFD city vehicles to switch to a designated frequency for the airport.

According to the incident commander, the initial mutual aid response from the city was a first alarm that involved three engines, two fire trucks, a medical vehicle, two battalion chiefs, the rescue squad, and himself. He considered it a normal response to the airport except that slide/rafts had been deployed in this event. While en route to the airport, he communicated with the city communications center and reminded them to have all companies switch to frequency C9. He attempted to tune his SFFD radio to C9 but could not because the radio shop had just reprogrammed all the radios, and "there was no C9."

Initially, the incident commander did not call for additional units from the city or call a yellow or red alert because he did not know the extent of the situation at the airport. He was still en route to the airport when he got a report from the city communications center that there was no fire on the airplane and that there were injuries. He considered whether more medics should be dispatched to the site. At the time, he thought that the slide/rafts were deployed and that people were evacuating the airplane, so he asked the city communications center to "give me two ambulances." When he got closer to the airport, he saw a light smoke column about 1.5 miles

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[70] A policy for HRET/piercing nozzle use was being developed at the time of the interview in November 2013. The assistant deputy chief was part of an affiliation of all the Index E ARFF chiefs, and he canvassed all of them about this topic. He was also using the FAA's advisory circulars and other guidance in developing the policy. Because he had only been on the job for 5 days at the time of the accident, he did not know what the training on the HRET had been before the accident.

away but was not sure of its origin because several industrial buildings were in that location. He asked the city communications center if there was fire with this incident and was told there was no information about fire at the time. The city communications center then asked a unit on the scene if smoke was visible, and the unit replied, “yes, there is a column of smoke.”

The fire attack supervisor stated that upon arriving at the scene with the incident commander, they received a briefing from the SFFD-AB shift captain (who was the initial incident commander) followed by a short discussion about what communication channel they should be on. Because frequency C9 was not available, he and the incident commander both switched to frequency C14. He stayed on C14 for the duration of the event and provided face-to-face instructions to ARFF drivers throughout the event because he could not talk to them on C14. He stated that he experienced no difficulty in communicating, and although he would have preferred to be able to talk to them on the radio, they “adapted and moved on.”

In addition to the radio frequency problem, multiple firefighters reported significant problems reaching command staff and receiving additional assistance when requested. One SFFD-AB firefighter stated that he radioed for assistance with victims several times but never received a response and believed that once mutual aid responded to the site, communications completely stopped. Another SFFD-AB firefighter stated that at one point, neither she nor two other SFFD-AB firefighters could reach the SFFD-AB shift captain (who served as initial incident commander).

In addition to the firefighters, ASOs and SFPD officers also reported communication difficulties. One ASO stated that he was unable to communicate with the firefighters because he was communicating on operations channel 1, and they were on a different channel. This ASO also reported that when he tried to use his truck’s public address system to rally people toward him, he discovered the system was not functional. Another ASO reported that the operations radios could be tuned to the fire frequency but that the emergency response buses only had the operations channel radio. An SFPD lieutenant reported that SFPD officers stationed at the airport could not speak directly to firefighters via radio.

There were also reports of breakdowns in communications involving the medical response. Several ASOs were among the first to recognize and respond to the presence of injured occupants in the debris field on the runway. One of these ASOs attempted to get a paramedic company to respond to the area but was told they would have to radio the incident commander to be released to help. Once the incident commander was informed about the seriously injured people on the runway and that no emergency medical services (EMS) personnel were on the east end of the airfield, he released the paramedic company to help. The ASO believed that the incident commander was not aware that help was needed at the rear of the airplane.

An SFFD-AB firefighter/paramedic, who initially served as lead triage officer, stated that at no time during the event was he informed about victims on the runway or further back in the debris field toward the water. He believed that all of the ambulances stayed at the triage/treatment area and loaded patients there. He stated that communicating with the ambulances and the other agencies that arrived was very difficult.

The SFFD-AB firefighter who served as the staging officer described communication difficulties at the staging area. He stated that some vehicles were escorted to staging and others arrived with no escort. He stated that communication was a big challenge. He stated that having everyone on the same channel would have been good and being able to distribute more radios and/or use fewer channels would have been beneficial.

1.15.4.4 Aircraft Rescue and Firefighting Training

Title 14 CFR 139.319(i)(2) states that each certificate holder must ensure that "all rescue and firefighting personnel are properly trained to perform their duties in a manner authorized by the Administrator. Such personnel must be trained before initial performance of rescue and firefighting duties and receive recurrent instruction every 12 consecutive calendar months." The curriculum for initial and recurrent training must include at least 11 specific areas, including live fire training.

The SFFD-AB shift captain, who served as the initial incident commander, had not yet received his FAA-required live fire training. The captain started work at the airport in April 2013, and according to the assistant deputy chief in charge of the SFFD-AB, he was scheduled to attend a live fire burn in July 2013, but it had not yet occurred at the time of the accident.

1.15.4.5 Triage

SFFD personnel stated, and industry guidance indicated, that in a mass casualty incident where the number of patients eclipses the number of first responders, the primary goal of triage is to attempt to do the most good for the most people as quickly as possible. As a result, rapid assessments (30 to 60 seconds) of patients' conditions are made. An inherent aspect of this goal is to prevent the inappropriate application of limited resources to victims who are dead or dying because other victims with a greater chance of survival would be neglected.

In addition to the firefighting personnel, who were all trained as either basic emergency medical technicians or paramedics, SFFD had two paramedics, one assigned to each of its medical vehicles (Rescue 91 and 93). Between 1132 and 1133, those vehicles arrived on scene and positioned on the north edge of taxiway F, just past the intersection with taxiway N. One of the paramedics assumed the role of medical group supervisor, and the other assumed the role of lead triage officer. The medical group supervisor responded to the incident command post and was in charge of coordinating the entire medical response while the lead triage officer and the driver of Rescue 91 began the Simple Triage And Rapid Treatment (START) process of placing red, yellow, green, or black triage tags on passengers' wrists.[71]

While the personnel on the fire apparatuses initially focused their efforts on controlling the exterior fire, the paramedics from Rescue 91 and 93 began triaging the walking wounded who had gathered in an area near the intersection of taxiway N and F. Passengers were instructed to move toward the medical vehicles to assist with the triage process. At 1136:30, an ambulance already at the airport on an unrelated call positioned near Rescue 91 and 93 and became the hub of triage activity for passengers who evacuated from the left side of the airplane. A second group of passengers who evacuated from the right side and tail of the airplane gathered behind the airplane. About 1153, the first mutual aid ambulance was seen in the accident area.

As stated earlier, it is likely that the last passenger was extricated from the back of the airplane about 1147. Although some of the extricated passengers were immediately placed on backboards, numerous SFPD officers and SFFD firefighters complained of a lack of backboards for seriously injured passengers, the quality of the available backboards, and the absence of a mass casualty supply bus. The initial shortage of backboards was remedied by the arrival of mutual aid medical vehicles with additional backboards.

Airport operations had two medical buses equipped with mass casualty supplies (including backboards) that were stored at the Airfield Safety Building. The SFO emergency procedures manual listed delivering these buses to the staging area or crash site as among the duties of ASOs in the event of an Alert 3 at the airport. The emergency plan stated that "aviation safety officers deliver…the two Emergency Medical Response buses…early in the response sequence and provide medical supplies and the Emergency Casualty Evacuation carts used by the litter bearers." In postaccident interviews, several ASOs remarked about a lack of mechanical reliability with the 29-year-old buses, and the captain who supervised the SFFD-AB medical personnel stated that during the airport's monthly Redcap drills, ASOs did not respond with the medical buses.

In postaccident interviews, numerous personnel reported requesting the medical buses at different points after the accident, beginning as early as 5 minutes after the event. According to the airport's chief operating officer, neither medical bus was driven to the accident site triage area by an ASO because all of the ASOs were busy with other duties, such as escorting mutual aid vehicles to the accident site. The chief operating officer further stated that in the event of an Alert 3 (an accident on or near the airport), the specifics of the event determined what specific equipment needed to be deployed and the medical buses would be delivered when requested by the incident commander. The chief operating officer reported that the airport operations supervisor received a request about 1238, from the airport duty manager, for the two medical

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[71] Developed in 1983, START is a triage method used by first responders to quickly classify victims during a mass casualty incident based on the severity of their injury. Three main criteria—respiration, perfusion, and mental status—are used to classify the injured. Those requiring immediate treatment are categorized as red, those for whom treatment and transport can be delayed are categorized as yellow, and the "walking wounded" with minor injuries are considered green. A black triage tag would be given to those who are either deceased or expected to die imminently.

buses to be brought to the ramp level of Gate 91. However, one of the two buses would not start, so only one was driven by an ASO to the gate. The supplies from this bus were used in providing secondary triage to passengers in the terminal.

According to SFFD records, the last patient was transported from the scene by ambulance about 1301. All ambulatory passengers who were relocated to the terminal underwent secondary triage. Numerous additional passengers reported injuries, and by about 1758, the last of those passengers were transported from the terminals to area hospitals.

Passenger 41E

In postaccident interviews, at least four emergency responders reported seeing passenger 41E before the first rollover event. The ASO who was the first responder to arrive on the scene reported seeing something that looked like a "big doll" on the ground. He stated that when he saw her, she had no obvious injuries, and there was no blood around her body. He did not find out she was a passenger until more than a day later. The firefighter who initially directed Rescue 10 around the body stated in his interview that he noticed a young female on the ground in the fetal position. She looked to be dead "by appearance," but he did not check her vital signs. While he was moving his driver into position, he saw a lieutenant and told her about the body. She replied, "yes, yes, okay, okay. We've gotta get a line inside." In her interview, the lieutenant stated that she saw the body and "immediately categorized it as a casualty."

A third firefighter saw passenger 41E while she was repositioning her vehicle in front of the left wing (before the arrival of Rescue 10). She avoided what looked like a small woman curled up (with her knees bent) on the ground. By her position, she thought the person was dead and reminded herself to take care because there might be other deceased persons around the airplane.

1.15.5 Injury Severity

The 40 passengers with serious injuries were primarily located in the aft cabin. They included 25 of the 114 passengers with assigned seats in C-zone (22%), 14 of the 158 passengers with assigned seats in B-zone (9%), and 1 of the 21 passengers with assigned seats in A-zone (5%). Figure 12 shows the injury classifications of all occupants by assigned seat and crewmember position.

Twenty-four passengers and five flight attendants sustained spinal injuries. The passengers with spinal injuries were also primarily located in the aft cabin, with 20 of the 24 passengers (83%) with spinal injuries located in C-zone. One seriously injured surviving passenger was diagnosed with multiple left-side skull and orbital wall fractures. Additionally, 11 passengers sustained one or more rib fractures. It was noted that only 1 of those 11 passengers (passenger 39G) had a right-side rib fracture.

1.15.6 Doors and Slide/Rafts

1.15.6.1 Slide/Raft Information

The slide/rafts were manufactured by Air Cruisers Company. The major components of each slide/raft included a slide/raft pack and a packboard with a lacing cover, which contained the slide/raft pack. The slide/raft pack consisted of the girt,[72] girt bar, the inflatable tube structure, and the inflation system, which included an inflation cylinder, a regulator valve, hoses, and aspirators.[73] The slide/raft was mounted on the door using hardware installed on the back of the packboard that included a release mechanism (see figure 13).

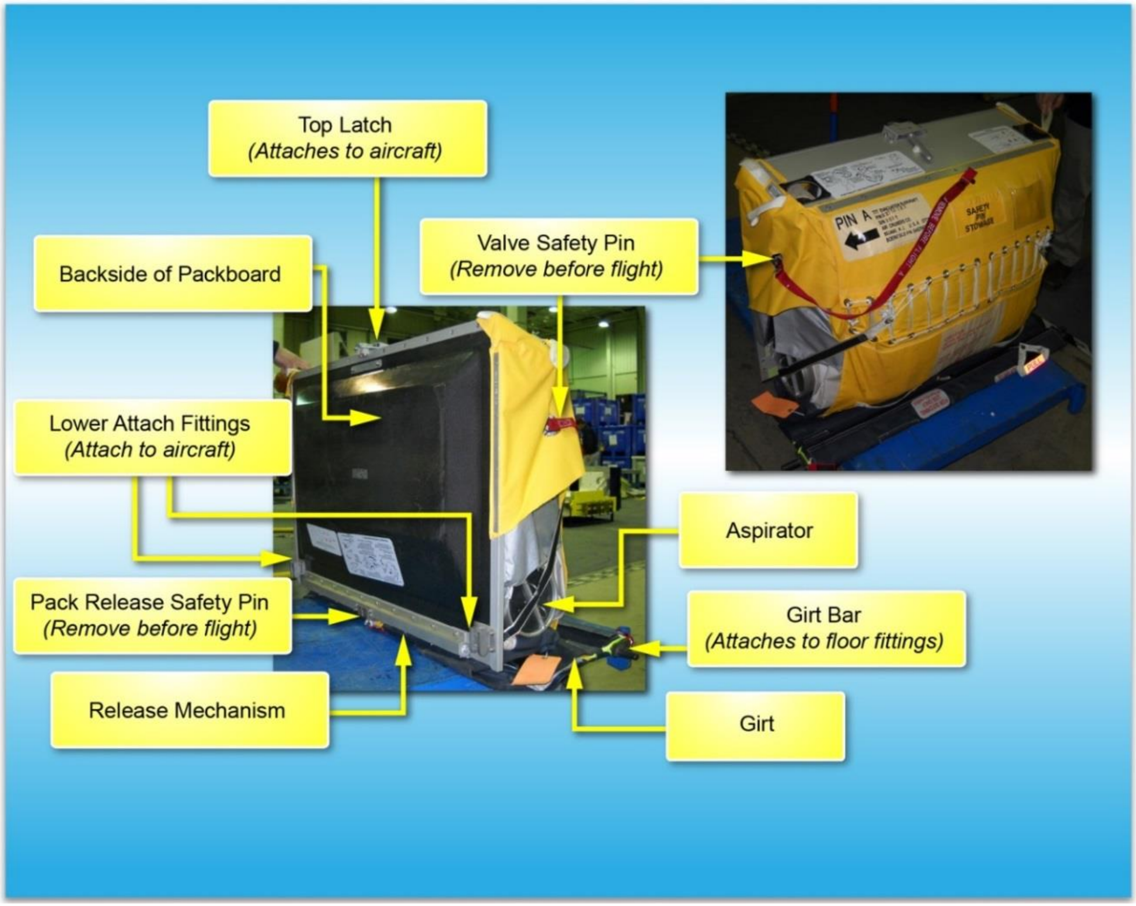

Figure 13. Slide/raft components.

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[72] The girt is a reinforced, high strength fabric panel that attaches the slide/raft to the airplane. One end of the girt is cemented to the inflatable tube structure, and the other end is attached to the girt bar (a rigid bar) that is attached to floor fittings on the airplane.

[73] An aspirator is a tubular structure containing internal nozzles that are connected to the inflation cylinder. When high pressure gas from the cylinder flows through the nozzles, flappers at the inlet end of the aspirator open due to the venturi effect, thereby drawing in surrounding ambient air to supplement the pressurized gas entering the inflatable tube structure.

Each slide/raft pack had two safety pins, one for the release mechanism and one for the inflation cylinder, that were to be used when a slide/raft was removed from a door for maintenance. When the slide/raft was reinstalled on the door, both of these pins were to be removed and stowed in a plastic pouch on the lacing cover. A red “remove before flight” warning flag about 4 ft long and 1 inch wide was provided for attachment to the inflation cylinder safety pin.

According to Air Cruisers, the slide/rafts were designed to function as follows:

(1) The door is closed and then armed, which attaches the girt bar to the floor fittings.
(2) Opening the armed door activates the release mechanism, separating the slide/raft pack from the packboard.
(3) The slide/raft pack begins to drop downward, and when it has dropped about 65 inches, the increase in tension on the inflation cable opens the valve on the inflation cylinder to initiate inflation.
(4) Gas released from the inflation cylinder rushes to the aspirators opening their flappers, which entrain ambient air. The unfolding of the slide/raft occurs in stages controlled by frangible attachments. The aspirator flappers close when the slide/raft pressure builds.
(5) The slide/raft extends and inflates fully within 6 seconds.

1.15.6.2 Door and Slide/Raft Performance

Postaccident examination of the cabin found doors 1L, 1R, 2L, 2R, 3R, and 4R had no visible structural damage. Door 3L exhibited slight bulging in the forward and aft doorway edge frame, and door 4L had separated from the airplane. The door sill heights to the ground were measured as follows:

- Door 1L: 110 inches
- Door 1R: 117 inches
- Door 2L: 98 inches
- Door 2R: 99 inches
- Door 3L: 53 inches
- Door 3R: 17 inches (to fuselage wreckage under door sill)
- Door 4L: 14 inches
- Door 4R: 27 inches

Doors 1L and 2L were found in the open position. Both video evidence and flight attendant statements indicated that the 1L and 2L slide/rafts fully deployed and were used during evacuation. Video evidence indicated that the 1L slide/raft was later punctured when firefighters placed a ladder on it to access the airplane’s interior.

Door 1R was found in the open position. The 1R slide/raft was found deployed and deflated inside the airplane on the exit passageway floor, extending forward into the forward galley and aft into the right main aisle about 1 to 2 ft. Door 2R was found in the closed position and was fire damaged. The 2R slide/raft was found deployed and deflated inside the airplane on the exit passageway floor, extending across the right main aisle, through the midcabin galley, and ending about 1 ft short of the left main aisle.

Door 3L was found in the open position. Video footage showed the door closed throughout the evacuation and opened from the inside by an emergency responder at 1207:43. The 3L slide/raft fell onto the ground and did not inflate. When NTSB investigators arrived, the uninflated 3L slide/raft was hanging from the girt bar on the door sill and resting on the ground. The slide/raft's inflation cylinder was fully charged, and the cylinder safety pin with the warning flag attached was stowed in the pouch on the lacing cover.

Door 3R was found in the open position. Passenger 30K reported opening door 3R during the evacuation and stated that it was "really easy." The 3R slide/raft was partially deployed when investigators arrived but had not inflated. The slide/raft was hanging from the girt bar and resting on top of the fuselage wreckage that was under the door sill. The slide/raft's inflation cylinder was fully charged, and the cylinder safety pin with the warning flag attached was stowed in the pouch on the lacing cover.

Door 4L was found on the ground outside the airplane about 13 ft laterally from the door sill. The door 4L slide/raft was found inside the airplane fuselage extending aft. The floor structure under the door sill and aft was missing, and the slide/raft was resting on the ground. The slide/raft was attached to the girt bar, which remained attached to the floor fittings. The inflation cylinder was empty. The slide/raft's aft aspirator had ingested either a blanket or a curtain cabin divider, and the forward aspirator had ingested a stack of folded paper towels. The ingested material in the aspirators was consistent with the slide/raft attempting to inflate during the impact sequence.

Door 4R was found in the open position. The girt bar was attached to the floor fittings, but the slide/raft's girt was torn at the girt bar. The slide/raft was found slightly to the right of airplane centerline at the break in the aft pressure bulkhead and extended aft away from the airplane. The inflation cylinder was fully charged with a safety pin installed in the valve; however, no warning flag was present on the safety pin. The cylinder safety pin warning flag (with no pin attached) was found in the pouch on the lacing cover.

The 1L and 2L slide/raft release mechanisms were both examined and were found to have no damage. A detailed examination of the slide/raft release mechanisms on the other six packboards was conducted at the manufacturer's facility in July 2013 (see section 1.16.5.1).

1.15.6.3 Slide/Raft Maintenance Information

Asiana Airlines provided maintenance records that indicated the 4R slide/raft was last overhauled by Asiana on December 17, 2010, and installed on the airplane on January 17, 2011. The installation procedure included a step to remove and stow the inflation cylinder safety pin in the pouch on the lacing cover. This procedure was stamped off as complete by the mechanic and was not stamped off by an inspector. According to Asiana maintenance personnel, an inspector signoff was not required. The maintenance records indicated that during a scheduled maintenance check, the cylinder safety pin was installed on December 2, 2012, and removed on December 8, 2012. This was the last recorded maintenance on door 4R before the accident.

Following the postaccident discovery of the safety pin installed in the inflation cylinder of the 4R slide/raft, the FAA performed seven ramp inspections of airplanes operated by Part 129 air carriers with a special emphasis on evacuation slide/rafts and found no discrepancies. Additionally, Asiana performed a voluntary inspection of all of its 777 slide/rafts (including spare slide/rafts) to identify the presence of a safety pin in any other slide/raft's inflation cylinder. None were found. Also, in response to the finding of the safety pin installed in the inflation cylinder of the 4R slide/raft, Asiana made a change to its slide/raft maintenance procedure. Previously, a single work order was issued per airplane for the installation and removal of the safety pins during maintenance. Under the new procedure now in use, two separate work orders are issued for each slide/raft location (16 work orders per airplane), one for the installation of the safety pin and one for the removal of the safety pin.

On March 29, 2013, the FAA published Airworthiness Directive (AD) 2013-05-10, effective May 3, 2013, and applicable to Boeing 777-200, -200LR, -300, -300ER, and 777F airplanes. The AD was issued to detect and correct possible corrosion to the slide/raft release mechanism, which could impair deployment of the slide/raft. Maintenance records provided by Asiana Airlines reflected that the AD was applicable to all eight door positions on the accident airplane and had been accomplished on six of the eight door positions. The compliance "accomplish by" date had not yet been reached for the slide/rafts installed on the 1L and 4R doors.

1.15.7 Cabin Damage

The A-zone business class cabin was heavily damaged by the postcrash fire. The fire damage in A-zone was slightly less on the right side of the airplane. All of the seats were damaged and consumed by fire. With the exception of four seats (1A, 1E, 1F, and 5A) for which fire damage precluded determination, all of the seats appeared to be attached to the floor.

The B-zone economy class cabin was heavily damaged by the postcrash fire. The fire appeared to be most severe on the left side of B-zone with the forward right side of the area receiving the least severe fire damage. There was localized floor buckling at seat row 15. The following observations were made regarding the B-zone seats:

- All of the seats were damaged or consumed by fire.
- Most of the seats appeared to be attached to the seat tracks except the center and right-hand side seats at row 15.
- Only two seat legs were found cracked or broken. Some of the seat legs were bent to the left. The general condition of the B-zone seat legs appeared to exhibit similar or slightly less bending than what was observed in C-zone.

The C-zone economy class cabin was heavily damaged in the crash sequence but did not sustain postcrash fire damage. The damage to C-zone appeared to be most severe aft of seat row 36, where the subfloor structure was destroyed to the extent that most floor panels appeared to be lying directly on the ground. The following observations were made regarding the C-zone seats:

- All of the seats remained inside the airplane, were still intact as a unit, and undamaged by fire.
- The seat tracks were intact and attached to the floor panels.
- Many of the seat units were rotated aft, including seats 42AB.
- All of the seatbelts were intact, undamaged, and unbuckled except for seat 42B, where the seatbelt was still buckled.
- The seat tubes were all intact at their junctions to the seat legs. The forward seat cross tubes at seats 41ABC and 42AB were fractured at the right end of the tube.
- The observed seat legs retained at least one seat track attachment point except seats 30HJK, 39ABC, and 41AB. The general condition of the C-zone seat legs exhibited similar or worse bending compared to the seat legs in B-zone. Several aft seat legs were broken. Many of the seat legs were bent to the left.

The aft galley was destroyed in the airplane's initial impact and slide down the runway. A small section of aft galley floor found just beyond the seawall was the earliest identifiable item from the airplane cabin in the debris field. The L4 and R4 jumpseats, each attached to a section of galley structure, were found to the right of the runway centerline about 500 and 550 ft, respectively, from the runway threshold. Witness (drag) marks leading to the L4 jumpseat and associated galley structure started just past the runway threshold, and witness marks leading to the R4 jumpseat and associated galley structure began about midway through the threshold markings. The four-point restraints for the 4L and 4R jumpseats were unlatched, undamaged, and functioned normally.

The M4A jumpseat was found inside the airplane still affixed to the aft lavatory wall in the aft galley; the four-point restraint was unlatched, and the outboard lap belt attachment shackle was fractured. The M4B jumpseat was found, attached to a section of the aft lavatory wall, about 50 ft aft of the airplane; the four-point restraint was latched, and both inertia reels and the buckle functioned normally.

1.16 Tests and Research

1.16.1 Airplane Performance Study and Simulator Evaluations

The NTSB conducted an airplane performance study to determine the time alignment among CVR events, FDR data, and ATC data; calculate the airplane's weight and balance; examine the actions of the low airspeed alerting system; compare the airplane's airspeed to maximum landing gear and flaps extended speeds; compare the airplane's flightpath to stabilized approach criteria; and correlate calculated pilot eye height with calculated PAPI beam guidance. In addition, the NTSB conducted engineering workstation simulation and pilot-in-the-loop simulator work using a Boeing 777-200ER engineering flight simulator (EFS) that Boeing provided. Pilots from Boeing, Asiana Airlines, the FAA, and the NTSB participated in the EFS pilot-in-the-loop simulator work.

Based on Asiana's stabilized approach criteria[74] and available factual evidence, at 500 ft above airport elevation, Asiana flight 214 had a sink rate greater than 1,000 fpm and did not meet the appropriate power setting guidance for flaps 30° with the gear down.[75] Below 500 ft above airport elevation, the approach was evaluated to be unstabilized due to a sink rate greater than 1,000 fpm, airspeed less than target speed by more than 5 knots, progressively large changes in pitch required to maintain the flightpath, and a significantly low glidepath as evidenced by the calculated PAPI guidance cues of four red lights.

1.16.1.1 Workstation Simulation

The nominal 777-200ER simulation model provided a good match for the airplane's previous normal landing and an adequate match for the segment of the accident final approach flightpath in free air (above about 200 ft agl). However, the simulation model did not match the segment of the accident flightpath in ground effect (below about 200 ft agl); rather, it yielded conservative results, producing progressively less lift and higher sink rates than the accident airplane with increasing angle of attack and decreasing airspeed. As a result, the simulated airplane flightpath descended below the accident airplane path, and the simulated airplane contacted the ground short of the accident airplane impact location. The mismatch was likely due to the fact that the accident airplane exceeded 10° angle of attack in ground effect and was operating outside the flight-test-validated envelope for the 777-200ER simulation model.[76]

Four alternate go-around scenarios were evaluated using the 777-200ER simulation model in a workstation environment. Each go-around scenario represented a specific flight crew technique (control input sequence) accomplished in an attempt to correct the low airplane path and low airspeed condition by initiating a go-around.[77] Because the simulation model was conservative in ground effect, each of the four hypothetical go-around scenarios was evaluated with the knowledge that the calculated go-around performance capability would be conservative in the ground effect region.

The simulation results indicated that the airplane had adequate performance capability to accomplish a go-around initiated 11 to 12 seconds before ground impact (depending on technique), assuming a minimum aft fuselage clearance during the maneuver of 17 ft above field

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[74] For information about Asiana's stabilized approach criteria, see section 1.17.1.4.

[75] For information about power setting guidance, see section 1.17.1.6.

[76] The 777-200ER aerodynamic ground effect simulation model was validated with flight test data for angle of attack values between -2° and +10°. Boeing reported that it does not conduct flight test maneuvers in ground effect beyond angle of attack values of +10° because of safety concerns.

[77] The rationale for choosing go-around scenarios to simulate began with the intent to model the go-around initiation technique attempted by the accident flight crew. The normal all-engine go-around initiation technique documented in existing Boeing guidance was added next. The subsequent comparison of available FDR data to the normal go-around guidance identified differences in engine thrust lever advancement rate and target pitch attitude rate. The effect of these variables was evaluated by constructing two additional hybrid go-around scenarios.

elevation.[78] The accident flight crew initiated a go-around by advancing the thrust levers about 7 seconds before ground impact.

1.16.1.2 Pilot-in-the-Loop Simulation

Test pilots from Boeing and the FAA, who were type rated and current in the 777, flew multiple runs simulating visual approaches to runway 28L at SFO with the A/P off, beginning 5 nm from the runway threshold with two sets of initial conditions. One set of conditions, referred to as the accident profile, modeled the accident flight with the starting altitude at 2,100 ft msl, about 400 ft above a 3° glidepath, and the other set, referred to as the standard profile, modeled a flight that was on a 3° glidepath by starting at 1,650 ft msl. Data from each run were evaluated to determine whether the approach was stable at and below 500 ft agl based on Asiana's stabilized approach criteria. The pilots had no difficulty in achieving stable approaches on any of the nine runs started at the standard profile conditions (on glidepath), and they were always able to comply with Asiana's guidance to avoid descent rates in excess of 1,000 fpm below 1,000 ft agl and in excess of 1,500 fpm between 2,000 and 1,000 ft agl.

When starting at the accident profile conditions (above glidepath), the pilots experienced difficulty in achieving stabilized approaches, and on 4 of the 10 accident profile runs, they were unable to achieve a stabilized approach. On all 6 runs that resulted in a stabilized approach, the pilots used descent rates in excess of 1,000 fpm below 1,000 ft agl, and on 5 of the 6 runs, the pilots used descent rates in excess of 1,500 fpm between 2,000 and 1,000 ft.

1.16.2 Mode Control Panel Examination

The MCP was removed from the instrument panel before the airplane was recovered from the accident site. Other than heavy soot contamination, the MCP appeared to be in good physical condition. Review of the information stored in the MCP's nonvolatile memory showed that no faults were recorded during the accident flight.[79] A functional test of the MCP was performed in accordance with the manufacturer's specifications. The tests included activation of all toggle switches, push buttons, and knobs on the MCP. The unit passed all performed tests except four. These tests failed because the bottom horizontal segment of the 100s digit in the vertical speed/flightpath angle liquid crystal display screen was missing.

Industrial computed tomography was used to internally check the FLCH push-button switch and the left and right F/D switches; no anomalies were identified in any of these switches. Vibration testing of the MCP was conducted, and the push-button switches were monitored during the testing for illumination indicating an unexpected mode engagement. No unexpected mode engagements occurred during the vibration testing.

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[78] The 17-ft clearance value was based on an estimated 7-ft allowance for lead-in light mounting height above the pier catwalk and a 10-ft allowance to account for the simulation-calculated altitude tolerance.

[79] The contacts for all toggle and push-button switches on the front panel of the MCP (including the left and right F/D switches and the FLCH push-button switch) are monitored by the MCP. If a fault is identified for any contact, it will be recorded in the unit's nonvolatile memory.

1.16.3 Autothrottle Component Examination

The thrust lever assembly, left A/T assembly, and right A/T assembly were removed from the airplane after it was recovered from the accident site. Other than soot and dust contamination, the components appeared to be in good physical condition. All components were lightly cleaned and installed into a control stand to perform a functional test.

The sections of the control stand functional test relevant to the A/T function, thrust lever function, takeoff/go-around (TO/GA) switch operation, and A/T disconnect switch operation were performed in accordance with the manufacturer's specifications. The control stand passed all sections of the test that were performed except for the right thrust lever angle resolver section. This test section was failed because the A and B channel readings for the right resolver transmitter assembly differed by about 2.6°.

According to Boeing, the airplane was designed so that if both channels from the same resolver transmitter assembly are valid, the A/T system receives and uses the higher of the two values. Review of FDR data indicated that during the flight, the recorded values for the left and right engine thrust lever angles were both within the expected tolerance of 34.0° +/- 0.25° when the levers were at the idle stop. Further, if the difference between the two channels is greater than 2° for more than 2 seconds, a noncorrelated maintenance message[80] will be generated and reported via the aircraft communications addressing and reporting system (ACARS).[81] Asiana reported that no maintenance messages related to a resolver transmitter channel disagree were reported through ACARS from the airplane in their available history dating back to June 20, 2013.

1.16.4 Enhanced Ground Proximity Warning System

The airplane was equipped with a Honeywell Mark V enhanced ground proximity warning system (EGPWS) designed to provide aural and visual alerts and warnings to prevent controlled flight into terrain and for low altitude windshear conditions. Review of the information stored in the EGPWS's nonvolatile memory revealed that no faults, warnings, or events were recorded for the time between the takeoff record and the landing record for the accident flight.[82] A functional test was performed on the EGPWS per the manufacturer's specifications, and it passed all portions of the test. An event analysis provided by Honeywell indicated that the accident flight did not meet the criteria to trigger any EGPWS alerts.

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[80] A noncorrelated maintenance message is one that does not have an associated flight deck effect.

[81] ACARS is a data link system to a ground station that allows for text-based communications.

[82] There were faults and warnings recorded more than 10 seconds after the time of the landing record. According to Honeywell, landing records are created when an airplane descends through 50 ft RA. According to the CVR transcript, the 50-ft RA callout occurred at 1127:45.8, and the initial impact occurred less than 5 seconds later at 1127:50.3, indicating that the recorded faults and warnings were postimpact.

1.16.5 Slide/Raft Examination and Testing

1.16.5.1 Slide/Raft Release Mechanism Examination

The slide/raft release mechanisms for the 1R, 2R, 3L, 3R, 4L, and 4R slide/rafts were examined at the manufacturer's facility in July 2013. No evidence of corrosion was found on any of the slide/raft release mechanisms. The release shafts of all of the mechanisms sustained damage with the most severe damage being to the 2R, 3R, and 4R release shafts.

At the NTSB's investigative hearing in December 2013, a representative of Air Cruisers described the damage to the release mechanisms as "catastrophic" and stated it was unlike anything the company had seen before in certification tests or in-service airplanes. A Boeing engineer, who was also involved with the investigation of a British Airways 777 accident at Heathrow Airport in 2008, confirmed that no similar damage was seen to the slide/rafts in that accident[83] and also stated Boeing had no previous reports of similar damage from in-service airplanes.

1.16.5.2 Slide/Raft Certification Information

According to Air Cruisers, during the 777 slide/raft certification process, inertia load testing for slide/raft certification was conducted by attaching a slide/raft assembly to a test fixture that simulated installation on a door. The test fixture was mounted at the end of a long centrifuge arm and rotated to an rpm calculated to achieve the required acceleration loads[84] (*g*[85] loads) at the slide/raft's center of gravity (CG). Starting from a stationary position, the rpms were increased to the desired rpm and maintained for a minimum of 3 seconds and then decreased to a stationary position. The slide/raft was required to remain intact on the fixture, stay within its allowable pack envelope, and then deploy from an aircraft door or equivalent test module. The tests met FAA and Boeing requirements, and testing to higher loads was not performed.

1.16.5.3 Slide/Raft Tests

In an effort to replicate the type of damage observed to the slide/raft release mechanisms from the airplane, two series of destructive tests were performed on exemplar 777 packboard release mechanisms. The first series of tests subjected the release mechanisms to an increasing

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[83] According to the Boeing representative, all of the slide/rafts deployed and inflated normally in that event.

[84] The required slide/raft acceleration test loads are specified in 14 CFR 25.810(a)(1)(v) by reference to 14 CFR Part 25.561(b), which states that although an airplane may be damaged in emergency landing conditions on land or water, it must be designed as prescribed in this section to protect each occupant under those conditions. The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when (1) proper use is made of seats, belts, and all other safety design provisions; (2) the wheels are retracted (where applicable); and (3) the occupant experiences the following ultimate inertia forces acting separately relative to the surrounding structure: (i) upward, 3.0*g*; (ii) forward, 9.0*g*; (iii) sideward, 3.0*g* on the airframe and 4.0*g* on the seats and their attachments; (iv) downward, 6.0*g*; and (v) rearward, 1.5*g*.

[85] The letter "*g*" denotes the ratio of a particular acceleration to the acceleration due to gravity at sea level. In accordance with common practice, this report refers to accelerations or forces in terms of *g*. For example, it is customarily understood that "5*g*" represents an acceleration of five times the acceleration of gravity at sea level.

(static) tensile load until ultimate failure. Three tests were performed in the inboard direction, and three were performed in the downward direction. The ultimate loads at failure during these tests varied between 1465 and 1781 lbs, which were three to four times higher than certification loads. In all six tests, the release mechanism experienced a failure (tearing) of the release shaft in the area of tang engagement similar to the damage on the release mechanisms for the 2R, 3R, and 4R slide/rafts on the airplane.

The NTSB also contracted with a research company to perform sled acceleration tests of six exemplar 777 slide/raft packs. Complete slide/raft packs were affixed to a test rig in a vertical orientation to apply inboard lateral loads, a horizontal orientation to apply downward loads, or a 45° orientation to apply a combined downward and inboard load. The packs were then subjected to test runs with increasing *g* loads until ultimate failure. The two slide/rafts subjected to inboard loads released at loads of 14.2*g* and 14.4*g*; however, there was no damage to the release shafts of the release mechanisms. The two slide/rafts that were subjected to downward loads released at loads of 12.7*g* and 13.5*g*, and the damage to the release shafts was similar to those from the 2R, 3R, and 4R slide/rafts on the airplane. The two slide/rafts that were subjected to combined inboard and downward (45°) loads released at loads of 12.4*g* and 12.9*g*, and again, the damage to the release shafts was similar to those from the 2R, 3R, and 4R slide/rafts on the airplane.

1.17 Organizational and Management Information

Asiana Airlines is a major Korean domestic and international airline based in Seoul, Korea. The company was established in 1988 and, at the time of the accident, provided passenger service to 23 countries and cargo service to 14 countries. Asiana had a fleet of 81 airplanes,[86] including 12 Boeing 777 aircraft, and employed 1,349 pilots, including 136 Boeing 777 captains and 129 Boeing 777 FOs.

1.17.1 Pilot Standard Operating Procedures

Asiana provided procedural guidance to its flight crews in several documents. The Asiana Flight Operations Manual (FOM) established general procedures and provided instructions and guidance for use by flight operations personnel in the performance of their duties. Flight crew procedures specific to the 777 were found in the Asiana 777 Pilot Operations Manual (POM).

Additional guidance was found in the Asiana 777 FCOM, which was prepared by Boeing for Asiana and included operating limitations, procedures, performance, and systems information. With the FCOM, Boeing also provided a 777 QRH that listed normal and nonnormal procedures in a checklist format. Further information and recommendations on maneuvers and techniques were found in Boeing's 777 Flight Crew Training Manual (FCTM).

Flight crews were expected to follow POM guidance where it was more restrictive than other guidance, such as that in the FOM, FCOM, or FCTM.

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[86] At the time of the accident, Asiana's fleet was composed of 10 Airbus A320, 24 Airbus A321, 13 Airbus A330, 14 Boeing 747, 8 Boeing 767, and 12 Boeing 777 airplanes.

1.17.1.1 Use of Automation

The 777 POM, chapter 2, “Supplementary [Normal Procedures] NP,” paragraph 2.1.6, “AFCS Procedures,” provided general guidance to pilots on the proper use of the AFDS and A/T. Subparagraph 2.1.6.1, “General,” stated that the flight crew must always monitor airplane course, vertical path, and speed; verify manually selected or automatic AFDS changes; and when selecting a value on the MCP, verify that the respective value changes on the flight instruments. Further, the subparagraph stated that the flight crew should use the FMA to verify mode changes for the A/P, F/D, and A/T and that to “call out loudly and clearly to the changes on the FMA and thrust mode display when they occur are a good CRM practice.”

Subparagraph 2.1.6.2, “AFCS guideline,” stated that “operations by A/P and A/T have preference to improve safety, to reduce workload and to enhance operational capability.” It stated that when “operating within terminal areas where air traffic congestion could be expected, the PF and the PM [should] make full use of A/P and A/T.” It further stated that the flight crew should use the A/P and A/T together and recommended use of A/T during all phases of flight, including manual flight.

Subparagraph 2.1.6.4, “A/P and A/T Disengage (Disconnect) Procedure,” stated that the PF should notify the PM when disengaging or disconnecting the A/P and/or A/T. The subparagraph included a note stating that the PF should call out “manual flight” upon disconnecting the A/P and “A/T disconnect” upon disconnecting A/T; the PM should verify that the change is indicated by a change in AFDS status or mode annunciation on the FMA and then call out the change.

Further guidance regarding AFDS and A/T mode selections and related callouts was found in paragraph 2.1.4, “Crew duties,” which stated that manipulating the controls and switches on the MCP is the PF’s responsibility, but when flying manually, the PF should direct the PM to make changes on the MCP. Also, paragraph 2.1.7, “Standard Callouts & Response Procedures,” stated that the pilot who is in charge of “flight mode change” must call out accomplishment of a mode change, and the other pilot must respond with a confirmation. This paragraph also stated that the PM should call out every FMA change.

Regarding the use of FLCH SPD mode, the 777 FCTM, page 5.26, stated, “Non-ILS approaches are normally flown using VNAV, V/S, or [flightpath angle] FPA pitch modes. The use of FLCH is not recommended after the FAF.”

The Asiana 777 chief pilot stated in an interview that the airline recommended using as much automation as possible. He agreed with the statement that Asiana pilots obtained most of their manual flying practice during approaches below 1,000 ft agl. He stated it was permissible for Asiana pilots to disengage the A/P above 1,000 ft, but turning the A/P off at 8 nm from the airport and at 2,800 ft, for example, would not be recommended. When asked if Asiana had a policy regarding when FLCH SPD could be used during an approach, he stated that there was no requirement but that it was not recommended on final approach. He stated that when executing a manually flown visual approach, it was mandatory to have the A/T on for final approach.

Other Asiana pilots interviewed agreed that it was standard practice to disengage the A/P about 1,000 ft agl on a manually flown approach. Two Asiana captains with prior flight experience at other airlines stated that most Asiana FOs preferred to make automated landings or to leave the A/P engaged to 1,000 ft agl or lower before taking over and landing manually. An Asiana contract simulator instructor stated that manual flying was a “big scare for everybody,” and he believed that pilots avoided flying manually because of concern that they might do something wrong and the company would blame them if they performed a go-around or had a hard landing that was captured by onboard flight data monitoring devices. He further stated that manual flying training that included the approximate power settings and pitch attitudes required to achieve a 3° glidepath was not in the training syllabus.

Asiana provided landing statistics for the year 2012 indicating that on the 777, 77.7% of the landings were made manually and 17.1% were automated landings.[87] The statistics also showed that 36% of all 777 landings in 2012 were made by the FO.

1.17.1.2 Descent Procedures

The FOM, paragraph 7.8.9, “Maximum Descent Rate,” stated that to avoid controlled flight into terrain, the maximum descent rate is 3,300 fpm for altitudes between 5,000 and 2,000 ft agl and 1,500 fpm for altitudes between 2,000 and 1,000 ft agl. Below 1,000 ft agl, the pilot should follow the stabilized approach criteria (see section 1.17.1.4).

The 777 POM, subparagraph 2.12.9.7, “Use of Speedbrakes,” stated that to avoid buffeting, the use of speedbrakes should be avoided at flap settings higher than 5°. It also stated that speedbrakes should be retracted before reaching 1,000 ft agl.

According to the 777 FCTM, page 4.21, “Descent Rates,” when operating at idle thrust and an airspeed of about 210 knots, the descent rate can be increased from 1,000 fpm to about 2,300 fpm with the use of speedbrakes.

1.17.1.3 Visual Approach

The 777 POM, section 2.18, “Visual Approach,” provided guidance to pilots for visual approaches. The section described how to set up downwind, base, and final legs using the FMC arrival page and how to use distance from the runway end and timing techniques to fly the visual traffic pattern. Subparagraph 2.18.1.4, “Final Approach,” stated that the recommended approach path angle was 2.5° to 3°; an altitude of about 300 ft above the airport elevation for each mile from the runway would provide a normal approach profile; and the airplane should be stabilized on the selected approach speed with a rate of descent of 700 to 900 fpm. It further stated that descent rates greater than 1,000 fpm should be avoided; however, rates a “little over 1,000 fpm” were acceptable and should be included in the approach briefing.

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[87] For the other 5.2% of 777 landings in 2012, the type of landing was not reported.

In the same simulator that was used for the pilot-in-the-loop simulations described in section 1.16.1.2, an Asiana training captain demonstrated the technique pilots were taught for performing a visual approach involving a standard traffic pattern. His demonstration, including the use of the FMC, timing to determine when to make turns, use of the VPI, and use of the A/P until about 1,000 ft agl on final approach, were consistent with the guidance in the Asiana 777 POM.

1.17.1.4 Stabilized Approach and Go-Around

The 777 POM, paragraph 2.13.6, "Stabilized Approach," addressed stabilized approach procedures and criteria. It stated, "every flight crewmember must confirm and monitor a stabilized approach, and "if a stabilized approach is not established, go-around." The paragraph also included a note that stated "deciding to make Go-Around does not mean that the procedure has been done wrong, but it means that crews follow[ed] the company safety policy and executed safety procedure normally."

> Subparagraph 2.13.6.5, "Stabilized Approach Criteria," stated, in part, the following:
>
> a. All approaches should be stabilized by 1,000 ft above airport elevation in [instrument meteorological conditions] IMC and 500 ft above airport elevation in VMC. An approach is considered stabilized when all of the following criteria are met:
> 1) the airplane is on the correct flightpath
> 2) only small changes in heading and pitch are required to maintain the correct flightpath
> 3) Speed: Max Target speed +10 knots, Min Target speed - 5 knots (Target speed = V_{ref} + Wind Correction)
> 4) the airplane is in the correct landing configuration
> 5) sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted
> 6) thrust setting is appropriate for the airplane configuration
> 7) all briefings and checklists have been conducted.

The subparagraph included a note that stated, in part, "an approach that becomes unstabilized below 1,000 feet [above field elevation] AFE in IMC or below 500 feet AFE in VMC requires an immediate go around."

The 777 POM, subparagraph 2.13.6.8, "Standard Callout & Response," stated that the PM should call out "five hundred" at 500 ft AFE; the PF should respond "stabilized" or "go-around;" and a go-around should be made if the approach was not stabilized.

In a postaccident interview, the PF stated that at 500 ft AFE, the airplane should be stabilized, and for a visual approach, the airplane should be stabilized by 300 ft AFE. For an unstable condition, he said a go-around should be performed. The PF stated that only the PIC, in this case the PM, had the authority to decide to go around. He said this was company policy resulting from a tailstrike event that had occurred when an FO had initiated a go around.

In a postaccident interview, the PM stated that "the PF was supposed to be the one calling out the go-around." However, he also stated that when he discussed executing a go-around with the PF during the flight, he said that if performance requirements were not met, he (the PM) would say "I have control."

The FOM, paragraph 7.10.2, "Decision to Land," subparagraph 7.10.2.1, "Responsibility," stated that the "captain has authority and responsibility to make a landing or missed approach (go-around) considering actual weather condition and stabilized approach condition."

The 777 POM, section 2.19, "Missed Approach (Go-around) Procedure," subparagraph 2.19.1.1, "Decision and Control," stated that "the decision to make a missed approach rests with the Captain. However, when the Co-pilot (F/O) flies the aircraft as PF, Co-pilot (F/O) can make a missed approach." Subparagraph 2.19.1.3, "Missed approach during Manual Instrument Approach or Visual Approach," stated that if a missed approach is required following a visual approach, the PF should "push either TO/GA switch, call for flaps 20, check go-around thrust set, and rotate smoothly toward 15 [degree] pitch attitude."

The Asiana 777 chief pilot stated in an interview that the first responsibility for conducting a go-around rested with the PIC but the PF could decide to perform a go-around at any time, and anyone in the cockpit could call for a go-around. He said he thought all Asiana captains would agree that an FO could initiate a go-around. Interviews with several Asiana pilots and instructors yielded similar interpretations of Asiana policy in this area. For example, an IP who conducted OE with the PF for flight 214 was asked specifically if it was acceptable for a captain in the left seat who was being instructed to make the decision to go around, and he responded that it was acceptable.

1.17.1.5 Flight Crew Duties During Approach

The 777 POM, section 2.13, "Approach Procedure," paragraph 2.13.1, "PF/PM's Duties," stated that for all approaches, the PF's duties were the following:

1. Maintain aircraft control and conduct the approach briefing
2. Follow published approach procedures
3. Cross check all flight instruments
4. When using the AFDS, the PIC should be ready for manual flight before passing the final approach fix.

The PM's duties for all approaches were the following:

1. Make active standard callouts
2. Cross check all primary instruments and raw data

3. Monitor any display of warning/caution flags or deviation from the intended flightpath and callout to the PF
4. Monitor speed and descent rate until touchdown
5. After landing, advise runway and taxiway to PF
6. When aircraft is unstabilized or safe landing is not assured, advise the PF to make a missed approach.

Subparagraph 2.13.2.2, “Deviation Callout,” stated that when airspeed, glideslope, localizer, sink rate, thrust, or visual guidance is out of approach limitation, the PM should call it out clearly.

Paragraph 2.13.5, “Scan Policy,” addressed the division of flight deck workload for instrument scan and acquisition of visual cues during landing. It stated that for a visual approach below 1,000 ft agl, after visual contact was made with the airport, both the PF and the PM should be scanning both inside and outside the airplane. It stated that the PM should monitor airspeed and sink rate through the touchdown, and when there was an additional pilot in the cockpit, he or she should perform backup duty for the PM during the approach.

1.17.1.6 Expected Pitch and Power on Final Approach

The 777 FCOM, chapter PI, “Performance Inflight,” pages PI.10.30-31, provided a chart listing approximate values for pitch attitude and power setting for various phases of flight. For flight on final approach (1,500 ft agl), gear down, thrust set to maintain a 3° glidepath, flaps 30, and speed V_{ref} plus 10 knots (142 knots for flight 214), at a landing weight of 450,000 lbs, the chart showed an expected pitch attitude of 0° and 57.9% N_1 speed. For a landing weight of 350,000 lbs, the chart showed an expected pitch attitude of -0.5° and 51.2% N_1 speed.

1.17.1.7 Evacuation

The 777 POM, chapter 4, “Non-Normal Procedures,” paragraph 4.1.4, “Authority and Responsibility in Emergency,” stated, “in an emergency situation that requires immediate action for the safety of passengers, crew and aircraft, the captain may deviate from prescribed operation procedures and aviation regulations. At that time the captain shall notify appropriate ATC facilities immediately [of] the deviated situation.”

Subparagraph 4.10.2.5, “After Landing or Rejected Takeoff,” addressed evacuation policy. It indicated that the captain should determine if an evacuation is necessary, and if so, to perform the QRH evacuation procedure; the evacuation procedure was located on the back page of the 777 QRH. The procedure required the parking brake to be set, the outflow valves to be opened, and the engine to be shut down before advising the cabin to evacuate.

A contract simulator instructor stated that if pilots missed a step on the evacuation checklist in training it would be a failure, and he did not think Asiana pilots would deviate from the evacuation checklist. He was asked if there was a step in the evacuation training that involved calling the tower before evacuating. He replied yes. He stated that it was not in the checklist, but in a situation where the crew was not sure about the condition of the airplane, the pilots would want to confirm with the tower whether a fire was visible. If the flight crewmembers were sure about the airplane's condition, they would have to immediately evacuate.

1.17.2 Flight Crew Training

Asiana Airlines provided its pilots with all training at its headquarters, including initial, recurrent, upgrade and transition ground training, simulator training, testing, and checks. Asiana employed contract instructors to conduct the full flight simulator portion of 777 training. All training curriculum, procedures, and standards were developed by the Asiana flight crew training team under the direction of the general manager of flight crew training.

The Asiana Airlines Flight Crew Training Regulation established operational standards and procedures for flight crew training and evaluation. For 777 pilot training, Asiana Airlines also used Boeing's 777 FCTM. The introductory section of the FCTM stated that procedures and restrictions published in the FCOM, QRH, and other documents took precedence over the FCTM.

1.17.2.1 Autothrottle Function Training

The PF's Asiana 777 transition training included detailed overviews of the 777 autoflight system presented during two instructor-led training modules, a 4-hour slideshow on the "Automatic Flight System," and a 2-hour slideshow titled "B777 Flight Controls – Recurrent Training." According to Asiana, the slides were based on screen captures of computer-based training lessons purchased from Boeing to which Asiana instructors added descriptions and references from the Asiana POM, Asiana FCOM, and the Boeing FCTM.

The "Automatic Flight System" training module described A/T function during FLCH descent and stated that the A/T activates in THR mode and transitions to HOLD mode if the thrust levers reach idle. This module also included information about the forms of flight envelope protection provided by the A/P, which included stall protection. One of the module's slides included the statement:

> DOES THE AUTOPILOT NEED TO BE ENGAGED TO HAVE FLIGHT ENVELOPE PROTECTION? NO
> (Demo in SIM[ULATOR])

The "B777 Flight Controls – Recurrent Training" training module contained the following additional information about stall protection:

> Stall Protection Feature
> - Reduces the possibility of reaching stick shaker
> - No trim below minimum maneuvering speed
> - Slow speed requires continuous back pressure
> - Autothrottle engaged automatically (if armed)

The "Automatic Flight System" transition training module and the "B777 Flight Controls – Recurrent Training" module did not indicate that the low speed protection function provided by the A/T would not activate if the A/T was in HOLD mode.

In a written statement, an Asiana 777 ground school instructor indicated that although the information was not included on any slides, he explained during a 777 ground school class attended by the PF that the A/T would sometimes remain in HOLD mode after the A/P was disconnected and airspeed could drop. He described this as an "anomaly in the Boeing 777's autothrottle functioning" that he had personally experienced on three separate occasions. He said he advised students that this could occur during a high energy descent in FLCH mode and that if they encountered this situation, they should change the AFDS pitch mode to V/S or VNAV. An Asiana pilot who was in this instructor's class with the PF reviewed his class notes and confirmed that the instructor had provided this information. The same student stated that another instructor had provided similar information during another 777 ground school class attended by the PF and advised students that they should not use FLCH to descend after crossing the FAF.

1.17.2.2 Asiana Pilots' Statements about A/T Function

The PF stated that the 777 A/T system would always maintain the selected airspeed as long as the A/T was on. He said that if a pilot overrode the thrust levers manually, the A/T would resume controlling airspeed when the pilot released the thrust levers. He stated that it was irrelevant whether he had pushed the FLCH button immediately before disconnecting the A/P during the accident approach because he was in manual flight and the A/T was always working. He thought the A/T should have automatically advanced the thrust levers upon reaching the MCP-selected airspeed during the accident approach, and he did not understand why that did not occur. Furthermore, he thought the A/T system should have automatically transitioned to TO/GA when the airplane reached minimum airspeed. In that respect, he believed that the 777 A/T functionality was similar to alpha floor protection on the Airbus A320/321.[88] Asked how confident he was in his understanding of the 777 AFCS, he said he had followed the Asiana training program but was not confident in his understanding, and he thought he needed to study more.

An Asiana 777 OE instructor captain who had conducted an OE instructor check flight with the PM was asked to predict how the 777 A/T system would behave if the FLCH pushbutton was selected while descending through 2,000 ft msl in V/S mode with the A/P on and the MCP altitude set to 3,000 ft msl. He said that the thrust levers would advance, and the airplane would try to climb. When asked what mode the A/T would be in if the pilot manually pulled the thrust levers back, he said that the A/T would remain in SPD mode, and the thrust levers would advance after the pilot released them. Three additional Asiana pilots were asked what would happen in this same scenario if a pilot pulled the thrust levers back manually and then disconnected the A/P. Another 777 OE instructor captain who had conducted an OE training

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[88] Alpha floor protection is a low speed protection feature of the Airbus autothrust system. When activated, it provides TO/GA thrust. As an Airbus airplane decelerates into the alpha (angle of attack) protection range, alpha floor protection is activated, even if the autothrust is disengaged. Alpha floor protection is inhibited below 100 ft RA, if autothrust is unserviceable, following a double engine failure on the four-engine A340 or a single engine failure on twin-engine models, and above Mach 0.53.

flight with the PM said he did not know what thrust mode the A/T would be in after this sequence of actions. Two 777 OE instructor captains who had conducted OE training flights with the PF said that the A/T would transition to HOLD mode and remain there until a different A/P pitch mode was selected by the pilot.

The Asiana 777 chief pilot was asked if there were any conditions in which the 777 A/T system would not provide low speed protection, and he said it would not provide low speed protection in HOLD mode. He said this information was not included in Asiana's 777 pilot training curriculum but was contained in the 777 FCOM, and he thought Asiana 777 pilots were aware of it. When the same question was posed to three OE training captains (two of whom had conducted OE training flights with the PM and one of whom had conducted an OE flight with the PF), they said that the A/T system did not provide low speed protection in HOLD mode; however, one said he had only learned that after the accident. A fourth OE instructor was asked the same question and said that the A/T system would not provide low speed protection if the A/P and A/T both failed. A contract simulator instructor (who had been providing 777 simulator training to Asiana pilots since 2006) was asked if he thought most pilots understood that the 777 A/T system did not provide low speed protection in HOLD mode, and he said he was not aware of that himself until Boeing provided an update to the 777 FCOM in 2012.[89]

1.17.2.3 Stall Protection Demonstration

The 777 FCTM, page 7.11, "Stall Protection Demonstration," described a demonstration to be used in 777 training to familiarize pilots with stall warning and the correct recovery technique for conditions approaching a stall, with and without the A/P engaged. In a series of three approaches to stall from level flight, the first maneuver demonstrated the A/T "wake up" feature, the second demonstrated nose-up trim inhibit and increased column force below minimum maneuver speed, and the third demonstrated A/P commanded descent at slightly above minimum maneuver speed when the A/T is disarmed.

Asiana adopted the FCTM stall protection demonstration in its 777 simulator training, and the pilots had observed the demonstration. During the demonstration, A/P and A/T were disengaged, thrust levers were retarded to idle, command speed was reduced below minimum speed on the speed tape, and the airplane was allowed to decelerate into the amber band on the airspeed tape (below minimum maneuvering speed). With no pilot intervention, the A/T system's "wake up" feature activated, and the system engaged in SPD mode and returned the airplane to minimum maneuver speed. The PF stated that when he saw the demonstration, he was "astonished" that the airplane would recover by itself from an approach to stall.

1.17.2.4 Flight Director Use During Visual and Circling Approaches

The FCTM, page 5.60-61, "Visual Approach –General," addressed procedures for flying a visual approach. No reference was made in this section to the use of F/Ds. The FCTM,

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[89] According to Boeing, this 2012 update relocated a discussion of the A/T's automatic activation feature from section 9.20, where it had been part of a larger discussion of stall protection features, to section 4.20, where it was included in a description of the A/T.

page 5.54, “Circling Approach – General,” did address the use of F/Ds during a circling approach, stating the following:

> When intercepting the visual profile, disengage the autopilot and continue the approach manually. At this point in the approach, the pilot’s attention should be focused on flying the visual profile rather than attempting to set the MCP or FMC to allow continued use of the autopilot. After intercepting the visual profile, cycle both F/D to OFF, and select the PM F/D to ON. This eliminates unwanted commands for the PF and allows continued F/D guidance for the PM in the event of a go-around when pitch or roll mode is changed. Complete the landing.
>
> Note: If a go-around is selected with either flight director switch in the OFF position, the flight director pitch or roll command bar on the corresponding side will disappear when the first pitch or roll mode is selected or engaged.

1.17.2.5 Instructor Pilot Training

A review of Asiana’s 777 flight instructor training guide showed that instruction techniques were taught, as well as execution of normal and nonnormal procedures. The simulator training included several scenarios in which the instructor trainee had to identify poor or dangerous performance by the pilot in the left seat and take action to recover the airplane safely. For example, in one scenario, the instructor trainee had to take control of the flight from the left seat pilot because of a takeoff overrotation, and in another scenario, the instructor trainee had to take over because of no flare during landing at 30 ft above the runway. The final stage of instructor training consisted of two flight legs of OE instruction and two flight legs of a check in the airplane. On the training flights and check flights, the instructor trainee flew the airplane from the right seat but gave no instruction.

1.17.3 Regulatory Oversight

Regulatory oversight of Asiana in the Republic of Korea is the responsibility of the KOCA. Regulatory oversight of Asiana in the United States is the responsibility of the FAA.

Within the KOCA, oversight of Asiana is conducted by the Air Operations Safety Division. According to the principal operations inspector (POI), he was responsible for approving the entire Asiana training manual, including all changes, and FOM special limitations. The POI stated that the KOCA only conducted pilot checkrides of upgrading captains, and he did about 10 flight examinations per year but did not conduct type rating checkrides.

To operate into the United States, foreign carriers must obtain a permit issued by the US Department of Transportation and obtain operations specifications issued by the FAA. Operations of foreign air carriers are regulated by the FAA under 14 CFR Part 129,[90] which

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[90] According to the FAA, as of July 2013, there were 482 foreign air carriers certified under Part 129.

specifies that each carrier must meet the safety standards contained in International Civil Aviation Organization (ICAO) Annex 6.[91]

In 1992, the FAA established the International Aviation Safety Assessments Program under which the FAA assesses whether another country's oversight of its air carriers operating into the United States complies with ICAO safety standards; as of July 2013, the Republic of Korea was determined to be in compliance.

The POI assigned to provide FAA oversight of Asiana Airlines in the United States explained that as a Part 129 POI, his activities focused on maintaining the operations specifications of each carrier he was responsible for, reviewing each carrier's performance, and generating recommendations for the work program. He stated that the only type of inspection the FAA was authorized to perform on Asiana was a ramp inspection. The POI stated that the FAA was not authorized to ride a foreign carrier jumpseat or to conduct cockpit or cabin en route inspections. He stated that the FAA did not approve operations manuals or crew training programs and had no oversight of these items.

A review of 140 entries in the FAA's program tracking and reporting subsystem regarding Asiana since October 2011 showed that most entries were related to ramp inspections or operations specifications revisions. A total of 118 ramp inspections were conducted at 11 US airports served by Asiana. One possible flight violation was noted, which was referred to and resolved by Asiana Airlines.[92]

1.18 Additional Information

1.18.1 Postaccident Safety Action

1.18.1.1 Asiana Airlines

In December 2013, Asiana Airlines provided NTSB investigators with a list of the company's postaccident actions, which included the following:

(1) Enhanced flight crew training and evaluation for all flight crewmembers:
  - Increased hours for basic, initial, and transition training
  - Increased training focus on automation logic and the capabilities of the A/T stall protection system

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[91] Annex 6 addresses the standards and recommended practices for the operation of aircraft.

[92] According to the FAA, during an approach to Seattle-Tacoma International Airport, an Asiana flight was cleared by ATC to track inbound on the localizer and maintain 5,000 ft. However, the flight started descending on the ILS glideslope before receiving clearance for the descent. According to the FAA, Asiana took immediate corrective actions including briefing and training the incident flight crew and informing other Asiana pilots of the circumstances of the event.

- Increased training focus on visual approaches and enhanced evaluation of visual approach performance
- Additional evaluation for captain upgrade

(2) Strengthened flight instructor training
  - Enhanced flight instructor screening and selection process
  - Increase in required training hours for ground school, simulator, and OE flight instructor training
  - Increased focus on special airports, visual and nonprecision approach, unstabilized approach, monitoring, and standard callouts

(3) Enhanced CRM training
  - Implementation of new advanced communications and CRM courses
  - Special training focusing on monitoring, workload management, and threat and error management

(4) Revamped safety management structure
  - New senior executive-level position to oversee safety operations
  - Additional staff devoted to internal safety audits, flight crew training support and development, and CRM instruction

(5) Other measures
  - Revision of safety management system program and company procedures and manuals to provide more detailed guidance on key issues

1.18.1.2 City and County of San Francisco

On January 17, 2014, the City and County of San Francisco provided a party submission that included a list of postaccident actions. These actions included the following:

(1) Training enhancements
  - 40-hours ARFF training for all personnel provided by Dallas/Fort Worth International Airport (DFW) Fire Training Research Center (FTRC)
  - Advanced-level ARFF training at the DFW FTRC budgeted for a 2014 start
  - Adoption of DFW curriculum for driver training and HRET training
  - Adoption of incident management training and certification of all officers

(2) System and equipment enhancements
  - Adoption of improved triage system to enhance mass casualty incident management and patient tracking
  - Adoption of an accountability system for tracking all fire and emergency personnel on scene
  - Budgeted for the purchase of two dedicated SFFD-AB mass casualty unit vehicles, each holding 250 backboards, one to be purchased in 2014/15 and one in 2015/16

- Integration of the new 700-MHz radio system at SFFD-AB with established interoperability with SFFD and San Mateo County
- Budgeted for the installation of an airfield fire hydrant to be located approximately 2,500 ft in from the 28R threshold, near Taxiways Charlie and November
- Purchase of a 767-200 aircraft to be used for emergency training
- In 2014, plan to require each airline regularly operating at SFO to review with airport officials its individual safety plans as required by federal law

(3) Personnel development
  - Upgrade of the EMS supervisor position from a 40-hour/week position to a 24/7 position
  - Agreement by the Fire Fighters' union that assignment to the SFFD-AB will be a 5-year commitment, rather than no previously imposed commitment
  - Development of a new managerial level position, effective January 6, 2014, for a Director of Safety and Strategic Programs

1.18.2 Boeing Certification Issue Involving A/T Automatic Engagement Logic

Boeing reported that during the 777 flight test certification program in 1995, a specific test was conducted to demonstrate that the A/T did not automatically engage when the A/P pitch mode was FLCH SPD. The flight test certification report documenting this flight, approved by the FAA on May 27, 1996, stated, "Per design, when the autopilot is controlling airspeed, the autothrottle automatic engage feature is disabled."

During the 787 flight test certification program in 2010, the FAA's primary project pilot for the program noted an issue involving the A/T automatic engagement feature. (According to Boeing, the 777 and 787 have the same automatic A/T engagement feature.) The FAA pilot reported that during a 787 test flight on August 30, 2010, he was flying the airplane from the left seat and descending from 10,000 to 3,000 ft msl in FLCH pitch mode when the traffic collision avoidance system issued a resolution advisory. He responded by disconnecting the A/P and manually leveling off. He subsequently noticed that the airspeed had decreased 10 or 15 knots. The airspeed continued to decrease until it was below the minimum maneuvering speed. At that point, he pushed the thrust levers forward and recovered the airspeed.

The primary project pilot stated that he had about 1,000 hours of flight experience in Boeing airplanes, including about 500 hours in the 777, and that the A/T system in the 787 had not functioned the way he expected during this incident. He thought the system behavior was "less than desirable" and could be improved. As a result, he drafted an FAA Flight Test Response Item (RI) report titled "Autothrottle does not wake up when in Thrust Hold mode." Identified as "RI-12," the report described the issue as follows:

> When in a descent such as FLCH with autothrottle in THR HOLD mode, and the descent has to be manually interrupted for something such as [a] traffic alert, the autothrottle will stay in THR HOLD mode and will not wake up as it does when you capture the original altitude. The speed will decrease well past maneuvering speed.

The primary project pilot said RI-12 prompted discussions between the FAA and Boeing. As a result, the FAA required Boeing to add the following passage to the 787 Airplane Flight Manual (AFM), which was added in August 2011:

> During a descent in FLCH mode or VNAV SPD mode, the A/T may activate in HOLD mode. When in HOLD mode, the A/T will not wake up even during large deviations from target speed and does not support stall protection.

The primary project pilot stated that a similar note was not added to the 777 AFM, which had been previously approved by the FAA.

The European Aviation Safety Agency (EASA) also voiced a concern about A/T automatic engagement on the 787 in a document titled "EASA Debrief Note on Boeing 787-8 RR EASA Validation Familiarization Flight Test Visit," dated May 22, 2011. In an item titled "Major Recommendation for Improvement #3," the debrief note pointed out that A/T automatic engagement (wake up) was not available in a FLCH or VNAV SPD descent with the A/T in HOLD mode and stated that "although the certification team accepts that this 'Autothrottle wake up' feature is not required per certification requirements, these two exceptions look from a pilot's perspective as an inconsistency in the automation behavior of the airplane." According to the note, a major recommendation for improvement is "an item which meets the required standard but where considerable improvement is recommended." The debrief note further stated that "the manufacturer would enhance the safety of the product by avoiding exceptions in the 'Autothrottle wake up' mode condition."

1.18.3 Federal Aviation Administration Actions About Manual Flight Operations

The FAA issued Safety Alert for Operators (SAFO) 13002, "Manual Flight Operations," on January 4, 2013, encouraging operators to promote manual flight operations when appropriate. It stated that a recent analysis of flight operations data (including normal flight operations, incidents, and accidents) identified an increase in manual handling errors. The SAFO acknowledged that autoflight systems are useful tools for pilots and have improved safety and workload management but cautioned that continuous use of autoflight systems could lead to degradation of the pilot's ability to quickly recover the aircraft from an undesired state. It encouraged operators to take an integrated approach by incorporating emphasis of manual flight operations into both line operations and training (initial/upgrade and recurrent).

The FAA issued a revision to 14 CFR Part 121, titled "Qualification, Service, and Use of Crewmembers and Aircraft Dispatchers," on November 12, 2013, intended to enhance US air carrier pilot training programs by emphasizing the development of pilots' manual handling skills. Among the changes was a new section, 14 CFR 121.423, "Pilot: Extended Envelope Training," which states, in part, that pilots must receive training that includes the following maneuvers and procedures: manually controlled slow flight, manually controlled loss of reliable airspeed, manually controlled instrument departure and arrival, upset recovery maneuvers, and recovery from bounced landing. Operators' compliance with this section is required no later than March 12, 2019.

1.18.4 Federal Aviation Administration Guidance on Use of HRET

At the NTSB's investigative hearing, an FAA representative stated that Advisory Circular (AC) 150/5210-23, "ARFF Vehicle and High Reach Extendable Turret (HRET) Operation, Training and Qualifications," dated September 30, 2010, provided guidance on HRET use. He added that "we don't directly tell them when to pierce, but we do provide information about piercing…we do provide guidance on how to pierce, but we don't provide any guidance really on when to pierce."

The AC included the results of FAA testing that compared the performance of a roof turret with an HRET, stating that the HRET and skin-penetrating nozzle evaluated at the fire test facility outperformed the standard roof-mounted turret and hand line. The AC further stated that during a full-scale fire field test using a training aircraft, the HRET with skin-penetrating nozzle showed the ability to control and contain the fire from spreading beyond the tail section, reduce high cabin temperatures from over 1,500°F to about 250°F, and provide rapid smoke ventilation. Additionally, the cabin conditions after discharging the fine mist water spray allowed firefighters to enter the aircraft.

FAA Report DOT/FAA/AR-11/15, dated November 2011, titled "Test and Evaluation of Next Generation 65-Foot, High-Reach Extendable Turret," stated that the benefits of the HRET include "the ability to penetrate inside an aircraft to cool the interior cabin and extinguish the fire," which "can increase passenger survivability, protect property, and extinguish fire faster during an aircraft postcrash incident."

1.18.5 Postaccident Flight Crew Toxicological Testing Requirements

Title 14 CFR Part 129 does not address drug and alcohol testing for foreign air carriers and operators following an accident in the United States. Title 14 CFR Part 120, which specifies the required drug and alcohol testing programs for US air carriers and operators, does not apply to Part 129 air carriers. According to 14 CFR 120.217(b), postaccident alcohol testing of flight crewmembers is required as soon as practicable following an accident (preferably within 2 hours and not later than 8 hours after an accident). According to 14 CFR 120.109(c), postaccident drug testing of flight crewmembers for the presence of marijuana, cocaine, opiates, phencyclidine, and amphetamines is required as soon as possible but not later than 32 hours after an accident.

In the Omnibus Transportation Employee Testing Act of 1991, the FAA was authorized to prescribe regulations requiring foreign air carriers to implement drug and alcohol testing programs, but only if such regulations were consistent with the international obligations of the United States and took into consideration foreign laws and regulations. Pursuant to this statute, in

February 1994, the FAA published a notice of proposed rulemaking to require foreign air carriers operating to the United States to implement testing programs like those required of US carriers. In January 2000, the FAA withdrew the proposed rule, stating that through ICAO, multilateral action had been taken to support an aviation environment free of substance abuse. The FAA further stated that it was leaving within the purview of each government the method chosen to respond to the ICAO initiatives and that it viewed a multilateral response as the best approach to evolving issues in the substance abuse arena. Additionally, the FAA stated that should the threat to aviation safety posed by substance abuse increase or require additional efforts and the international community did not adequately respond, the FAA would take appropriate action, including the possible reinitiation of rulemaking.

During the 38th session of the ICAO Assembly held from September 24 to October 4, 2013, the United States presented a paper, authored by the FAA, that proposed developing an ICAO standard on postaccident drug and alcohol testing of flight crewmembers. The paper stated that although postaccident testing is referenced in the ICAO Standards and Recommended Practices, the lack of a common approach to accident investigations, particularly postaccident testing, may result in an inability of some nations to properly determine the existence of, or impairment from, drugs and alcohol. The paper further stated that the establishment of an ICAO standard for postaccident drug and alcohol testing would promote international acceptance and implementation of such programs. ICAO agreed to review existing standards, recommended practices, and guidance material to determine the need for a specific standard to address postaccident drug and alcohol testing of flight crewmembers.

2. Analysis

2.1 General

The flight crewmembers were properly certificated and qualified in accordance with Korean regulations and 14 CFR Part 129. The investigation found no evidence that the flight crews' performance was affected by any behavioral or medical condition or by the use of alcohol or drugs.

The airplane was loaded within weight and CG limits and was equipped, certified, and maintained in accordance with KOCA regulations and 14 CFR Part 129. The investigation found no evidence of any preimpact structural, engine, or system failures, including no indications of problems with the airplane's AFCS.

Weather conditions at the time of the accident were suitable for a visual approach. Air traffic controllers vectored flight 214 toward the extended centerline of runway 28L and, after the pilots reported the airport in sight, issued a clearance for the visual approach at a position and altitude that allowed for a normal descent and approach to the runway. The speed restriction issued on approach was in accordance with FAA procedures, and the flight crew accepted the speed assignment. The MSAW system was configured within FAA standards and performed as expected; it would not have activated based on the airplane's proximity to the runway.

The NTSB concludes that the following were not factors in the accident: flight crew certification and qualification; flight crew behavioral or medical conditions or the use of alcohol or drugs; airplane certification and maintenance; preimpact structural, engine, or system failures; or the air traffic controllers' handling of the flight.

A NOTAM had been published indicating that the ILS glideslope for runway 28L was out of service due to a construction project, and the flight crew was aware of the outage. While the electronic vertical guidance provided by a glideslope is required for approaches in certain low visibility conditions and can be a useful aid in all weather conditions, a glideslope is not required for a visual approach. The flight crew had numerous other cues to assist in planning and flying an appropriate vertical flightpath to the runway. Flight crews routinely plan descents based on speed and distance from airports or navigational fixes and published crossing altitudes on approach charts. Aids such as the ND's green altitude range arc and VNAV features were available to guide the pilots in the initial portion of the descent. As the airplane neared the runway, the PAPI lights and the visual aspect of the runway surface provided additional cues. The NTSB concludes that although the ILS glideslope was out of service, the lack of a glideslope should not have precluded the pilots' successful completion of a visual approach.

The following analysis describes the accident sequence and examines the safety issues associated with the flight crew's performance and the operation of the airplane's systems during the approach.

2.2 Accident Sequence

2.2.1 Approach from 14 to 5 nm from the Runway

The airplane intercepted the final approach course for runway 28L about 14.1 nm from the runway threshold and 4,800 ft msl, which was close to the desired glidepath and set up the flight crew for a straight-in visual approach. However, after the flight crew accepted the ATC instruction to maintain 180 knots to 5 nm from the runway, the crew made inputs to the AFCS that reduced the airplane's descent rate and caused it to diverge well above the desired 3° glidepath.

The PF decreased the MCP-selected speed from 210 knots to 180 knots and commanded flaps 5. While these selections at this time were appropriate, leaving the AFDS in FLCH SPD pitch mode without using the speedbrake to ensure an adequate rate of descent was not effective because the A/P was controlling airspeed with elevator inputs and the reduction in selected speed caused the airplane to pitch up and the descent rate to decrease. As a result, the airplane started to drift above the desired glidepath. In addition, the PF did not appear to promptly recognize that the airplane was drifting above the desired glidepath after he had selected a lower airspeed in FLCH SPD.

A cue available to the flight crew indicating the airplane's position relative to the desired glidepath was the green altitude range arc on the ND's map display. After they were cleared for the approach, the flight crewmembers had selected an MCP altitude of 1,800 ft because it is the crossing altitude for the DUYET waypoint, located 5.4 nm from the runway. The FMC used the airplane's vertical speed and groundspeed to calculate and display an arc showing where the airplane was expected to reach the MCP-selected altitude. Throughout the initial part of the approach, the green arc would have shown that the airplane would not arrive at 1,800 ft until well past the DUYET waypoint.

When the airplane was about 11.5 nm from the runway, descending through 4,300 ft msl, the PF changed the A/P pitch mode from FLCH SPD to V/S and adjusted the vertical speed to -1,000 fpm; there was a corresponding automatic change in the A/T mode from HOLD to SPD. The airplane's vertical speed began to increase toward the target value; however, a descent rate of 1,000 fpm was not high enough to maintain, let alone recapture, the desired glidepath, so the airplane continued to drift above it.

When the airplane was about 8.5 miles from the runway threshold, descending through 3,400 ft msl at an airspeed of 188 knots, the PF commanded landing gear down. Gear extension added drag and made it easier to decelerate. Although he did not do so, the PF could also have commanded flaps 20 at this time, adding additional drag, because the airspeed was 7 knots below the flaps 20 limit speed of 195 knots. The airplane was about 900 ft above the desired glidepath, and a higher flap setting would have allowed the flight crew to descend the airplane at a steeper angle while maintaining the assigned airspeed and would have saved time later when the flight crew needed to establish a landing configuration and decelerate to final approach speed.

After moving the gear handle to the down position, the PM commented on the airplane's position above the desired glidepath, stating, "this seems a little high." The PF agreed. The PM continued, "this should be a bit high." After a few seconds, the PF queried, "do you mean it's too high?" The PM made an unintelligible response, and the PF stated, "I will descend more," then decreased the selected vertical speed to -1,500 fpm. This exchange was followed by 21 seconds of no communication between the pilots as the airplane's descent rate increased and the airplane drew closer to the desired glidepath.

When the airplane was about 6.3 nm from the runway at about 2,600 ft msl and an airspeed of 178 knots, the selected vertical speed was changed back to -1,000 fpm. By examining the altitude and distance to the runway, both of which were displayed on the instrument panel, and applying the well known rule of thumb that a 3° glidepath requires about 300 ft of altitude loss per nm, the pilots could have quickly estimated that they were still several hundred feet high. Changing the vertical speed back to -1,000 fpm at that time was, therefore, inappropriate because the airplane was still well above the desired glidepath, and the flight crew needed to continue descending the airplane at more than 1,000 fpm to return to the desired glidepath. The crew's action indicated a lack of awareness of the airplane's position relative to the desired glidepath and of cues in the cockpit that could have alerted them to this. As a result of this lack of awareness and their early reversion to a descent rate of 1,000 fpm, the airplane remained high.

When the airplane reached the 5 nm point, it was about 400 ft above the desired glidepath, descending through 2,085 ft msl, at an airspeed of about 174 knots. As a result, the PF needed to slow the airplane below the flaps 30 limit speed of 170 knots, while also losing the excess altitude. When test pilots from Boeing and the FAA attempted to fly a stabilized approach in a flight simulator beginning from this starting point, they found it difficult to achieve a stabilized approach by 500 ft agl. In fact, they found it impossible to do so without exceeding maximum descent rates published in Asiana's FOM. However, when the starting point was changed to an on-desired-glidepath altitude (1,650 ft msl) with the same airspeed, the test pilots were consistently able to achieve a stabilized approach by 500 ft agl, and they did so without exceeding Asiana's maximum descent rates. Clearly, the airplane's excess altitude increased the difficulty of achieving a stabilized approach. The NTSB concludes that the flight crew mismanaged the airplane's vertical profile during the initial approach, which resulted in the airplane being well above the desired glidepath when it reached the 5 nm point, and this increased the difficulty of achieving a stabilized approach.

2.2.2 Approach from 5 nm to the Runway

The flight crew's difficulty in managing the airplane's vertical path continued as the approach progressed. The PF was aware of the need to lose excess altitude and attempted to do so using FLCH SPD pitch mode, which initiated a sequence of events that had the unintended consequence of deactivating automatic airspeed control. The changes on the FMA that occurred during the airplane's descent from 1,850 to 1,330 ft msl, when it was between about 4.5 and 3.0 nm from the runway threshold, are shown in figure 14 and discussed below.

Figure 14. Automation sequence from 1,850 to 1,330 ft msl.

After passing the DUYET waypoint, the PF called out and set the MCP altitude to 3,000 ft, the planned altitude in the event of a go-around. After passing the 5 nm point, the PF commanded flaps 20; the PM moved the flap lever to the flaps 20 position; and the PF set the MCP speed to 152 knots (panel A of figure 14), the target speed for flaps 20.[93] The PF then commanded flaps 30, but the PM delayed setting them to the flaps 30 position because the airspeed had not yet slowed to below the flaps 30 limit speed.

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[93] The PF correctly determined the target speed for flaps 20 by following the procedure as described in the 777 FCOM of adding 20 knots to V_{ref} (132 + 20 = 152 knots).

About 13 seconds after the PF commanded flaps 30 and 3 seconds before the PM set flaps 30, the AFDS pitch mode changed from V/S to FLCH SPD. By design, the A/T mode simultaneously changed from SPD to THR. Because the MCP-selected speed of 152 knots was less than the airplane's current airspeed of 172 knots (and in FLCH SPD, the AFDS controls speed via elevator pitch commands), the AFDS responded to this mode change by increasing pitch to slow the airplane. Also, the F/D command bars displayed an increase in target pitch. Because the MCP-selected altitude of 3,000 ft was above the airplane's current altitude of about 1,550 ft msl (and in THR mode, the A/T applies thrust appropriate to attain the selected altitude), the thrust levers began to advance to initiate a climb. About three seconds later, the PF disconnected the A/P and manually countered the forward motion of the thrust levers, moving them to the idle position. He then decreased the pitch by pushing the control column forward. As a result of the PF's manual override of the A/T, the A/T mode switched to HOLD, a mode in which the A/T would not move the thrust levers and was not controlling thrust or airspeed.

During a postaccident interview, the PF volunteered that he considered selecting FLCH SPD while descending in V/S mode because the airplane was high and he thought FLCH SPD would cause the thrust levers to move to the idle position and stay there, facilitating a more rapid descent than he could achieve in V/S mode. He added that he was not sure whether he selected FLCH SPD. During a follow-up interview, when informed that FLCH SPD had been selected, he initially reiterated his uncertainty but stated that it did not matter because selecting FLCH SPD would not have affected the functioning of the A/T and its automatic control of the selected airspeed.[94] When questioned further, he stated that he did not believe he had selected FLCH SPD.

Postaccident testing of the MCP and A/T components revealed no system faults that could have caused the transition to FLCH SPD without deliberate pilot action via the MCP. Based on the fact that the PF was flying the airplane and responsible for manipulating the MCP at the time of the mode transition, his recollection that he considered selecting FLCH SPD, and the fact that immediately after FLCH SPD was engaged, the PF disconnected the A/P and counteracted the climb inputs that had just been initiated by the autoflight system, it is likely that the PF selected FLCH SPD. Further, it is likely that he reconsidered his decision when he realized the AFCS was initiating a climb, disconnected the A/P, and then unintentionally put the A/T in HOLD mode by manually resisting the advance of the thrust levers.

When the PF selected FLCH SPD mode on the MCP, he did not announce doing so, as required by the Asiana 777 POM. By design, when the FLCH SPD mode was selected, the following visual changes occurred: the green light on the FLCH push-button switch illuminated, the MCP V/S window dropped the -1,000 fpm value that previously had been selected (because the AFDS mode was no longer V/S), and, as shown in panel B of figure 14, the FMA displayed boxed indications of THR in the A/T position and FLCH SPD in the pitch position. These MCP and FMA indications were important cues to the PM and the observer about the AFDS and A/T mode changes, but neither reported noticing these indications. Another visible cue indicating that

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[94] It was apparent from the PF's interview statements that he did not understand the implications of the A/T mode transitions that occurred as a result of his selecting FLCH SPD. See section 2.4.1 for discussion of the training the pilots received on the A/T system.

the AFDS mode had changed was the increase in target pitch of the F/D command bars, but according to the PM and the observer, they also did not notice this indication.

Because the PM moved the flap lever to the flaps 30 position about 3 seconds after the PF selected FLCH SPD on the MCP, it is likely that at that time, the PM was monitoring the airspeed in preparation for changing the flap setting, which may have been why he missed the cues indicating the AFDS and A/T mode changes. At the same time as the PM selected flaps 30, the PF disconnected the A/P by double-clicking the wheel switch, which prevented the A/P disconnect aural alarm from sounding. The PF did not make the required "manual flight" callout when he disconnected the A/P. However, the disconnection of the A/P was apparently noticed by the PM because he called out "flight director," indicating the change to the AFDS status displayed on the PFDs (panel C of figure 14). About 1.5 seconds later, the PF responded, "check." Between these two callouts, the A/T mode changed from THR to HOLD. Neither pilot called out the change in the A/T mode, which would have been visible as a boxed HOLD annunciation (see panel D of figure 14). In postaccident interviews, no flight crewmember recalled noticing the A/T transition to the HOLD mode. This is not surprising in light of human factors research demonstrating that pilots frequently do not notice mode changes on the FMA, especially those that are unexpected (Sarter et al. 2007, 347-357).

The process of decelerating and configuring for landing would have been much easier, the pace of activities slower, and the workload less if it was not necessary for the PF and PM to both lose excess altitude and slow down after reaching the 5 nm point. Because they had to do both, they encountered a period of increased workload when they were engaged in parallel tasks for an extended period of time during a critical portion of the approach. This, in addition to the PF's failure to make a callout when he selected FLCH SPD pitch mode on the MCP, reduced their ability to effectively crosscheck each other's actions and monitor changes in the status of the autoflight system. The NTSB concludes that the flight crew's mismanagement of the airplane's vertical profile during the initial approach led to a period of increased workload that reduced the PM's awareness of the PF's actions around the time of the unintended deactivation of automatic airspeed control.

After setting the target approach speed of 137 knots in the MCP, the PF commanded, "flight director off." It was Asiana's informal practice to fly visual approaches with the PF's F/D turned off and the PM's F/D turned on, but only after turning both F/D switches off first.[95] In postaccident interviews, the PF and PM stated that the PM followed this practice. However, QAR data indicated that the PM turned off the PF's F/D switch but did not turn off his F/D switch. If both F/Ds had been in the off position at the same time, this would have cleared the AFDS modes and caused the A/T to transition to the SPD mode and resume automatic control of airspeed. However, the AFDS remained active and continued to display the FLCH SPD guidance that the PF had commanded. The PF's and PM's FMAs continued to display A/T HOLD mode, LOC roll mode, and FLCH SPD pitch mode (see panel E of figure 14). The PM's F/D command

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[95] As further discussed in section 2.6.1, the purpose of having the PM's F/D on during a circling approach was to ensure that it would be active in the event of a missed approach. Asiana had an informal practice of also following this procedure on visual approaches.

bars were providing guidance to stay on the localizer and pitch to maintain the commanded 137-knot speed. The PF's F/D command bars were removed.

When the PF's F/D switch was turned off, the airplane's descent rate was about 1,000 fpm. About 2 seconds later, the PM stated "it's high," and the PF responded by pitching the airplane down and increasing the descent rate to capture the desired glidepath. Over the next 8 seconds, the descent rate increased to about 1,500 fpm. When the flight passed 1,000 ft, the PAPI would have been showing a too-high indication of four white lights, and over the next few seconds, the PF increased the descent rate to as much as about 1,800 fpm. The observer called out "sink rate, sir" three times in the next 9 seconds; he later stated this was because the Asiana FOM states that the descent rate must be 1,000 fpm or less below 1,000 ft agl. He further stated that the PF and PM were slow to respond to his sink rate callouts but they did respond, and the sink rate decreased, so he stopped making sink rate callouts.

As the airplane reached 500 ft, the descent rate diminished to about 1,200 fpm. At that time, the PAPI indication was three white lights and one red light showing the airplane was slightly high but approaching the desired glidepath. The thrust levers were still at idle, with N_1 speed about 23%. The airspeed, which had been decreasing rapidly, reached the proper approach speed of 137 knots. The decreasing trend in airspeed then slowed, and the airspeed remained about 135 knots for about the next 4 seconds. Review of recorded flight data showed that about 5 seconds after it descended through 500 ft, the airplane finally attained, but passed through, a 3° glidepath.

Although, at 500 ft, the airplane met some of Asiana's stabilized approach criteria as listed in the 777 POM (including being on target airspeed, in the landing configuration, and on the correct flightpath), it failed to satisfy other criteria. It was descending at greater than 1,000 fpm, and the thrust setting was not appropriate (it should have been about 56% N_1 speed). Because the approach was not stabilized at 500 ft agl, the flight crew should have conducted a go-around. Either the pilots did not notice that these parameters exceeded stabilized approach criteria[96] or they believed that the deviations were minor and could easily be corrected. In either case, the crew's decision to press ahead was not unusual, as industry statistics indicate about 97% of unstable approaches are continued to landing (Burin 2011).

Asiana's POM guidance for visual approaches stated that the PM should call out "five hundred" at 500 ft above the touchdown height, and the PF should respond "stabilized," or "go around." The PM did not make a 500-ft callout, and the PF did not say "stabilized" or "go around." However, about 5 seconds after passing through 500 ft, when the airplane finally attained the desired glidepath and the PAPI was giving an on-path indication of two white and two red lights, the PM made a callout, stating "on glidepath," and the PF replied "check." Thus, the flight crew did not make standard callouts for the mandatory stabilized approach check.

About 5 seconds after the PAPI on-path indication, the airplane descended through about 330 ft, and the PAPI indication changed to three red lights and one white light, meaning the

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[96] See section 2.3.3 for a discussion of the flight crew's monitoring performance.

airplane was now slightly below the PAPI glidepath. All three flight crewmembers later stated in interviews that they were aware of the PAPI indication changing to three red lights but for the 12 seconds between the PM stating “on glidepath” and his next remark, “it’s low,” none of the pilots remarked about the changing glidepath. The PM’s remark of “it’s low” (made as the airplane passed 180 ft, about 17 seconds from impact) could have applied to either the airspeed (which was about 118 knots) or the glidepath since, about 2 or 3 seconds earlier, the PAPI indication had changed to four red lights, showing that the airplane was significantly below glidepath. Both the airspeed indication, which was more than 5 knots below target approach speed, and a PAPI indication of four red lights required a go-around, but the flight crew continued the increasingly unstabilized approach.

In a postaccident interview, the PF stated that he never saw four red PAPI lights. However, FDR data indicate that immediately after the change to four red PAPI lights and the PM’s comment “it’s low,” the PF increased the pitch from 5° to 7.5° by pulling back on the control column. This suggests that the PF interpreted the PM’s comment as referring to low glidepath, that the PF was aware of the low glidepath, and that he attempted to correct the low glidepath by pulling back on the control column.[97]

In a postaccident interview, the PM recalled that he first noticed the airspeed was low (120 knots) about 200 ft and thought at that time that the A/T was not working. FDR data are consistent with his recollection that the airspeed was 120 knots at 200 ft. The observer also recalled noticing that airspeed was low and seeing that the red hatch marks at the bottom of the airspeed tape (the barber pole) were moving up around 200 ft. He estimated that this was 5 or 10 seconds before impact (the airplane reached 200 ft about 18 seconds before impact). The observer did not recall a specific airspeed value at 200 ft.

In a postaccident interview, the PF said he was briefly “blinded” by a bright light similar to a glare or reflection outside the airplane between 500 and 200 ft, and when he looked down, he noticed the low airspeed and the EICAS “airspeed low” caution alert. However, the PF also stated that the bright light was visible only momentarily, that it did not subsequently affect his vision, and that its only effect was to cause him to look at the instrument panel shortly after the quadruple chime sounded. In addition, neither of the other pilots reported seeing a bright light or having it interfere with the performance of their duties. Thus, the visual phenomenon described by the PF seems to have had little effect on the performance of the flight crew, aside from possibly causing the PF to look at the instrument panel. As further discussed below, it is also possible that the PF’s attention was drawn to the instrument panel by the low airspeed alert’s quadruple chime or master caution light.

About 8 seconds after the PAPI indication changed to four red and 7 seconds after the PM recalled seeing the airspeed at 120 knots, the quadruple chime caution aural alert sounded, and the master caution light illuminated. The airplane was about 11 seconds from impact at an

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[97] The PF’s reaction at this point would be consistent with his reaction to the PM’s earlier comment “it’s high” at 11:26:44, after which the PF pitched the airplane down to increase descent rate because they were well above the glidepath (as indicated by four white lights on the PAPI).

altitude of 124 ft and a speed of 114 knots. According to the performance study, after this point, the airplane likely no longer had performance capability to accomplish a go-around.

The PF and PM recalled seeing the accompanying “airspeed low” message on the EICAS. Their attention was likely drawn to the EICAS as a result of the quadruple chime caution aural alert and/or master caution light. The PF and PM also recalled seeing low airspeed indications on the PFD at that time. About 4 seconds after the quadruple chime sounded and 7 seconds before impact, when the airplane was at an altitude of 90 ft and a speed of 110 knots, the PM said, “speed,” and added go-around thrust. Shortly thereafter, the control column reached the full aft position, and the stall warning stick shaker activated. Pitch attitude increased to 12°, and, passing 30 feet, the PM called out “go-around.” Seconds later, the airplane struck the seawall.

The observer recalled that he first noticed airspeed was low when the airplane was about 200 ft but could not recall what speed was displayed at that time. He said he did not advise the other pilots about the low airspeed because the PF was already reacting. He thought this happened about 5 or 10 seconds before impact. However, it was the PM who pushed the throttle levers forward, and he did so about 11 seconds after the airplane passed through 200 ft. In addition, the airplane passed through 200 ft about 18 seconds before impact. Therefore, it is uncertain when the observer first became aware of the low airspeed, but it was probably sometime between 200 ft and the point where the PM moved the throttle levers forward (86 ft). The NTSB concludes that about 200 ft, one or more flight crewmembers became aware of the low airspeed and low path conditions but the flight crew did not initiate a go-around until the airplane was below 100 ft, at which point the airplane did not have the performance capability to accomplish a go-around.

2.3 Flight Crew Performance

2.3.1 Fatigue

The NTSB evaluated a number of criteria, including recent sleep, sleep quality, circadian factors, and time awake to determine whether the flight crewmembers were experiencing fatigue at the time of the accident. There is no evidence that any of the pilots began their duty period with a preexisting sleep debt or fatigue.

In the 24 hours before the accident, the PF, the PM, and the observer obtained about 5.5 hours, 8 hours, and 10.5 hours of sleep, respectively, as compared to their self-reported sleep needs of about 7.5 hours, 7 hours, and 7.5 hours. Thus, the PF received less sleep than normal in the 24 hours before the accident.

The hours of sleep reportedly obtained by each pilot during the 24 hours before the accident occurred in multiple sleep periods. Nonconsolidated sleep is less restorative than consolidated sleep. Thus, although the PM and observer reported obtaining enough total sleep, their recent sleep was fragmented, reducing its restorative value.

In addition, the accident occurred at a time when the PF, PM, and observer would normally have been asleep (about 4.5 hours, 3.5 hours, and 1 hour later than their normal bedtimes, respectively). As a result, the accident occurred during the pilots' circadian trough, a period about midway through the normal sleep period when a person's physiological state of arousal is normally at its lowest. The human body cannot adapt to transiting 8 time zones in the span of 10 hours; therefore, all three pilots were likely fatigued as a result of circadian disruption. Multiple lines of research indicate that cognitive performance is reduced during the circadian trough and that circadian-related performance reductions can be exacerbated by prior sleep loss. Cognitive measures that are sensitive to circadian effects include vigilance, reaction time, processing speed, working memory, and logical reasoning (Goel et al. 2013, 155-190).

The PF made several errors that might be attributable, at least in part, to fatigue. These errors included his selection of FLCH SPD at 1,550 ft without remembering that he had already selected the go-around altitude in the MCP altitude window less than 1 minute earlier, being slow to understand and respond to the observer's sink rate callouts, not noticing the decrease in airspeed between 500 and 200 ft, and not promptly initiating a go-around after he detected the low airspeed condition.

The PM also made several errors that might be attributable, at least in part, to fatigue. These errors included not noticing the PF's activation of FLCH SPD at 1,550 ft or subsequent indications on the FMA, not ensuring that a "stabilized" callout was made at 500 ft, not noticing the decay in airspeed between 500 and 200 ft, and not immediately ensuring a timely correction to thrust was made when he detected the low airspeed.

Although the observer did not make as many errors during the approach, he made a significant error that might be attributable, at least in part, to fatigue. To monitor the approach, the observer had to monitor both PFDs because he could only see the right side of the PF's PFD (not including the airspeed indicator) and the left side of the PM's PFD (not including the altitude indicator). His callouts and recollections during his postaccident interview suggest that he became fixated on the altitude and vertical speed indicators on the PF's PFD and did not adequately monitor airspeed information on the PM's PFD.[98]

In summary, the pilots' reported recent activities indicate that all three pilots were likely experiencing some fatigue at the time of the accident, and each made errors that were consistent with the effects of fatigue. Therefore, the NTSB concludes that the flight crew was experiencing fatigue, which likely degraded their performance during the approach.

Asiana had taken several steps to prevent and mitigate fatigue. These included training pilots (including the accident crew) on the causes and effects of fatigue and strategies for minimizing fatigue, providing flight crew rest facilities (business class seats that reclined flat), and rotating the primary and relief pilots so that the pilots who had most recently napped conducted the approach. In addition, the airline had assigned the observer to monitor the

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[98] The observer stated that he could not see the PAPI lights below 500 ft due to the deck angle, so it is uncertain whether he made an error in not noticing the PAPI change to four red lights.

performance of the primary flight crew during the approach, enhancing the flight crew's monitoring capability. However, despite these countermeasures, the scheduling of the accident flight was likely to result in some fatigue.

The NTSB acknowledges that it would be very difficult, if not impossible, to completely eliminate flight crew fatigue in the operation of all long-distance transmeridian flights. However, it is possible for an airline to collect data on pilot fatigue during line operations and make small adjustments in scheduling and other factors to maximize pilot rest and minimize the occurrence of fatigue during high-workload safety-critical phases of flight. Such an approach is advocated in ICAO guidance materials on the development of fatigue risk management systems (FRMS) (ICAO 2012). At the time of the accident, Asiana was at the preliminary planning stage of developing an FRMS. The NTSB believes that, once developed and implemented, an FRMS could potentially reduce flight crew fatigue during Asiana's long-range transmeridian flights and encourages Asiana to expedite the development of its FRMS.

Encouraging flight crew compliance to operator SOPs, enhancing flight crew training, and improving flight crew interface design might also help to mitigate the effects of fatigue on long-range flight operations. Improvements in each of these areas are recommended in other sections of this report.

2.3.2 Flight Crew Communication

The PF, PM, and observer reported that they had normal crew interactions, callouts, responses, and actions during the accident approach. A review of CVR recordings revealed a relaxed but professional cockpit atmosphere. However, CVR recordings also indicated that the PF did not tell the PM that he was stressed about performing the approach without the benefit of an electronic glideslope to aid him in managing the airplane's vertical path. If the PF had expressed his concern, the PM might have discussed the availability of cues like the altitude range arc or VPI or suggested alternate methods for conducting the approach, such as flying a VNAV approach that would have provided precise vertical guidance via the F/D. The PF was likely reluctant to acknowledge his lack of confidence in this area, and, as a result, the flight crew missed an opportunity to discuss ways that they could have effectively managed the airplane's vertical path.

An evaluation of flight crew communications during the approach also revealed that the flight crew did not consistently adhere to Asiana's SOPs in the area of MCP selections and related callouts.

When the A/P was on, the PF was supposed to make selections on the MCP and accompany these selections with a callout. The PM was supposed to respond "check" and call out every mode change displayed on the FMA. Throughout the approach, the pilots sometimes adhered to this procedure but did not consistently do so. For example, at 1121:12, the PM called "heading select" with no preceding callout from the PF. At 1123:51, one of the pilots selected an MCP speed of 172 knots, but there was no callout from the PF. At 1123:58, the PM called "V/S" with no preceding callout by the PF. At 1125:31, the PM called "one thousand," referring to the

MCP-selected vertical speed, with no preceding callout from the PF. At 1126:32, the PM called "flight director" with no preceding callout by the PF. All of these callouts were accompanied by changes to the MCP. These communications indicate that the PF was not consistently performing both the selection and the accompanying callout when the A/P was on, per Asiana's SOPs.

The pattern of nonadherence to standard procedure involving selections and callouts pertaining to the MCP is likely the reason the PF did not call out "flight level change" when he pushed the FLCH button at 1,550 ft. As a result, and for other reasons discussed earlier, the PM did not notice that FLCH SPD was engaged at 1,550 ft.

A possible reason for the PF's and PM's lack of adherence to procedures may have been a lack of clarity concerning their roles. Confusion about their pilot roles may have been due, in part, to the fact that the PF and the PM were both captains, and the PF was performing the role of captain while the PM was the PIC and the PF's OE instructor for the flight. This may have caused the PF to be more deferential towards the PM than he would have been to an FO, for example, waiting for guidance from the PM before initiating actions and following his lead regarding the initiation of changes to the AFCS and performance of related callouts. In addition, this was the PM's first flight as an OE instructor, so he was new to the role of instructing another captain on the line. His job was to serve as the PIC and coach the PF as needed in terms of how to fly the aircraft while respecting the airline's policies and procedures pertaining to the prescribed roles of the PF and PM during the flight. The PM's inexperience in managing these multiple roles may have made it difficult for him to balance his multiple responsibilities. The NTSB concludes that nonstandard communication and coordination between the PF and the PM when making selections on the MCP to control the AFDS and A/T likely resulted, at least in part, from role confusion and subsequently degraded their awareness of the AFDS and A/T modes.

A review of Asiana's procedures for dealing with MCP selections and related callouts indicated that they would have been adequate if followed. Adherence to SOPs involving communication and coordination can be improved through training. Therefore, the NTSB recommends that Asiana reinforce, through its pilot training programs, flight crew adherence to SOPs involving making inputs to the operation of autoflight system controls on the Boeing 777 MCP and the performance of related callouts.

2.3.3 Flight Crew Monitoring

The flight crew did not adequately monitor airspeed between 500 and 200 ft. This likely resulted from a combination of workload, expectancy, and a coincidence of timing. When the PF inadvertently disabled automatic airspeed control about 1,500 ft, he pulled the thrust levers to idle to counteract the momentary increase in thrust that resulted from the airplane trying to climb to the MCP altitude of 3,000 ft. He incorrectly believed that the A/T would use thrust to target the selected airspeed of 137 knots thereafter, which would have required the thrust levers to remain at or near the idle position for a significant period of time as the airplane slowed from 168 to 137 knots. Therefore, the lack of thrust lever movement between 1,500 and 500 ft was in line with the PF's expectations and likely reinforced his incorrect understanding that the A/T system was controlling airspeed. At the 500-ft stable approach gate for the visual approach, the

PM checked the airspeed and saw that (by coincidence) it was within a couple knots of the target approach speed. The decreasing trend even halted for a few seconds at 134 knots (although the airspeed trend arrow predicted a continued decrease). The fact that airspeed was very close to the target airspeed at 500 ft and stabilized briefly at 134 knots likely confirmed the PM's expectation that airspeed was being controlled automatically.

If the PM had continued monitoring airspeed and thrust, he would have noticed that the airplane was not truly stabilized at the target approach speed. However, the PM's stable approach check occurred between multiple "sink rate" callouts from the observer (which resulted from the PF trying to descend rapidly to attain the desired glidepath by 500 ft), the PM's radio exchanges with ATC obtaining landing clearance, the PM's execution of the landing checklist, and his monitoring of the PF's rapid interception of the glidepath (as indicated by the PAPI). The need to perform these multiple concurrent tasks in a short period of time would have required the PM to perform the stable approach check very quickly, which increased the probability of an error like the one he made. Thus, the quality of the PM's monitoring of airspeed during the stable approach check and his failure to recognize that airspeed was not truly stabilized at the desired approach speed likely resulted from a period of increased workload involving multiple concurrent tasks. This increased workload was created, in part, by task compression resulting from the flight crew's ineffective management of vertical path earlier in the approach.

Below 500 ft, the airplane was getting close to the runway, and it was important to control the airplane precisely and promptly correct any flightpath deviations to ensure that the airplane would be in a position to land safely. Asiana SOPs stated that both pilots were supposed to alternate their visual attention inside and outside the airplane on final approach. Below 500 ft, however, the airplane began to sink below the desired glidepath. Although it was primarily the PF's task to control these parameters, the PM knew that the PF was new to the airplane and likely felt that it was important to closely monitor the PF's performance in these areas. Consequently, both the PF and PM recalled focusing their visual attention outside the airplane (on the runway environment and PAPI) between about 500 and 200 ft. As a result of their focus outside the airplane, they did not notice the continued decrease in airspeed that occurred below 500 ft. The PF appears not to have monitored the airspeed indicator for at least 24 seconds after the airplane descended below 500 ft (until the low airspeed alert activated), and the PM appears not to have monitored the airspeed indicator for about 17 seconds after the airplane descended below 500 ft (until the airplane was about 200 ft).

The observer also demonstrated a delayed recognition of the decaying airspeed in that he did not recognize that airspeed had decreased below target speed until 200 ft or lower. The observer made several sink rate callouts between 1,000 and 500 ft, indicating that he was closely monitoring vertical speed during at least part of the approach. Effective monitoring would have required the observer to frequently alternate his visual attention between vertical speed and airspeed (as well as other sources of information) and mentally compare the values he perceived to desired targets. The observer's delayed recognition of low airspeed indicates deficiencies in his visual scan and/or attention during the approach.

The observer's monitoring performance could have been adversely affected by the same increased workload that affected the PF and PM below 1,000 ft; however, because he was not required to perform many of the activities that they were assigned, his task load was less than theirs. The observer's postaccident interview and investigator observations in the 777 simulator indicated that the observer's view of the instrument panel was partially obscured by materials affixed to the PF's and PM's control wheel clipboards. From his position seated on the center jumpseat, the observer would likely have been able to see only the right half of the PF's PFD (showing altitude and vertical speed) and the left half of the PM's PFD (showing airspeed). This vantage point would not have prevented him from monitoring all necessary sources of information but would have increased the amount of effort required to effectively monitor. It is possible that the observer was fixated on the vertical speed information shown on the PF's PFD as a result of the high descent rates he had previously observed. It is also possible that his monitoring performance, and that of the other flight crewmembers, was degraded by fatigue, which is known to influence attention and increase vigilance errors (Van Dongen et al. 2003, 117-126).

Human factors research has demonstrated that system operators often become complacent about monitoring highly reliable automated systems when they develop a high degree of trust in those systems and when manual tasks compete with automated tasks for operator attention. This phenomenon occurs in both beginner and expert operators and cannot easily be overcome through practice (Parasuraman and Manzey 2010, 381-410). Attentional resources are limited, so shifting them away from automated tasks and toward manually controlled tasks during periods of increased workload can be viewed as adaptive because one of the functions of automation is to ease operator workload. However, the use of such systems has predictable adverse consequences on human performance. Specifically, it reduces monitoring and decreases the likelihood that a human operator will detect signs of anomalous or unexpected system behavior involving the processes under automatic control. In this case, the PF, PM, and observer believed the A/T system was controlling speed with thrust, they had a high degree of trust in the automated system, and they did not closely monitor these parameters during a period of elevated workload. Thus, the flight crew's inadequate monitoring of airspeed and thrust indications appears to fit this pattern involving automation reliance. The NTSB concludes that insufficient flight crew monitoring of airspeed indications during the approach likely resulted from expectancy, increased workload, fatigue, and automation reliance.

2.3.4 Go-Around Decision-Making

As stated earlier, the pilots did not initiate a go-around until reaching an altitude of 90 ft, which was about 7 seconds before the impact. This delay prevented a successful go-around because the airplane was not able to develop the power necessary to climb out in the time available before impact. As shown during testing, a go-around that was initiated 11 seconds before the impact (at an altitude of 124 ft) likely would not have resulted in the ground impact. In fact, the go-around should have been initiated well before that point: when the airplane reached 500 ft and the approach was unstabilized. The previous section discussed the role of insufficient monitoring in the flight crewmembers' failure to execute a go-around between 500 and 200 ft. This section will discuss the possible reasons for their delay in executing the go-around below 200 ft.

Either the glidepath-too-low indication of four red PAPI lights or the airspeed exceeding the low tolerance criterion for a stable approach should have prompted an immediate go-around. The PF indicated that he never saw a PAPI indication of four red lights and that he first noticed the airspeed was low when the “airspeed low” caution alert appeared on the EICAS display. The PM said that he first noticed four red lights and the low airspeed when the airplane was about 200 ft. However, he did not push the thrust levers forward to initiate a go-around until about 11 seconds after the airplane descended through 200 ft. The observer said that he was unable to see the PAPI due to a high deck angle and that he first noticed that the airspeed was low about 200 ft or just before the time when the PM pushed the thrust levers forward.

Available evidence does not support the PF’s report that he did not see a PAPI indication of four red lights. Despite his statement that he never noticed the PAPI indication change to four red lights, he also stated that he was looking at the runway environment, noticed the change to one white and three red, and was very concerned about a change to four red because he believed that would cause him to “fail” his OE training flight. As a result, the PF would likely have been monitoring the PAPI lights very closely. In addition, the PAPI changes from two white/two red to one white/three red then to four red were followed immediately by step-wise increases in the airplane’s pitch. These pitch increases resulted from the PF’s control inputs, suggesting the PF saw and reacted to both changes. It is likely, therefore, that the PF saw the PAPI indication change to four red lights within 1 or 2 seconds after it occurred (at 1127:31 and 219 ft). Thus, he saw the PAPI indication change to four red lights about 11 to 12 seconds before the PM initiated the go-around.

No evidence contradicts the PF’s statement that he was unaware of the low airspeed until the “airspeed low” caution alert message appeared on the EICAS. It is likely that his visual attention was focused primarily outside the airplane below 500 ft because he was manually flying the airplane and attempting to correct a vertical deviation that developed during this period. Therefore, the PF’s statement about his lack of awareness of low airspeed until after the chiming of the low airspeed caution alert is the best available evidence about his awareness of airspeed during that period.

Accordingly, it is likely that the PF and PM were aware of unacceptably low PAPI indications for about 11 seconds, and the PM was aware of an unacceptably low airspeed indication for about 11 seconds before a go-around was initiated. The flight crew’s delay likely resulted from a combination of surprise, nonstandard communication, and role confusion. Both the PF and the PM were under the impression that the A/T had been controlling airspeed for them, and they were surprised and confused when they realized it was not.

Human factors research indicates that reaction time is longer for unexpected than for expected events. When a flight crew is confronted with a sudden, abnormal event, responses are more likely to be delayed or inappropriate. In one study, for example, pilots who encountered an expected low-altitude aerodynamic stall during simulator training responded rather uniformly and quickly (an average of 1.33 seconds), but those who encountered an unexpected stall took much longer to respond (an average of 8.36 seconds). Moreover, there was a broad range of response times to the unexpected stall (from 1.9 to 18.2 seconds) (Casner et al. 2013, 477-485). Thus, the PF's and PM's surprise likely contributed to their delayed reaction.

About a second after the PM noticed the PAPI was displaying four red lights and that airspeed was 120 knots, the CVR recorded the PM saying, "it's low" and the PF responding "yeah."[99] Per Asiana SOPs, the PM should have called out "low glidepath" and "low speed" or simply "go around," so his statement "it's low" was nonstandard. As previously stated, the PF seemed to interpret the PM's callout as referring to the airplane being low on the glidepath because he attempted to correct the situation by pulling back on the control column. Although this would have been an effective solution if power was also added, neither the PF nor the A/T was managing thrust and airspeed; therefore, the application of pitch alone was insufficient to achieve the desired glidepath.

As discussed earlier, the PF was likely aware that the PAPI was indicating four red lights when the PM said "it's low." He would have known that this indication required an immediate go-around. He may have continued the approach because he believed he could correct the vertical path deviation, because he did not want to acknowledge the error and "fail" his OE training flight, or because he was deferring to the PM (a more senior crewmember).

The PF appears to have remained unaware of low airspeed for at least another 7 seconds, until the quadruple chime sounded. Postaccident interviews indicate that at this point, both pilots' eyes were drawn down to the EICAS display where they read the "airspeed low" message. Both then inspected airspeed indications and recognized the urgent necessity of a go-around. At this point, the PF recalled thinking about increasing thrust, but the PM acted first.

The PF said he believed that only the PIC, in this case the PM, could call for a go-around. He said this was company policy resulting from a tail strike event that had occurred when an FO had initiated a go-around. This statement contrasted with Asiana's written policy in the 777 POM, which stated, "The decision to make a missed approach rests with the captain. However, when the co-pilot (F/O) flies the aircraft as PF, the co-pilot (F/O) can make a missed approach." In addition, multiple Asiana managers and pilots said there was no company policy preventing junior crewmembers from initiating a go-around. However, the Asiana FOM states only that the captain has the "authority and responsibility to make a landing or missed approach (go-around)"; it does not address the authority of the FO to initiate a go-around.

The PF's uncertainty about whether he had the authority to make a go-around decision could have stemmed from confusion due to the inconsistent written policy in this area. In either case, the PF's deference to authority likely played some role in the fact that he did not initiate a go-around. The PM, on the other hand, said he believed that the PF was responsible for initiating a go-around. Thus, the PF and PM had differing understandings about whose role it was to initiate a go-around in the event that one was required. The NTSB concludes that the delayed initiation of a go-around by the PF and the PM after they became aware of the airplane's low

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[99] The PM recalled telling the PF they were "slightly low" and applying a little backpressure on the control column when the airplane was on short final approach; however, he recalled that this occurred about 500 ft.

path and airspeed likely resulted from a combination of surprise, nonstandard communication, and role confusion.

2.4 Autoflight System Training and Design

In postaccident interviews, the PF made several statements that indicated he had an inaccurate understanding of some aspects of the airplane's autoflight system. He said that although the A/T could be manually overridden by the flight crew, the A/T system was always working. He stated that pilots normally left the A/T engaged but it was not important whether the A/T system was engaged because the A/T moved the thrust levers automatically to maintain the selected speed. He stated that when the A/T was disconnected, the A/T would move the thrust levers to maintain airspeed. Asked whether the A/T would resume control of airspeed after a manual pilot override in FLCH SPD mode, he said the A/T would resume controlling speed. He said that if the 777 A/T system was turned off and airspeed became very low, the A/T would transition to TO/GA mode, and he believed that the airplane's functionality in this respect was similar to that of the Airbus A320. These statements indicate that the PF had an inaccurate understanding of how the AFDS and A/T interact to control speed in FLCH SPD mode, what happens when the A/T is overridden and the throttles transition to HOLD in a FLCH SPD descent, and how the A/T automatic engagement feature operates.

The complexity of autoflight systems can contribute to faulty mental models of automation logic. The systems installed on airplanes like the 777, for example, contain multiple subsystems. Each of these subsystems has various modes of operation, and these subsystems are intercoupled in various ways. Human factors research involving pilots suggests that they have difficulty comprehending the subtleties of the interconnections between various autoflight subsystems (Billings 1999). These difficulties lead to gaps in pilots' mental models that can be particularly problematic in highly dynamic and/or nonroutine situations (Sarter and Woods 1997, 553-569). The problem of faulty pilot mental models of complex autoflight systems can be alleviated by improving systems training and reducing design complexity.

2.4.1 Autoflight System Training

The PF's Asiana 777 transition training included two instructor-led ground school lessons totaling 6 hours that addressed the 777 autoflight system. The presentations given in these lessons used slides based on screen captures of computer-based training lessons purchased from Boeing. Use of the AFDS and A/T systems was also covered in other ground and simulator lessons. Despite having completed all classroom and simulator training, the PF said he was not confident in his understanding of the system.

Other Asiana pilots and instructors who were interviewed by investigators after the accident also appeared to have inaccurate mental models of AFDS and A/T system functionality in some of the same areas as the PF. A review of the Asiana 777 transition training slides revealed that they did not provide a complete picture of AFDS and A/T system design logic involving the functioning of the A/T in HOLD mode or the availability of minimum speed protection when the A/T was in HOLD mode. For example, a training slide labeled "stall protection features" made the unqualified statement that "autothrottles engage automatically (if armed)." No description was provided of the circumstances when the A/T will not automatically engage. These circumstances, which were listed in the 777 FCOM, include when the AFDS pitch mode is FLCH SPD (as it was during the accident flight) or TO/GA, or the airplane is below 400 ft above the airport on takeoff or below 100 ft RA on approach.

Further, the Boeing 777 FCTM, upon which Asiana based much of its training, did not explain the conditions under which the A/T would not automatically engage. The FCTM recommended A/T use during all phases of flight, including manual flight, and presented a stall protection demonstration that did not include situations when the A/T would not automatically activate. Asiana adopted the FCTM stall protection demonstration in its 777 simulator training, and the PF had observed the demonstration.

During the demonstration, A/P and A/T were disengaged, thrust levers were retarded to idle, MCP-selected speed was reduced below minimum speed on the speed tape, and the airplane was allowed to decelerate into the amber band on the airspeed tape (below minimum maneuvering speed). With no pilot intervention, the A/T system "woke up," engaged in SPD mode, and returned the airplane to minimum maneuvering speed. The PF stated that when he saw the demonstration, he was "astonished" that the airplane would recover by itself from an approach to stall. Because the training the PF received did not adequately describe the circumstances in which the A/T would not automatically engage or expose him to such circumstances, this demonstration likely gave him false confidence that the A/T would provide speed protection at all times.

Additionally, the PF was exposed to some informal, partially accurate information about the interrelationship between the FLCH SPD pitch mode and the HOLD A/T mode during his 777 transition training. An Asiana 777 ground school instructor stated that he had, on three occasions, experienced an "anomaly" in the behavior of the A/T in that it did not automatically engage while in FLCH SPD mode, and he personally explained this experience to pilots in his ground school classes. He stated that the PF had been in a class that had been given this explanation. Apparently, the PF was not able to recognize and apply this knowledge during the accident flight. The instructor's description of these experiences as "anomalies" rather than a result of the system's design logic and the fact that the instructor's comments were not incorporated into Asiana's 777 formal training curriculum indicate that this aspect of AFDS and A/T functionality was not accurately described or adequately emphasized.

The NTSB concludes that, as a result of complexities in the 777 AFCS and inadequacies in related training and documentation, the PF had an inaccurate understanding of how the AFDS and A/T interacted to control airspeed, which led to his inadvertent deactivation of automatic airspeed control.

As previously mentioned, interviews with other Asiana pilots and instructors indicated that they also lacked understanding of AFDS and A/T system functionality in some of the same areas as the PF. Further, the training materials that Asiana was using, including ground school materials and the FCTM, were supplied by Boeing, and these materials are not unique to Asiana but are used by numerous other airlines. Therefore, the NTSB recommends that the FAA require Boeing to develop enhanced 777 training that will improve flight crew understanding of A/T modes and automatic activation system logic through improved documentation, courseware, and instructor training. Further, the NTSB recommends that once the enhanced Boeing 777 training has been developed, as requested in Safety Recommendation A-14-37, the FAA require operators and training providers to provide this training to 777 pilots.

The NTSB also recommends that the FAA require Boeing to revise its 777 FCTM stall protection demonstration to include an explanation and demonstration of the circumstances in which the A/T does not provide low speed protection. Further, the NTSB recommends that once the revision to the Boeing 777 FCTM has been completed, as requested in Safety Recommendation A-14-39, the FAA require operators and training providers to incorporate the revised stall protection demonstration in their training.

It is unlikely that deficiencies in pilot training addressing the underlying logic and operational use of autoflight systems are limited to the 777. A 2012 study conducted by Boeing, the International Air Transport Association, and the International Federation of Airline Pilots Associations surveyed airline transport pilots across multiple regions, airlines, and airplane types. The findings of this survey suggest that incomplete mental models stemming from deficiencies in training are common among pilots transitioning to a new airplane type (Holder 2012). Forty-two percent of respondents reported that autoflight system training was minimal or inadequate. Few (23%) felt comfortable with autoflight system operation during their initial line flight in a new airplane type, and the majority (62%) did not feel comfortable until after they had operated on the line for 3 months or more. Respondents estimated that 42% of their autoflight system learning occurred during line flying, rather than during classroom training or self-study.[100]

In its 2013 study of flight deck automation, the FAA also recommended training enhancements to “improve pilot knowledge and skills for successful flightpath management” (FAA 2013). This report stated that regulatory guidance and requirements determining the content and duration for training and certification should include the following considerations:

- Management and use of automated systems, including achieving and maintaining mode awareness;
- Handling known automated system anomalies or situations known to cause crew difficulties in line operations or in training;
- The decision-making process concerning the selection for applicable modes.

Pilot training could be improved across airplane types to support better pilot understanding of automated systems for flightpath management and their use in operational

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[100] In addition, most pilots surveyed thought autoflight system training could be improved through more attention to automation surprises (57%) and hands-on use of automation in operational situations (52%). A third (33%) thought training could be improved through greater attention to transitions between modes, and slightly more than a quarter (27%) thought training could be improved through greater emphasis on basic knowledge of the system.

situations. Therefore, the NTSB recommends that the FAA convene an expert panel (including members with expertise in human factors, training, and flight operations) to evaluate methods for training flight crews to understand the functionality of automated systems for flightpath management, identify the most effective training methods, and revise training guidance for operators in this area.

2.4.2 Autoflight System Design

As previously mentioned, reducing design complexity is another method by which faulty pilot mental models of complex autoflight systems can be alleviated. Human performance researchers have identified mode awareness as a significant and continuing area of concern in aviation safety (FAA 1996 and 2013). Lack of mode awareness can lead to automation surprise when an automated system causes an airplane to behave contrary to flight crew expectation, and late detection of this behavior can lead to undesirable system behavior. Three factors have been found to contribute to a lack of mode awareness: poor mental models, low system observability, and highly dynamic and/or nonroutine situations (Sarter and Woods 1997, 557-569). All three factors were present in this accident.

The FAA has also highlighted problems involving pilot mode awareness. In its 2013 automation study, the FAA concluded that although current flight deck designs have incorporated many useful safety and operational improvements through new systems and technologies, the highly integrated nature of current flight decks has also increased flight crew knowledge requirements and introduced complexity that can lead to pilot confusion and error (FAA 2013). According to the FAA, short-term strategies for mitigating this problem include enhanced flight crew training, and long-term strategies should involve changes to equipment design.

The 787 and the 777 share a common type rating and have very similar if not identical AFCS logic. Although the FAA accepted the design logic of this system when the 777 was certified in 1995, the FAA and EASA identified the potential need for a design modification during the 787 flight test certification program in 2010. Both organizations expressed concern that the system did not provide minimum speed protection when the AFCS was in FLCH SPD or VNAV SPD pitch mode with the A/T in HOLD mode. They expressed concern about the intuitiveness of this design from a pilot’s perspective and argued that safety would be enhanced by avoiding these exceptions in the design logic. Boeing did not modify the logic of the 787 AFCS as a result of these concerns. Instead, a note was added to the 787 AFM that stated, “During a descent in FLCH mode or VNAV SPD mode, the A/T may activate in HOLD mode. When in HOLD mode, the A/T will not wake up even during large deviations from target speed and does not support stall protection.” The FAA accepted this outcome. Similar information addressing these aspects of A/T automatic activation logic is not included in the 777 AFM but is included in the 777 FCOM. However, the information in the 777 FCOM must be carefully pieced together by the reader because it is provided in two different notes with dissimilar wording that could be interpreted as describing different issues.

The PF's statements indicate that he did not have an accurate understanding of the context in which the A/T would transition to and remain in HOLD mode as a result of manual thrust lever override. Interviews with other Asiana pilots, including some instructors, indicated that they also had inaccurate mental models of system design logic in these areas. Although this was likely due, in part, to inadequate training and documentation, it was also likely due, in part, to the complexity of the design logic and a lack of intuitiveness from a pilot's perspective.

On the accident approach, if the A/T automatic engagement feature had been available, it would have engaged the A/T about 1 second after the airspeed reached 124 knots, which occurred about 21 seconds before impact. The NTSB concludes that if the A/T automatic engagement function ("wakeup"), or a system with similar functionality, had been available during the final approach, it would likely have activated and increased power about 20 seconds before impact, which may have prevented the accident.

System observability is another aspect of design that can influence the likelihood of mode confusion. Observability has been described as "the degree to which events, changes, and anomalies in the monitored process are effectively communicated to the operator through the interface" (Nikolic and Sarter 2007, 553-565). The 777 AFCS communicates AFDS and A/T mode status and changes to the pilot primarily through indications on the FMA. However, as discussed earlier in this report, pilots frequently do not notice mode changes that are presented in this fashion, especially when they are busy with other visual tasks or do not expect a mode change to occur. Although it can be argued that pilots could eventually become aware of such changes by noticing changes to flight parameters that are a result of undetected mode changes, flight crew monitoring of parameters they believe to be under the control of highly reliable automatic systems is imperfect.

Due to the limitations of human attention and monitoring capabilities, modern flight deck systems have been designed to provide flight crews with alerts that draw their attention to critical changes. The 777 flight deck, for example, provides an aural warning alert when the A/P is disconnected. Unless this warning is canceled in advance by double clicking the A/P disconnect button, this alert actively informs the crew that the airplane is no longer controlling pitch and roll, and the flight crew needs to manually manage these parameters or reengage the A/P. Similarly, an aural caution alert sounds if the A/T is disconnected, informing the flight crew that the A/T is no longer controlling thrust. However, the A/T disconnect alert only sounds when the A/T is turned "off." It does not sound when the A/T transitions, either autonomously or as a result of pilot action, to a mode where it is no longer controlling airspeed.

This is potentially problematic when, as occurred in the accident, the A/T transitions to HOLD at a time when the pilot does not expect it to do so. The risk of this occurring is increased by faulty mental models of system logic and by system design characteristics that cause the same pilot inputs to have differing effects depending on the operating mode. For example, manually overriding the throttle levers in V/S pitch mode and SPD A/T mode has no effect on the A/T operating mode, but manually overriding the throttle levers during a climb in FLCH SPD pitch mode changes the A/T operating mode from THR to HOLD. This inconsistency increases the opportunity for pilot error, especially in situations that are nonroutine. The surprise of the accident pilot and the FAA's 787 test pilot regarding A/T response to manual override in FLCH SPD suggests that a pilot's manual intervention during a descent in FLCH SPD does not occur very often. Thus, flaws in a pilot's mental model of system functioning in this particular context may remain undetected for some period of time until the pilot encounters this aspect of the system's functionality. Such encounters are more likely to occur during dynamic, nonroutine situations, like a traffic collision avoidance system advisory during a FLCH SPD descent or a pilot's unintentional initiation of a FLCH SPD climb. During such situations, a flight crew faces increased workload and operational distractions that can reduce systematic scanning of the FMA and flight instruments, thereby reducing the likelihood that such a change will be detected.

This problem might be ameliorated by eliminating the inconsistency of the A/T's behavior when the pilot's manual throttle override occurs in different pitch modes. However, the HOLD mode is so thoroughly integrated into the 777 AFCS that removing this inconsistency might be impractical because it would require a fundamental redesign of the 777 and 787 AFCS. Another possibility would be to provide an alert to the pilot every time the A/T transitions to HOLD mode so that the pilot is more likely to notice that the A/T is no longer automatically controlling airspeed. However, the A/T normally enters HOLD mode many times during a flight, and providing an aural alert every time the HOLD mode activates would reduce the attention-getting property of the alert.

Since the 777 was designed in the mid-1990s, much has been learned about human-centered design of automated systems, and it is possible that a review of lessons learned from this accident and other operational data could provide insights that could lead to improvements in the design of the 777 and 787 AFCS systems, as well as the autoflight systems featured in future flight deck designs. The NTSB concludes that a review of the design of the 777 AFCS, with special attention given to the issues identified in this accident investigation and the issues identified by the FAA and EASA during the 787 certification program, could yield insights about how to improve the intuitiveness of the 777 and 787 flight crew interfaces as well as those incorporated into future designs. The FAA has a process for postcertification evaluations known as a special certification review, which is described in FAA Order 8110.4. The order describes a special certification review as a way to evaluate potentially unsafe design features on previously approved products and includes a list of potential safety problem areas for which a special certification review may be appropriate that includes complex or unique design features and complicated interrelationships and unusual features. Therefore, the NTSB recommends that the FAA convene a special certification design review of how the Boeing 777 AFCS controls airspeed and use the results of that evaluation to develop guidance that will help manufacturers improve the intuitiveness of existing and future interfaces between flight crews and autoflight systems.

2.5 Pilot Training

2.5.1 Visual Approach Training

To conduct a visual approach in a fast-paced busy terminal environment without an ILS glideslope, a flight crew must be able to plan an appropriate vertical profile, select an appropriate control strategy (manual flight or some combination of autoflight modes), and adapt this plan in real time to satisfy externally imposed constraints, such as airspeed restrictions. There are many acceptable strategies for executing such approaches, but all require a flight crew to be able to effectively manage thrust, drag, and pitch to control airspeed and vertical speed, which in turn allow the flight crew to manage energy and remain on a desirable glidepath. Managing drag in such scenarios often requires strategically adjusting the timing of configuration changes, and this must be done while simultaneously respecting the airplane's operating limitations, the airline's operational policies, and ATC clearances. Success requires in-depth knowledge and a broad array of skills. Pilots acquire the requisite knowledge and skills through training, operational experience, and informal exchange of information among other pilots. However, the FAA's 2013 automation study indicated that pilots "often lack sufficient in-depth knowledge and skills to most efficiently and effectively accomplish the desired flightpath management related tasks" (FAA 2013). This accident reflects such a lack of knowledge and skills on the part of the PF.

The PF was an Asiana captain who was transitioning from the A320 to the 777. He was about halfway through OE, which was the final portion of his training before being released to fly the 777 as PIC. The accident flight was the first time he had flown a visual approach without an ILS glideslope in the 777 outside the simulator. During a postaccident interview, the PF expressed a lack of confidence in his ability to fly a stabilized approach without an ILS glideslope, saying he was "stressed" about having to do so.

The accident took place on a clear day with good visibility, and the pilots saw the airport early in the descent. The PF expected to be vectored by ATC to arrive both higher and faster than normal. However, the only ATC restriction the flight received applied to speed, and the flight was given ample distance to become established on an appropriate glidepath. As discussed earlier in this report, the PF did not descend rapidly enough early in the approach, which left the airplane significantly above the desired glidepath as he began the final portion of the approach.

Additionally, once past the 5 nm point, the PF continued to have difficulty achieving the desired glidepath and did not properly use the airplane's AFCS and the FMC's VNAV function to help manage the airplane's glidepath. In fact, his attempt to facilitate a more rapid descent by selecting FLCH SPD pitch mode when the MCP-selected altitude was above the airplane's altitude led to the unintentional deactivation of automatic airspeed control. (When the PF responded to the resulting climb by disconnecting the A/P and manually retarding the thrust levers, the A/T transitioned to HOLD mode.)

Further, because the FMC had been programmed with the LOC 28L procedure, the airplane's VNAV system had computed a 3° glidepath from DUYET to the runway threshold, and a VPI was displayed on both pilots' NDs. Once the airplane crossed DUYET (5.4 nm), the VPI showed the airplane's distance above or below this computed 3° glidepath for the remainder of the approach. However, when asked about the VPI, the PF said he did not make use of it during the approach. These deficiencies suggest that the PF's training in conducting visual approaches without an ILS glideslope was inadequate.

All approaches the PF had flown during his OE training before the accident flight were ILS approaches. During the full flight simulator portion of the PF's 777 transition training, he completed six visual approaches and landings. However, these approaches were accomplished in a standard traffic pattern using timed turns, computed guidance, visual displays, and A/P engagement until the simulator was positioned on final approach about 3 nm from the runway threshold. During one simulator period, the instructor reviewed a "high-energy landing technique" with the PF. Although it was unclear from the training record if a high-energy approach was flown or just discussed, it is unlikely it was flown because the 777 captain transition training syllabus in use at the time did not require a high-energy approach.

As noted above, to fly a visual approach, a pilot must possess a broad array of skills, including the ability to accurately judge the airplane's height, speed, and distance from the runway; anticipate the airplane's altitude and speed changes in response to configuration changes; and make the necessary adjustments to remain stable. However, these skills can atrophy through lack of practice. Throughout his training, the PF used the A/P regularly and typically relied on the ILS glideslope as a cue to proper altitude and flightpath. Thus, he did not have an opportunity to practice the skills necessary to anticipate and control the airplane's flightpath while making a straight-in speed-restricted approach with no ILS glideslope.

The PF's lack of exposure in 777 transition training to straight-in speed-restricted visual approaches played a role in the flight crew's mismanagement of the airplane's vertical profile. Following the accident, Asiana added straight-in speed-restricted approaches to its 777 transition training syllabus.

2.5.2 Instructor Pilot Training

The PM was an experienced 777 captain who was on his first flight as an IP. He had never flown with the PF but observed him fly the takeoff, climb, and cruise from ICN proficiently, and he noted the PF communicated well, confirmed his actions, and made effective callouts and responses. As a result, the PM likely did not see the need to provide the PF with continuous active coaching.

The PF made several errors during the initial part of the approach that should have alerted the PM that more active coaching was needed. After the flight was cleared for the visual approach and given the speed restriction, the PF did not descend aggressively enough. As the airplane remained high on profile, the PM said, "this seems a little high," and the PF, who did not recognize he was not on the proper glidepath, said, "do you mean it's too high?" The PM did not suggest a descent rate or ensure that the PF stayed on the desired glidepath, brief the PF about the need to decelerate and configure for landing as soon as the airplane reached the 5 nm point, or ensure that the subsequently selected vertical speed of -1,500 fpm was used long enough to recapture the desired glidepath. Even though the PF was demonstrating poor awareness of altitude and airspeed, the PM did not intervene or otherwise ensure that needed corrections were made to the airplane's vertical path.

Asiana 777 IP training included ground school, simulator instructor panel operation training, flight instructor training while operating in the right seat, and OE; examinations or checks were also performed for each of these phases of training. A review of the PM's training records and interviews with his OE instructors showed he performed well during training.

A review of the instructor training syllabus showed instruction techniques were taught, as well as execution of normal and nonnormal procedures. The syllabus included several events in which the instructor trainee had to identify poor or dangerous performance by the pilot in the left seat and take action to recover the airplane safely. For example, on two simulator training sessions, the instructor trainee had to take control of the flight from the left seat pilot because of a takeoff overrotation, and on another session, the instructor trainee had to take over because of no flare during landing at 30 ft above the runway. This training should have been adequate to prepare the PM to recognize and recover from the unstabilized accident approach. However, it took place in the structured environment of a flight simulator where the problems were known in advance.

The final stage of instructor training consisted of two flight legs of OE instruction and two flight legs of a check in the aircraft. On the training flights and the check flights, the PM flew the airplane from the right seat but gave no instruction. The PM did not have the opportunity during his OE instructor training to supervise and instruct a trainee while being observed by an experienced instructor. Having the opportunity to supervise a trainee on an actual flight would have improved the PM's awareness of the dynamic and often unpredictable challenges that he would encounter as an OE instructor.

The NTSB concludes that if the PM had supervised a trainee pilot in operational service during his instructor training, he would likely have been better prepared to promptly intervene when needed to ensure effective management of the airplane's flightpath. Therefore, the NTSB recommends that Asiana revise its flight instructor OE qualification criteria to ensure that all instructor candidates are supervised and observed by a more experienced instructor during OE or line training until the new instructor demonstrates proficiency in the instructor role.

2.6 Operations Issues

2.6.1 Cycling of Flight Director Switches

In interviews, four Asiana flight instructors verified that it was Asiana's informal practice, after the A/P was disconnected, to turn both F/Ds off and then turn the PM's F/D back on when conducting a visual approach and that this was taught in training. However, in Asiana's 777 POM guidance on visual approaches and Boeing's 777 FCTM guidance on visual approaches, the subject of F/D switch position was not mentioned.

The FCTM did contain guidance on the conduct of circling approaches, which included F/D switch cycling. It stated that turning both F/Ds off and then turning the PM's F/D back on "allows continued FD guidance for the PM in the event of a go-around when pitch or roll mode is changed." If a circling approach cannot be completed, the flight crew is expected to follow the published missed approach procedure, and F/D guidance can be beneficial. However, there is no instrument missed approach segment following a visual approach. A go-around from a visual approach must be done using visual references until specific instructions are received from ATC.

F/D use is appropriate on both instrument and visual approaches when it provides valid navigational guidance. However, F/Ds cannot provide guidance when the underlying navigational signal or data is not available and should not be displayed when the pilot does not intend to follow it. During a visual approach, when F/D pitch and roll guidance is not needed, it can be a distraction. The FAA's *Airplane Flying Handbook*, page 12-6, "Flight Director/Autopilot," states that when an airplane is being hand-flown, if the F/D is not being used at any particular moment, it should be off so that the command bars are pulled from view.

During the accident flight, after the A/P was disconnected, the PM loosely followed Asiana's informal practice. However, because the two F/D switches were not both in the off position at the same time, the AFDS remained active with the pitch mode FLCH SPD, and the F/D command bars on the PM's PFD provided unneeded pitch guidance. Also, the A/T remained in the HOLD mode. If the PM had turned both F/D switches off, the F/D command bars would have been removed from his PFD, and the A/T mode would have changed to SPD mode and maintained the MCP-selected speed of 137 knots.

A review of the 777 FCOM and FCTM did not identify a specific statement that when the A/P is off and both F/D switches are turned off, the A/T mode goes to SPD and maintains the MCP-selected speed. Although this information can be inferred from FCOM information, it is critical for flight crews to have a complete understanding of the system functionality (as discussed above) and the effects of changes that they can make, particularly during critical phases of flight.

The NTSB concludes that if Asiana had not allowed an informal practice of keeping the PM's F/D on during a visual approach, the PM would likely have switched off both F/Ds, which would have corrected the unintended deactivation of automatic airspeed control. Therefore, the NTSB recommends that Asiana Airlines issue guidance in the Boeing 777 POM that after disconnecting the A/P on a visual approach, if F/D guidance is not being followed, both F/D switches should be turned off. The NTSB further recommends that Boeing revise the Boeing 777 FCOM to include a specific statement that when the A/P is off and both F/D switches are turned off, the A/T mode goes to SPD mode and maintains the MCP-selected speed.

2.6.2 Manual Flight

Asiana's automation policy, as stated in the POM, and interviews with Asiana pilots indicated that the company emphasized the full use of all automation and did not encourage manual flight during line operations. The Asiana POM stated that the PF and PM should make full use of the A/P and the A/T, and the A/T should be used even in manual flight. When interviewed, the Asiana 777 chief pilot supported the statement in the POM, stating that the airline recommended using as much automation as possible. He also agreed with the statement that Asiana pilots obtained most of their manual flying practice during approaches below 1,000 ft agl. Other Asiana pilots interviewed agreed that it was standard practice to leave the A/P on to about 1,000 ft on final approach before disengaging it to complete a manually flown approach. An Asiana contract simulator instructor stated that he believed that pilots avoided flying manually because of concern that they would do something wrong. He stated that manual flying training that included the approximate power settings and pitch attitudes required to achieve a 3° glidepath was not in the training syllabus.

The maneuvering needed to place an airplane on the final approach course and stabilized at the appropriate altitudes prescribed by policy is highly variable and depends on a number of factors, including terrain, traffic, and flight crew interaction with ATC. Autoflight systems are very useful in minimizing crew workload during this maneuvering but function best when preprogrammed with the anticipated course and approach procedure. A change in ATC clearance can significantly revise the planned flightpath, changing the assumptions the crew made and requiring a rapid reassessment of the flight's needed path and energy. A turn toward the airport sooner than anticipated, for example, can make the flight higher and faster than planned, requiring an adjustment in speed, descent rate, and drag required. Such an adjustment can often be made most easily by manually flying the airplane. Manual corrections to flight controls can be made more quickly than A/P inputs, and manual movement of the thrust levers can be made directly and without automatic control input, simplifying the pilot's tasks.

Not all approaches can be flown or completed using automation. For example, some runways have offset LOC approaches, which require that the A/P be disconnected and the airplane aligned with the runway manually. Occasionally, partial runway closures displace runway thresholds by significant amounts, as much as 3,000 to 4,000 ft, requiring A/P disconnect and manual landing. Certain charted visual approaches, such as the Parkway Visual Approach to runways 13L/R at New York's John F. Kennedy International Airport or the River Visual Approach to runway 19 at Ronald Reagan Washington National Airport, require manual flight. Additionally, normal instrument approach navigational signals may experience failures or anomalies requiring the flight crew to disconnect the A/P and continue manually. Pilots must have both training and recent experience in manually manipulating the controls so as to have the skill and confidence to perform manual flight maneuvers safely.

As the airplane slowed after the PF disconnected the A/P (about 81 seconds before impact), the amount of backpressure required to maintain a positive pitch attitude increased due to the airplane being below its trim reference speed of 170 knots, which was due to the PF not using any pitch trim after disconnecting the A/P. Normally, a 777 pilot would use pitch trim to relieve such control forces, but the PF did not do so. Instead, he gradually increased backpressure to maintain pitch. He did not recognize this important tactile cue that the airplane was out of trim. If he had trimmed the airplane when it reached approach speed, the increasing force on the control wheel would have been an unambiguous cue indicating that the airplane was getting slow. Additional practice in manual flight would have prepared him to trim the airplane at approach speed and add power to correct any low airspeed condition he detected as a result of changes in force feel. Had he had more opportunity to manually fly the airplane during training and line operations, he would most likely have used trim, recognized this tactile cue, and corrected the airspeed using power.

Both SAFO 13002 and the FAA's amendment to 14 CFR Part 121 addressed the lack of proficiency in manual flight that has developed as a result of pilot reliance on increasingly sophisticated, highly automated airplanes such as the 777. In this accident, the PF, an experienced pilot who had 9,684 hours of flight time, a background as an instructor for Asiana, and a record of successful completion of ground school and simulator training in the 777, lacked critical manual flying skills. This demonstrates that without greater opportunity for pilots to manually fly the airplane, their airplane handling skills degrade.

Asiana provided statistical data that showed that in 2012, 77.7% of Asiana 777 landings were made manually. However, the data did not indicate at what point the A/P had been disengaged before the manual landing. Based on the interviews referred to above, it seems likely that most flight crews making manual landings did not perform manual airplane handling and maneuvering above 1,000 ft.

By 1,000 ft on final approach, the airplane is typically already stabilized in its landing attitude, configuration, speed, and power setting, and usually only minor adjustments must be made to the flight controls until the flare. Under normal conditions, the flare only requires a 2º to 3° pitch change and thrust reduction. In the case of the 777, even the thrust reduction is performed for the pilot by the A/T. By manually flying only the last 1,000 ft of an approach, pilots do not get to experience the necessary control inputs and feedback performance of the airplane that takes place in climbs, descents, turns, accelerations, decelerations, and configuration changes and do not develop or maintain an ability to "stay ahead" of the airplane, meaning the ability to anticipate the airplane's performance. The NTSB concludes that by encouraging flight crews to manually fly the airplane before the last 1,000 ft of the approach, Asiana would improve its pilots' abilities to cope with maneuvering changes commonly experienced at major airports and would allow them to be more proficient in establishing stabilized approaches under demanding conditions; in this accident, the PF may have better used pitch trim, recognized that the airspeed was decaying, and taken the appropriate corrective action of adding power. Therefore, the NTSB recommends that Asiana Airlines modify its automation policy to provide for more manual flight, both in training and in line operations, to improve pilot proficiency.

2.7 Low Energy Alert

The 777 was equipped with a low airspeed alerting system that was first certified on the 747-400 in 1996 and then certified for the 777-200B in 1997. This system, developed as a result of a safety-related incident reported by a customer airline in 1995,[101] was designed to alert flight crews of decreasing airspeed to avoid imminent stalls. The system, which activates when airspeed decreases 30% into the amber band, was not designed to alert crews that their airspeed had fallen below V_{ref} during approach. According to Boeing, the triggering threshold for the low airspeed alert was selected to avoid nuisance alerts during normal operations and to minimize them during intentional operations at low airspeeds. Minimizing nuisance alerts is an important

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[101] According to Boeing, this incident involved a slow, unintended deceleration during cruise, followed by stick shaker activation and the loss of several thousand ft of altitude during recovery.

consideration in the design of alerts because too many false alerts can increase flight crew response times or cause crews to ignore alerts altogether.

In this accident, the low airspeed alert triggered about 11 seconds before impact, and the PM advanced the thrust levers about 4 seconds later. However, the attempted go-around was not successful because there was not enough time for the engines to develop sufficient power to arrest the airplane's descent before impact. The only way for an alert to facilitate a successful recovery in such a situation would be for the alert to activate at a higher airspeed, so kinetic energy (airspeed) could be traded for potential energy (altitude) until thrust increased, and/or at a higher altitude, so potential energy (altitude) could be traded for kinetic energy (airspeed) until thrust increased.

Boeing classified the low airspeed alert as a "caution" rather than a "warning" alert. In accordance with the 777 centralized crew alerting system, the low airspeed caution alert was designed to sound a master caution alert (the quadruple chime) to draw the flight crew's attention to the EICAS screen, where an "airspeed low" message would be displayed. Boeing expected that this type of alert presentation would result in a flight crew response time of about 4 seconds. (As stated above, in this accident, the PM did respond in about 4 seconds.) Boeing also expected that the low airspeed alert would activate at least 10 seconds before the onset of stall warning for common high-altitude stall scenarios and, therefore, concluded that an expected flight crew response time of about 4 seconds was sufficient to give the flight crew advance indication of the low airspeed condition and reduce the likelihood of a startle response. When the low airspeed alert activated in this accident, however, there was no question that immediate flight crew action was required due to low speed and low altitude. For the accident scenario, therefore, a warning level alert would have been more appropriate in order to reduce flight crew response time. However, even if the alert had been a warning that required immediate flight crew response, it likely would not have prevented this accident. The warning still would have occurred about 11 seconds before impact, and additional time would have been required for the flight crew to take corrective action. By this time, the airplane was in a very low energy condition (low airspeed, low altitude, and low thrust) and, based on the performance study, likely did not have the performance capability to accomplish a go-around. Nevertheless, this accident provides information that can be used as part of ongoing efforts to develop requirements for low airspeed alerting systems during all phases of flight.

The NTSB has long recognized the need for low airspeed alerting systems, having issued recommendations in this area following the investigations of a 2002 accident involving a Raytheon (Beechcraft) King Air A100 (NTSB 2003) and a 2009 accident involving a Bombardier DHC-8-400 (NTSB 2010). Safety Recommendations A-03-53 and -54 asked the FAA to convene a panel of experts to determine whether a requirement for the installation of low airspeed alert systems in airplanes engaged in commercial operations under 14 CFR Parts 121 and 135 would be feasible, submit a report of the panel's findings, and, if feasible, establish requirements for such systems. These recommendations were superseded by Safety Recommendation A-10-12, which urged the FAA to require, for all airplanes engaged in commercial operations under 14 CFR Parts 121, 135, and 91 Subpart K, the installation of low airspeed alert systems that provide pilots with redundant aural and visual warning of an impending hazardous low airspeed condition.

The FAA responded by tasking the Aviation Rulemaking Advisory Committee (ARAC) with developing recommendations for requirements to address low airspeed alerting systems. In February 2013, the FAA received the ARAC report that addressed scenarios for retrofitting low airspeed alerting systems in 14 CFR Part 25 airplanes operating under 14 CFR Part 121. The FAA has completed its evaluation of the ARAC recommendations and determined that low speed alerts are a highly effective safety enhancement for airplanes operating under 14 CFR Parts 121 and 129. On May 9, 2014, the FAA informed the NTSB that it was conducting a cost and effectiveness review for implementing low airspeed alerts, which it expected to complete by December 2014, and that it might pursue rulemaking pending this review. The FAA also said that it would continue to evaluate retrofit requirements for 14 CFR Part 25 airplanes operated under 14 CFR Parts 135 and 91 Subpart K.

The 777's low airspeed alerting system provided both an aural and a visual alert. However, this accident demonstrates that existing low airspeed alert systems that are designed to provide pilots with redundant aural and visual warning of an impending hazard due to low airspeed may not be adequately tailored to alert pilots to an impending hazard due to a combination of conditions (i.e., low airspeed combined with low altitude). During the approach phase of flight, an alert may need to be designed so that its activation threshold takes airspeed (kinetic energy), altitude (potential energy), and engine response time into account. In addition, the alert should take into account expected flight crew response time to an unexpected, critical event, based on the alert's method of presentation. A context-dependent low energy alert system would take all of these variables into account to determine the most appropriate activation threshold and method of presentation.

The terms "low airspeed" and "low energy" are sometimes used interchangeably, and indeed, both terms appear in the ARAC's final report. However, both terms are ultimately linked to situations in which the airplane's angle of attack is approaching or has exceeded a predetermined threshold and therefore are primarily concerned with the airplane's proximity to stall warning and stall. Neither term in the ARAC final report refers specifically to an alert that includes either the airplane's altitude above the ground or thrust setting in the logic that governs the triggering of the alert. Nonetheless, in general the term "energy," when referring to the total energy of the airplane, encompasses both airspeed (kinetic energy) and altitude (potential energy). Furthermore, the engine power level will govern the rate of total energy increase or loss. Therefore, the NTSB will refer to an alert that considers airspeed, altitude, engine power level, and flight crew response time in its alerting logic as a "low energy alert." The NTSB concludes that a context-dependent low energy alert would help pilots successfully recover from unexpected low energy situations like the situation encountered by the accident pilots.

The complexity of a context-dependent low energy alerting system means that the development of such a system needs to carefully balance the requirement for timely alerts in different phases of flight with the requirement to avoid nuisance alerts in all phases of flight. These competing requirements need to be assessed to determine whether the development of such systems is feasible. The FAA's Avionics Systems Harmonization Working Group (ASHWG) was tasked with evaluating the technical feasibility of low airspeed alerting systems. Doing so required the participation of human factors, aviation operations, and aircraft design specialists. Consideration of technological challenges and requirements for low energy alerting systems would require a collaboration across the same specialties. In addition, due to its past work, the ASHWG would likely have a high degree of familiarity with issues related to the development of low energy alerting systems. Therefore, the NTSB recommends that the FAA task a panel of human factors, aviation operations, and aircraft design specialists, such as the ASHWG, to develop design requirements for context-dependent low energy alerting systems for airplanes engaged in commercial operations. Further, the NTSB recommends that Boeing, using the guidance developed by the low energy alerting system panel created in accordance with Safety Recommendation A-14-43, develop and evaluate a modification to Boeing wide-body automatic flight control systems to help ensure that the aircraft energy state remains at or above the minimum desired energy condition during any portion of the flight.

2.8 Survival Aspects

2.8.1 Accident Survivability

2.8.1.1 Evacuation

According to the PM and the cabin manager, after the airplane came to a stop, the cabin manager came forward to the cockpit and asked if the flight attendants should evacuate the airplane, and the PM told her to wait. The PM's outside view was obscured by dust, and he did not fully realize the extent of damage to the airplane. In accordance with Asiana procedures, the PM contacted the ATCT (about 20 seconds after the airplane came to rest). The PM recalled that once he understood that emergency vehicles were responding, he completed the initial steps of the QRH checklist and issued the evacuation order.

By this time, flight attendant L2A had already commanded the evacuation after observing fire outside door 2R. Upon hearing his command, the cabin manager opened door 1L and also began commanding passengers to evacuate. Review of video footage indicated that doors 1L and 2L were opened nearly simultaneously about 1 minute 33 seconds after the airplane came to a stop. Such a lengthy delay was not reported by any of the crewmembers in their statements; however, it is not unusual for human perceptions of time to be erroneous, especially when in disorienting, highly stressful events. The NTSB concludes that the flight attendants acted appropriately when they initiated an emergency evacuation upon determining there was a fire outside door 2R. Further, the delay of about 90 seconds in initiating an evacuation was likely due partly to the PM's command not to begin an immediate evacuation, as well as disorientation and confusion.

The flight attendants who opened doors 1L and 2L reported no problems with their doors or slide/rafts, and both were used during the evacuation. However, the slide/rafts on doors 1R and 2R inflated inside the airplane during the airplane's final impact, injuring and temporarily trapping two flight attendants and rendering the doors unusable during the evacuation.[102] The 1R slide/raft inflated into the forward galley area, which was forward of all passenger seats; because A-zone passengers on the right side of the airplane could cross through the seat rows to evacuate

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[102] For further information about why these slide/rafts inflated, see section 2.8.2.

from door 1L, the inflation had little to no effect on passenger evacuation time. The 2R slide/raft inflated into the midcabin galley and blocked the right aisle between B-zone and A-zone, preventing B-zone passengers on the right side of the airplane from moving forward into A-zone and crossing to door 1L. Instead, these passengers crossed B-zone to reach door 2L creating a bottleneck at door 2L, making it difficult for passengers to move forward to reach door 1L. This helps to explain why the flow of passengers out of door 2L remained constant and heavy for about 2 minutes 30 seconds while the flow of passengers evacuating out of door 1L slowed considerably after about 30 seconds.

Despite fastening her restraint before landing, flight attendant R3 was thrown to the floor and seriously injured during impact, and passengers assisted her from the airplane through door 3R after it was opened by passenger 30K. Therefore, flight attendant L3 was the only crewmember in the back half of the airplane who was capable of assisting with the evacuation. Her attempt to open door 3L was unsuccessful,[103] so she stayed in the area of her jumpseat and directed passengers to evacuate from both doors 2L and 3R.

In summary, the evacuation was accomplished by 5 of the 12 flight attendants (the cabin manager, L1B, L2A, L2B, and L3) using 3 of the 8 doors (1L, 2L, and 3R).

2.8.1.2 Fatalities

Passengers 41B and 41E

Fatally injured passengers 41B and 41E were both seated in triple seat unit 41DEG for landing; passenger 41B was in seat 41D and observed covered with a blanket; and passenger 41E was in her assigned seat and observed not wearing her seatbelt.[104] Passenger 41G was in her assigned seat and reported wearing her seatbelt for landing; she remained in her seat during the impact sequence and sustained only minor injuries.

Seat 41D's seatbelt was found unbuckled and undamaged with no signs of stretch or other evidence of use during the crash. Passenger 41B was found on the right side on the runway, not far from where one of the aft flight attendants was found (see figure 15).

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[103] Door 3L was later opened by an emergency responder after the evacuation.

[104] In postaccident interviews, students seated in the same row as passenger 41E reported that she was not wearing her seatbelt for landing. Flight attendants and passengers reported that at least two flight attendants performed prelanding seatbelt compliance checks in C-zone and were "very diligent" in ensuring compliance with seatbelt regulations.

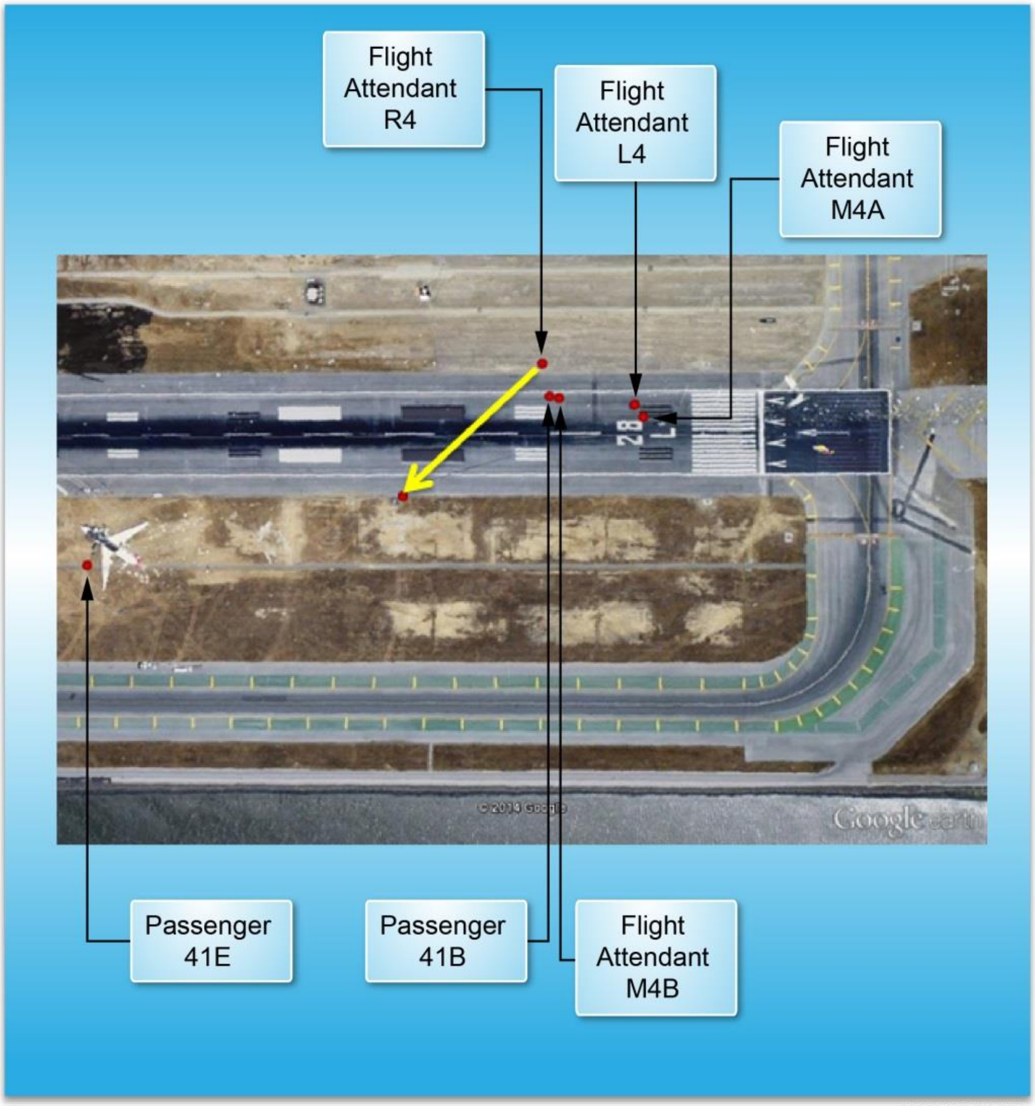

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Figure 15. Location where ejected occupants were found.

Passenger 41E was found in front of the left wing. Three possible scenarios could explain how passenger 41E arrived in front of the left wing after the impact sequence: (1) she arrived at the location under her own power; (2) she was taken to the location by an emergency responder or other passenger after being rescued from the airplane and forgotten; or (3) she was ejected from the airplane and landed at that location.

Seat 41E's seatbelt was found unbuckled and undamaged with no signs of stretch or other evidence of use during the crash. Passenger 41E sustained multiple serious injuries, including a laceration of the aorta without associated rib fractures,[105] which is a deceleration injury consistent with striking internal components of the aircraft or with ejection. She also sustained external abrasions that were similar to others who were ejected from the airplane and inconsistent with a vehicle rolling over her. The severity of these injuries would have precluded self-evacuation from the airplane. Additionally, passenger 41E was visible in a photograph on the ground in front of the left wing early in the evacuation before the arrival of emergency responders, and there were no reports of passengers helping her out of the airplane. Finally, independent observations by multiple medically trained first responders described a person who appeared to be deceased before the first vehicle rolled over her.

The NTSB concludes that passengers 41B and 41E were unrestrained for landing and ejected through the ruptured tail of the airplane at different times during the impact sequence. It is likely that these passengers would have remained in the cabin and survived if they had been wearing their seatbelts.

Passenger 42A

Interviewed passengers made no observations regarding passenger 42A’s seat location for landing or seatbelt status. Review of medical records and first responder statements indicated it was likely that a total of five passengers were extricated from the rear of the airplane. Several firefighters reported extricating an unresponsive female passenger from the area near seat 42A, and video footage indicated that a passenger matching their descriptions was carried from the airplane at 1144:43. This was likely passenger 42A because the other four passengers who required extrication from the back of the airplane can be accounted for by matching their injuries to the descriptions given by first responders. Passenger 42A was one of only two passengers to sustain a skull fracture; however, other passengers who were assigned seats in her immediate area, including passenger 42B seated next to her, sustained only minor injuries in the accident. This suggests that an extremely violent event that was localized to the area around seat 42A caused her injuries. The separation of door 4L, which was torn from the airplane in the final impact, is consistent with such an event in her immediate environment. Further, seat pair 42AB was documented to have rotated completely backward such that the seatbacks were in contact with the floor, which would have left passenger 42A, who was closest to the door, in an extremely exposed position. Although seat 42A’s seatbelt was found unbuckled and undamaged with no signs of stretch or other evidence of use during the crash, this finding is not unexpected given the forces that caused the backward rotation of the seat pair. The NTSB concludes that passenger 42A was likely restrained for landing, and the severity of her injuries was likely due to being struck by door 4L when it separated during the airplane’s final impact.

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[105] This was a horizontal laceration at the level of the ligamentum artieriosum with a significant associated hematoma.

2.8.1.3 Injuries

Aft Flight Attendants

The R4 and L4 jumpseats were ejected from the airplane and found still attached to large pieces of galley structure about 1,100 and 1,300 ft (respectively) down the runway from the airplane. Flight attendants R4 and L4 sustained major skin avulsion injuries, and flight attendant L4 additionally received serious leg, foot, spine, and sternum fractures; these injuries are indicative that these flight attendants were also ejected during the airplane's slide. Although both four-point restraints were undamaged and unbuckled, large blood stains found on the ground beneath both jumpseats indicated that flight attendants R4 and L4 remained buckled in their jumpseats and slid with them down the runway. About 22 minutes after the accident, video footage showed an individual walking from the vicinity of the R4 jumpseat toward the airplane and numerous passengers running to assist the person in the vicinity of a distance remaining marker behind the airplane. Two ASOs described seeing an injured flight attendant who was laying on the ground in this area being attended to by a group of passengers. Based on the ASOs' statements and the video footage, it is very likely that the person seen walking across the runway in the video was flight attendant R4.

Flight attendants M4A and M4B were found on the runway more than 1,000 ft from their jumpseats and sustained injuries including major skin avulsions, fractures, and other serious internal injuries that indicated both were ejected during the airplane's slide. Jumpseat M4B was ejected from the airplane and found about 50 ft behind the aft pressure bulkhead while jumpseat M4A remained in the airplane. Jumpseat M4B's restraint was found still buckled and undamaged, as was the seatpan; therefore, it is not clear how flight attendant M4B became separated from her jumpseat during the ejection. Jumpseat M4A's four-point restraint was unbuckled but had a fractured lap belt shackle and a damaged seatpan, which would have allowed flight attendant M4A to slip down and out of the restraint and seat. Given their final locations, it is likely that both flight attendants were pulled from their jumpseats during the airplane's slide and were then completely unprotected from ground impact and abrasive injuries. Based on their injuries, the locations where they were found, and the statements of first responders, the four aft flight attendants were ejected out of the ruptured tail of the airplane during the airplane's slide down the runway.

Passengers

The serious injuries sustained by passengers were analyzed in an effort to understand how they occurred. Three obvious patterns emerged. First, most of the seriously injured passengers (25/40) were seated in C-zone. This pattern corresponded with the airplane dynamics observed on video footage of the accident, which showed the right wing rise and the airplane spin counterclockwise while sliding down the runway. The aft end of the airplane rose off the ground higher than the rest of the airplane and then forcefully impacted the ground. This essentially caused the occupants in the back of the airplane to "fall" from the greatest height and experience higher g loads than the other occupants in the airplane. Higher g loads naturally lead to more significant injuries.

The greater number of serious injuries in C-zone also matched the interior damage documented by investigators. Virtually the entire floor of C-zone was fractured due to the displacement of subfloor structure during the airplane's final impact. Despite this fact, all but three of the seat units in C-zone remained attached to their respective seat tracks by at least one seat track attachment point. Most of the seat units in C-zone showed some deformation, with the overall pattern showing the seats shifting to the left and rotating aft (backward).

The second pattern that emerged in the analysis of serious passenger injuries was that of the 11 passengers who sustained rib fractures, 10 sustained rib fractures on their left side. Again, this finding fits with the observed video footage and interior documentation. At the time of the airplane's final impact, the airplane was continuing to spin in a counterclockwise direction. Evidence of this rotation can be seen on the exterior of the airplane where the underside of the fuselage bowed out significantly under the right side, causing the decreased doorsill height beneath door 3R. Restrained passengers inside the airplane would have been thrown to the left as the airplane came in contact with the ground and decelerated rapidly. Occupants in their seats would have continued their motion to the left until striking something to stop their motion. For most occupants, the first object they would have contacted would have been the left armrest of their seats with the left lower side of their chest and abdomen. This was the likely mechanism for most of the rib fractures.

A further consequence of the left lateral impact forces appears to be the multiple skull fractures sustained by passenger 11C, a 45-year-old male, who was the only surviving passenger to sustain skull fractures. An examination of the airplane's seating configuration provided insight into how he sustained these injuries. Like the other B-zone passengers, passenger 11C had only a lap belt for restraint, but he was the only passenger who had no seat directly in front of him with a seat to his left front (seat 10B). It is likely that the combined forward and lateral forces acting on his body and the absence of a seat back in front of him allowed passenger 11C's head to strike the back of the very stiff inboard armrest of seat 10B. Any marks from this strike on the armrest were obscured by the postimpact fire. However, passenger 11C's skull fractures included the left frontal skull, left temporal bone, left orbital roof and wall, the very areas that would be expected in such a strike scenario. Thus, it is highly likely that passenger 11C's serious head injuries were caused by striking the inboard armrest of seat 10B. The NTSB concludes that the dynamics of the impact sequence in this accident were such that occupants were thrown forward and experienced a significant lateral force to the left, which resulted in serious passenger injuries that included numerous left-sided rib fractures and one left-sided head injury.

The basic principle of 16*g* seat crashworthiness is that in addition to the seat pan, the seatback in front of the occupant serves as an impact absorber. The seatback is designed to "break over" when impacted from behind, slowing the occupant's head acceleration and keeping it within a survivable envelope. For seats to be certified, the FAA requires testing using a crash test dummy to measure head acceleration to discern the level of head injury that might be sustained at different crash loads. In an accident with purely longitudinal deceleration, restrained occupants with open space in front of them would flail forward around the lap belt, but critical head decelerations may be avoided because there would be no object to strike. However, in this accident, the dynamics were such that occupants were thrown forward and experienced a significant lateral force to the left.

While current FAA dynamic seat certification requirements do include testing row/row seat interactions with seats positioned slightly off the longitudinal axis, they would not likely approximate the forces encountered in this accident, and it is not clear how many different seat arrangements would need to be tested. The NTSB is aware of at least one technology—air bag seatbelts—that is already in service on some commercial airplanes and could potentially mitigate the type of injury sustained by passenger 11C. Therefore, the NTSB recommends that the FAA conduct research that examines the injury potential to occupants in accidents with significant lateral forces, and if the research deems it necessary, implement regulations to mitigate the hazards identified.

The third pattern that emerged in the analysis of serious passenger injuries was a high number of serious injuries to the high thoracic spine.[106] The majority of passengers who sustained spinal injuries (20/24) were seated in C-zone. Many of these passengers suffered more than one spinal injury including compression fractures of multiple vertebrae and ligament injuries spanning several levels. A total of 17 passengers suffered 43 injuries within the thoracic spine; 31 of these injuries occurred in the high thoracic spine. Five passengers experienced both a sternal fracture and high thoracic spine injuries. Generally, fractures of the upper thoracic spine are rare because of the thoracic spine's relatively protected and immobile position within the thoracic cage. The exact mechanism of compression fractures of the upper thoracic spine is not well understood. Because of the normal curvature of the lumbar spine, vertical loads applied while in a seated position typically cause compression fractures in the high lumbar spine or at the junction between the thoracic and lumbar spines; only a few such lumbar spine injuries occurred in this crash.

Although the exact mechanism causing these high thoracic spine injuries is not known, the combination of multiple, highly dynamic impacts and the ability of the upper body to flail about the lap-belted pelvis may have resulted in significant loading of the upper thoracic cage at the time of the final impact. The NTSB concludes that the reasons for the high number of serious injuries to the high thoracic spine in this accident are poorly understood. Therefore, the NTSB recommends that the FAA conduct research to identify the mechanism that produces high thoracic spinal injuries in commercial aviation accidents, and if the research deems it necessary, implement regulations to mitigate the hazards identified.

2.8.1.4 Accident Survivability Summary

A total of six occupants (two of the three fatally injured passengers and the four seriously injured aft flight attendants) were ejected from the airplane during the impact sequence. The four aft flight attendants were likely wearing their restraints but were ejected due to the destruction of the aft galley, which resulted in severe damage to jumpseat M4A and the ejection of jumpseats R4, L4, and M4B. In contrast, none of the passenger seat units were ejected from the airplane. As stated above, had the two ejected passengers been restrained, they likely would have survived the accident.

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[106] From the head down, the spine consists of 7 vertebrae in the cervical (neck) area, 12 in the thoracic (chest) section, and 5 in the lumbar (low back) area. Within the thoracic section, the 8 upper vertebrae constitute the high thoracic spine.

The airplane's structure and seats absorbed a tremendous amount of energy, which, despite multiple spinal fractures, resulted in a complete lack of passenger paralyzations. Only two passengers who were not ejected sustained skull fractures, and one of those two was able to self-evacuate. Protecting people to the point they can get off the airplane by themselves and do not need to be rescued is one of the main goals of the FAA's crashworthiness program. Despite the catastrophic nature of the crash, the airplane provided protection to the extent that 99% of the occupants survived and 98% of the passengers were able to self-evacuate.

2.8.2 Slide/Raft Performance

2.8.2.1 Slide/Rafts 1R and 2R

As part of the effort to explain the inadvertent inflation of the 1R and 2R slide/rafts inside the cabin, a detailed examination of the release mechanisms of all the airplane's slide/rafts was performed. While there was no damage to the 1L and 2L release mechanisms, the other six release mechanisms were all damaged with the 2R, 3R, and 4R release mechanisms sustaining damage that was described by the slide/raft manufacturer as "catastrophic."

In an effort to replicate the type of damage to the slide/raft release mechanisms that was observed, two series of destructive tests were performed. In the first series of tests, exemplar release mechanisms were subjected to increasing static tensile loads. The release mechanisms failed under *g* loads that were calculated to be three to four times higher than the loads required for certification of the slide/rafts. In the second series of tests, exemplar slide/raft packs were subjected to increasing dynamic loads. The release mechanisms of those slide/rafts failed at *g* loads of about twice the certification requirement in the down direction and about four times the certification requirement in the inboard direction.

Due to the extremely complex nature of the airplane's movements after impact with the seawall and a lack of reliable FDR data shortly after the initial impact, insufficient information was available to calculate the forces experienced by the airplane and occupants during the accident. However, as a result of the findings from both sets of destructive tests, it is evident that the forces experienced by the slide/rafts during the impact sequence far exceeded their certification limits, leading to overload failures of the slide/raft release mechanisms on the 1R and 2R slide/rafts. Measurements made after the testing indicated that once released from the packboard, despite its 65-inch inflation cable, a slide/raft would only need to fall inboard and move about 6 inches for the inflation cable to release from the valve on the inflation cylinder. The NTSB concludes that the release and inflation of the 1R and 2R slide/rafts inside the airplane cabin was a result of the catastrophic nature of the crash, which produced loads far exceeding design certification limits.

Given the critical nature of these evacuation devices and their proximity to essential crewmembers, slides and slide/rafts must be certified to sufficient loads so that they will likely function in a survivable accident. Although this exact accident scenario is unlikely to occur again, the NTSB believes that the data obtained during this accident investigation could prove useful for future slide/raft design. Therefore, the NTSB recommends that the FAA analyze, in conjunction with slide/raft manufacturers, the information obtained in this accident investigation and evaluate the adequacy of slide and slide/raft certification standards and test methods specified in FAA regulations and guidance materials. If appropriate, modify certification standards and test methods for future slide and slide/raft design based on the results of this evaluation.

2.8.2.2 Slide/Rafts 3L and 3R

About 20 minutes after the last passenger had been rescued, door 3L was opened by an emergency responder, and the 3L slide/raft pack fell about 53 inches onto the ground and did not inflate. When door 3R was opened by a passenger during the evacuation, the 3R slide/raft pack fell about 17 inches onto wreckage below the door sill and did not inflate. Both door sill heights were less than the 65-inch minimum distance required to increase the tension on the inflation cables sufficiently to open the valves on the inflation cylinders. Because the door sill heights were less than 65 inches, the 3L and 3R slide/rafts did not fully deploy and inflate.

2.8.2.3 Slide/Rafts 4L and 4R

Door 4L was torn from the doorframe and found on the ground outside the airplane. The door 4L slide/raft was found still connected to the girt bar in the area that had been the aft galley with the inflation cylinder empty and ingested material in both aspirators. This indicated that the 4L slide/raft came free from its packboard at some point after the airplane’s initial impact and attempted to inflate inside the cabin, likely due to the destruction of the floor of the aft galley area.

The 4R slide/raft’s girt bar was attached to the floor fittings; however, unlike the 4L slide/raft, the 4R slide/raft’s girt was torn. The slide/raft was found near the break in the aft pressure bulkhead with the pressure cylinder fully charged, and the cylinder safety pin was found installed in the valve. Records indicated that the most recent maintenance on the airplane that would have required installation and later removal of the safety pin took place in December 2012, and it is likely maintenance personnel installed but did not remove the safety pin at that time. Because maintenance personnel installed and then failed to remove the inflation cylinder safety pin, the 4R slide/raft would not have been functional in the event it was needed for an evacuation.

In response to the finding of the safety pin installed in the inflation cylinder of the 4R slide/raft, the FAA conducted ramp inspections of airplanes operated by Part 129 air carriers and found no similar discrepancies. Additionally, Asiana changed its slide/raft maintenance procedure from issuing a single work order per airplane for the installation and removal of slide/raft safety pins to issuing two separate work orders per slide/raft (one for installation and one for removal).

2.8.3 Emergency Response

2.8.3.1 Firefighting Tactics and Use of High-Reach Extendable Turrets

SFFD-AB firefighting tactics accomplished the primary ARFF purpose by engaging the fire and protecting the egress path for passengers. Firefighters also performed a successful interior attack inside the cabin of the airplane. Three firefighters took initiative and entered the cabin with a handline through door 2L. They checked the cabin for occupants, found five injured passengers in the back of the airplane, and with the assistance of SFPD personnel, rescued them amid conditions that were rapidly deteriorating as the postcrash fire spread. It is likely these passengers would have died from the effects of the postcrash fire had they not been extricated by the firefighters and police officers. As further discussed below in section 2.8.3.3, the successful rescue of these five passengers who were unable to self-evacuate amid rapidly deteriorating cabin conditions was possible because the airport's staffing level provided the opportunity for simultaneous interior and exterior fire attacks.

The ARFF response could have been improved, however, in that the HRET-equipped vehicles (Rescue 9 and 10) were not used effectively in the initial response to this accident. About 1 minute after initially arriving on scene, the crew of Rescue 9 decided to reposition from a 1 o'clock position to the left rear and, eventually, the right rear of the airplane. However, from these positions, Rescue 9 could neither effectively apply agent to the fire near door 2R nor protect an evacuation path for passengers. Additionally, the path used to reposition Rescue 9 (around the nose and down the left side of the airplane) took the truck into the area where passengers and crew were still evacuating, increasing the risk of a vehicle strike (although one did not occur at that time). Eventually, Rescue 9 moved to a 3 o'clock position near the airplane's right wing, and its HRET was first used to pierce the fuselage and dispense agent near door 2R about 20 minutes after it arrived on scene.

Rescue 10 arrived on scene about 1 minute after Rescue 9, and the driver chose to take a 10 o'clock position near the airplane's left wing tip. After about 4 minutes, Rescue 10 moved closer to the area of the missing left engine and applied bursts of foam for about 3 minutes, creating a foam blanket to protect against ignition of leaking fuel. However, Rescue 10 then returned to a position farther from the fuselage near the left wing tip, where it could not effectively apply agent to the growing fire in the midcabin area. Eventually Rescue 10 moved closer to the fuselage, and Rescue 10's HRET was first used to pierce the fuselage and dispense agent near door 2L about 20 minutes after it arrived on scene.

The positioning of both of SFFD's most sophisticated vehicles near the left wing and aft areas of the airplane rendered them incapable of direct fire attack. There was a time window between about 1133 and 1144 when the exterior fire was knocked down or extinguished, and an HRET vehicle's forward-looking infrared camera could have provided firefighters useful information about the status of an interior fire, which had already ignited inside the cheek area of the airplane below door 2R. Had an operator identified the interior fire below door 2R, the

HRET's skin-penetrating nozzle could have been used to inject agent into the airplane's cheek area below the floor, potentially arresting or preventing the fire's spread into the cabin.[107]

Additionally, neither HRET was used until after the last passenger was extricated from the back of the airplane (about 1147), well after it was amply evident that the interior of the airplane was fully involved with fire. The driver of Rescue 10 indicated in his postaccident interviews that he waited for an "all clear" from the firefighters inside the airplane before piercing the airplane; the assistant deputy chief in charge of SFFD-AB confirmed that at the time of the accident, SFFD-AB had no policy on when to use an HRET to pierce an airplane.

It is not certain whether a more rapid attack using the HRETs could have extinguished or slowed the spread of the interior fire. However, FAA research has clearly demonstrated the effectiveness of using an HRET to aggressively fight an interior fire and increase occupant survivability. AC 150/5210-23 provides guidance on the use of HRETs and states that testing has shown that an HRET with a skin-penetrating nozzle can control and contain fire from spreading, reduce high cabin temperatures, and provide rapid smoke ventilation. Although the AC provides information on how and where to pierce an airplane, it does not include any guidance to firefighters on when to pierce.

In summary, neither HRET-equipped vehicle was used to the best of its capabilities in the initial fire attack. This was initially due to improper decision-making and vehicle positioning on the part of the ARFF crewmembers. Once the vehicles were out of position, command personnel failed to properly reposition them such that they could be most effectively used. These errors, combined with the lack of guidance on when to use an HRET to pierce an airplane, led to the spread of the interior fire and the eventual destruction of both A-zone and B-zone.

The NTSB concludes that clearer guidance is needed to resolve the concern among airport fire departments and individual firefighters that the potential risk of injuring airplane occupants while piercing aircraft structure with a skin-penetrating nozzle outweighs the potential benefit of an early and aggressive interior attack using this tool. The NTSB acknowledges that the issue is complex. Therefore, the NTSB recommends that the FAA and the ARFF Working Group work with equipment manufacturers to develop and distribute more specific policies and guidance about when, how, and where to use the HRET's unique capabilities.

2.8.3.2 Medical Response Issues

Emergency Buses

Multiple requests were reportedly made for the airport's two emergency medical buses to respond to the scene; however, despite procedures in the airport's emergency procedures manual indicating that ASOs would deliver them, neither of the medical buses arrived at the accident

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[107] It is unknown whether the HRET operator would have pierced the airplane below floor level, but it is unlikely given SFFD-AB's operating guidance, which was to wait until all passengers were extricated from the airplane before piercing.

site. As a result, there was initially a shortage of backboards for the seriously injured passengers at the scene. Although the initial shortage of backboards was eventually remedied by the arrival of mutual aid medical vehicles with additional backboards, the NTSB is concerned about this lack of adherence to the airport's emergency plan.

When questioned after the accident about why the buses did not respond to the scene, the airport's chief operating officer reported that they were not driven to the scene by an ASO because all of the ASOs were busy with other duties, such as escorting mutual aid vehicles to the accident site. The SFO chief operating officer further stated that in the event of an Alert 3 at the airport, the specifics of the event determined what specific equipment needed to be deployed, and the medical buses would be delivered when requested by the incident commander. This response contradicts the airport emergency procedures manual, which stated that ASOs would deliver the buses "early in the response sequence." This suggests that the timeliness of getting the buses to the scene of a mass casualty event may not have been appropriately prioritized by SFO airport operations staff and/or the ASOs were overtasked in the emergency procedures manual.

Additionally, when the buses eventually responded to the airport terminal for secondary passenger triage, it was discovered that only one bus was operable, and several ASOs remarked about a lack of mechanical reliability with the 29-year-old buses before the accident. Further, the NTSB learned that the monthly emergency drills conducted by the airport did not include deployment of the buses either as a matter of routine or as part of the unique scenario being evaluated. The use of the buses in these drills would have helped to reinforce the utility of these resources in mass casualty events, and as a result, SFO airport operations staff may have placed a higher priority on responding with the emergency medical buses to the accident site. The NTSB concludes that medical buses were not effectively integrated into SFO's monthly preparation drills, which played a part in their lack of use in the initial response to the accident and delayed the arrival of backboards to treat seriously injured passengers.

In its posthearing submission, the City and County of San Francisco stated that it has budgeted for the purchase of two dedicated SFFD-AB mass casualty unit vehicles, each holding 250 backboards. According to its submission, one vehicle is to be purchased in 2014/2015, and the second is to be purchased in 2015/2016. The NTSB believes that the purchase of new mass casualty supply vehicles and the decision for SFFD-AB (rather than the airport) to maintain and operate the vehicles will enhance the capability of the on-airport medical response. To ensure that all vehicles are appropriately prepared, the NTSB recommends that the City and County of San Francisco routinely integrate the use of all SFFD medical and firefighting vehicles in future disaster drills and preparatory exercises.

Triage of Passenger 41E

Of the four responders who saw passenger 41E before she was struck by any ARFF vehicles, two had the necessary medical training and were in a position to triage her. About 1137, there was a period of between 30 and 45 seconds when the passenger's location had been identified and firefighters were in her immediate vicinity before she had been covered by foam or rolled over by a vehicle.

At the NTSB's investigative hearing, the assistant deputy chief in charge of SFFD-AB stated that the firefighters' training and experience led them to the determination that she was "obviously deceased," and they defaulted to the higher priority task of performing a rescue. However, the NTSB notes that there was a complete lack of blood around the passenger and that her body was not disfigured or dismembered in any way. Further, video evidence shows that there was adequate time for a brief triage examination for respiration, perfusion, and mental status that would not have significantly affected the preparations for the interior search. Although at least two firefighters had both the time and opportunity for triage to be performed on passenger 41E to verify their visual assessment of her condition, they did not do so.

In this case, only one passenger was at significant risk of being rolled over by a vehicle due to her close proximity to the burning airplane, and there was an opportunity for triage; however, there are other accident scenarios where many injured persons could surround an accident airplane. The FAA's position is that the primary purpose of ARFF is to begin a concentrated effort to knock down an aircraft fire so that crew and passengers will have a safe evacuation route. The ARFF personnel will be augmented by a mutual aid response from off-airport sources to provide personnel for rescue and medical triage purposes. The NTSB agrees with the FAA that responding ARFF personnel should focus on active fire suppression, maintaining an escape path for occupants, and occupant rescue as appropriate. However, the NTSB was unable to locate any guidance or training materials that specifically address the issue of task prioritization or how ARFF personnel should deal with the seriously injured or deceased persons who may be in the immediate vicinity of an accident airplane.

In his interview, the assistant deputy chief in charge of SFFD-AB stated that throughout their training, firefighters were trained to try to maintain anything that was a potential crime scene and to disturb things as little as possible, including obviously deceased passengers. He thought this training might explain why his personnel did not move passenger 41E. Neither at the time of the accident nor at the time of his interview was there a policy on the movement of deceased victims. In talking with other ARFF chiefs about the topic, the assistant deputy chief could not find another department that had a policy on these topics. In a January 16, 2014, letter to the ARFF Working Group, the assistant deputy chief requested that the group convene to develop standard protocols for addressing deceased victims in ARFF operations. Also, in a letter to the San Mateo County Coroner, the assistant deputy chief requested any recommended protocols for the removal or retention of bodies at risk of being struck or rolled over by a vehicle during ARFF operations. The NTSB concludes that guidance on task prioritization for responding ARFF personnel that addresses the presence of seriously injured or deceased persons in the immediate vicinity of an accident airplane is needed to minimize the risk of these persons being struck or rolled over by vehicles during emergency response operations. Therefore, the NTSB recommends that the ARFF Working Group work with medical and medicolegal professional organizations to develop and distribute guidance on task prioritization for responding ARFF personnel that includes recommended best practices to avoid striking or rolling over seriously injured or deceased persons with ARFF vehicles in a mass casualty situation.

Overall Triage

Given the large size of the accident site and the large number of seriously injured occupants, SFFD and the responding mutual aid agencies effectively and capably triaged more than 300 occupants in a timely manner. All occupants were transported from the accident site within about 90 minutes of ARFF's arrival on scene, and 192 injured occupants were transported to local hospitals. On July 7, 2013, the chief of surgery at San Francisco General Hospital commended the triage and appropriate prioritization of patients that the hospital received. The NTSB concludes that the overall triage process in this mass casualty incident was effective with the exception of the failure of responders to verify their visual assessments of the condition of passenger 41E.

2.8.3.3 Staffing

Seven SFFD-AB ARFF vehicles responded to the accident initially, and eventually at least 23 SFFD-AB ARFF personnel arrived on scene. This equipment level greatly exceeded the FAA minimums established in 14 CFR 139.317. Because of the amount of available ARFF vehicles and personnel, the SFFD-AB was able to simultaneously perform exterior and interior firefighting. Particularly, the extrication of the five passengers in the back of the airplane was successful because the airport's staffing level provided the opportunity for multiple firefighters to perform an interior fire attack and search for injured occupants while other firefighters simultaneously performed an exterior suppression attack.

The issue of ARFF staffing levels at airports is not a new one. After an accident in Little Rock, Arkansas, in 1999, the NTSB issued Safety Recommendation A-01-65, which asked the FAA to amend 14 CFR 139.319(j) to require a minimum ARFF staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers. The FAA responded by asking the ARAC to establish an ARFF requirements working group. The working group reviewed 139.319 ARFF requirements, including ARFF staffing levels. On June 23, 2009, the ARAC stated the committee was unable to reach a consensus on the findings.

According to the FAA, due to the lack of a consensus from the ARAC, it sponsored a research project through the Airport Cooperative Research Program (ACRP) that reviewed air carrier passenger aircraft accidents from 1989 through 2008 to determine if changes to ARFF standards would have reduced the number of fatalities or serious injuries resulting from these accidents. Completed in January 2011, ACRP Project 11-02, Task 12, "Risk Assessment of Proposed ARFF Standards," concluded that a change in ARFF staffing standards would not have reduced fatalities or serious injuries in any of the accidents that were reviewed. The FAA agreed with the findings and did not amend Section 139.319(j). Therefore, the NTSB classified Safety Recommendation A-01-65 "Closed—Unacceptable Action" on October 28, 2011.

As stated earlier, the FAA does not require a specific number of ARFF personnel to staff an airport; rather an Index E airport is required to have three vehicles carrying an adequate amount of extinguishing agent. This requirement could be met with only three vehicle drivers. It is fortunate that most (if not all) Index E airports in the United States are staffed with sufficient ARFF personnel to accomplish an interior fire attack, if needed; however, this is not the case at many small and midsize US airports. Therefore, passengers involved in an aviation accident at a smaller airport may not be afforded the same level of emergency response that the passengers of flight 214 had. The NTSB concludes that the SFFD's ARFF staffing level was instrumental in the department's ability to conduct a successful interior fire attack and successfully rescue five passengers who were unable to self-evacuate amid rapidly deteriorating cabin conditions. Although the FAA did not amend 14 CFR 139.319(j) in response to Safety Recommendation A-01-65, this accident again demonstrates that the need remains for ARFF staffing levels to be sufficient to allow for interior firefighting and rescue.

The NTSB notes that the ARFF Working Group, which is a nonprofit international organization that facilitates the sharing of ARFF information between airport firefighters, municipal fire departments, and others concerned with aircraft firefighting, has considerable expertise regarding all aspects of ARFF. Therefore, the NTSB recommends that the ARFF Working Group develop a minimum ARFF staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers. Further, the NTSB recommends that the FAA, once the minimum staffing level has been developed by the ARFF Working Group, as requested in Safety Recommendation A-14-60, amend 14 CFR 139.319(j) to require a minimum ARFF staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers.

2.8.3.4 Incident Command

When SFFD city supervisory personnel arrived about 24 minutes after the accident, a city assistant chief assumed incident command and assigned a city battalion chief as fire attack supervisor. Neither of these individuals had any previous experience working at an airport, nor had they been involved in a disaster exercise at SFO. When reviewing the video footage recorded on a helmet-mounted digital video camera worn by the fire attack supervisor, the NTSB noted that some of his decision-making reflected a lack of ARFF knowledge and training.

For example, while personnel from one of the SFFD-AB vehicles (Rescue 37) were applying agent through the airplane's windows near door 2L, the fire attack supervisor instructed the vehicle's driver to discharge the agent through the 2L door instead. The fire attack supervisor was apparently unaware that there was a bulkhead inside the door that limited the effectiveness of applying agent through the door.

Additionally, when approached by an SFFD rescue squad requesting to conduct a limited search inside the back of the airplane, the fire attack supervisor initially denied their request, stating that he had been notified everyone had already evacuated and remarking that it was not possible that anyone was still alive inside the airplane. Although it is always a difficult decision whether to send responders into harm's way, there was no fire in the back of the airplane, the rescue squad had specialized training, and the final passengers had been extricated from the rear of the airplane only 15 minutes earlier.[108] Due to the persistence of the rescue squad, the fire attack supervisor eventually relented and allowed the search to proceed. A fire attack supervisor with ARFF training would likely have had a better understanding of the potential for survivability inside a burning airplane and either ordered or agreed to the search without delay.

Further, when notified that four "cabin crew" were missing, the fire attack supervisor made statements indicating that he considered the missing "cabin crew" to be the flight crewmembers and took subsequent actions based on that erroneous assumption, including ordering a search of the cockpit. It is also clear that he lacked an appreciation of the strength and thickness of cockpit windows by ordering one be broken from a ladder when door 1L was already open and would have provided quick access to the cockpit.

In summary, the NTSB is concerned that the arriving incident commander placed a nonARFF trained officer in charge of the fire attack in this accident. The fire attack supervisor made statements and decisions that reflected a lack of ARFF knowledge and training. The NTSB concludes that although no additional injuries or loss of life were attributed to the fire attack supervisor's lack of ARFF knowledge and training, the decisions and assumptions he made demonstrate the potential strategic and tactical challenges associated with having nonARFF-trained personnel in positions of command at an airplane accident.

While reviewing the training records for the ARFF-trained personnel who responded to the accident, it was noted that the SFFD-AB shift captain who served as incident commander for a time had not yet participated in live fire training, which is required for some ARFF personnel by 14 CFR 139.319(i)(3). FAA AC 150/5200-31C, "Airport Emergency Plan," defines the role of the incident commander as the individual who directs and controls personnel and equipment, as well as provides overall management at a specific incident site. In a legal interpretation provided to the NTSB on May 21, 2014, the FAA stated that it views this position as a "communications and coordination role for the various situations described in an airport's emergency plan rather than a position limited to airport rescue and firefighting." According to the interpretation, the FAA believes that the training requirements under 14 CFR 139.319(i)(2) and (i)(3) "may not apply to an Incident Commander because that person could rely on the trained firefighting command staff" to direct the firefighting operations. This interpretation allows for a situation in which an incident commander working at a Part 139 airport lacks the training that his subordinates have received but is tasked with making critical decisions and directing the actions of firefighters who are fully ARFF trained. This would be of particular concern at smaller airports where it is less likely for additional trained command staff to be present.

The FAA requires specialized training for ARFF personnel because burning airplanes present unique challenges for firefighters, including an oddly shaped structure, difficult entry locations, and large amounts of fuel. In addition, the unique capabilities of the firefighting equipment and vehicles (such as the HRET) would be poorly understood by nonARFF-trained

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[108] The battalion fire chief arrived on the scene after the last passenger was extricated from the rear of the airplane and was likely not aware when the extrications had been completed.

personnel. The NTSB is concerned that the FAA does not require even a minimum level of ARFF training for command officers working at a certificated airport.

Therefore, the NTSB recommends that the FAA work with the ARFF Working Group to develop and distribute policy guidance and training materials to ensure that all airport and mutual aid firefighting officers placed in command at the scene of an aircraft accident have at least a minimum level of ARFF training. Further, the NTSB recommends that the ARFF Working Group develop and distribute, in conjunction with the FAA, guidance and training materials to ensure that all airport and mutual aid firefighting officers placed in command at the scene of an aircraft accident have at least a minimum level of ARFF training.

While the FAA does not currently require a specific ARFF staffing level, 14 CFR 139.319(i)(6) states that sufficient rescue and firefighting personnel must be available during air carrier operations to "operate the vehicles, meet the response times, and meet the minimum agent discharge rates." As an Index E airport, SFO was required by 14 CFR 139.317 to have three ARFF vehicles in order to meet its response time/agent requirements; therefore, the airport had a de facto minimum staffing of three trained firefighters in order to drive those vehicles. As stated earlier, SFO was staffed with 23 ARFF personnel on the day of the accident.

The NTSB asked the FAA for a legal interpretation of 14 CFR 139.319(i)(6) to clarify exactly which on-airport ARFF personnel are required to be trained and when the required training must be received. The FAA responded that "all personnel assigned to rescue and firefighting duties must meet the initial and recurrent training and live-fire drill requirements, even if an airport assigns personnel to those duties above those minimally required to comply with 14 CFR 139.319(i)(6)." The FAA interpretation further stated that such responders must be fully trained before they perform ARFF duties and that untrained personnel would not be permitted to operate the airport's firefighting equipment. This interpretation represents a significant change from the way inspectors from the FAA's Office of Airport Certification and Safety have historically enforced these regulations. In the past, ARFF departments at Part 139 airports were considered in compliance with regulations when their de facto FAA minimum staffing level personnel were fully trained. Therefore, the NTSB recommends that the FAA issue a CertAlert[109] to all Part 139 airports to distribute the information contained in the FAA's legal interpretation of 14 CFR 139.319 that requires all personnel assigned to ARFF duties to meet the initial and recurrent training and live-fire drill requirements and clarify how the FAA will enforce this regulation.

2.8.3.5 Communication

Numerous problems with radio communication during the emergency response were reported, the most critical of which was the inability of responding mutual aid units to speak directly with units from the airport on a common frequency. In addition, multiple firefighters reported significant problems reaching command staff and receiving additional assistance when

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[109] According to the FAA, CertAlerts provide the FAA's Airport Safety and Operations Division a quick way of providing additional guidance on Part 139 airport certification and related issues to airport management, ARFF personnel, and FAA inspectors.

requested. ASOs and SFPD personnel also expressed concern over the inability to communicate with one another on scene, and communication difficulties were reported by medical personnel. In all, at least 10 interviewed emergency responders described significant problems with the ability of individuals and agencies to communicate with one another during the event.

Also, while en route to SFO, the eventual incident commander was given erroneous information about a lack of fire at the accident site, likely due to a lack of communication between the airport and city dispatch centers. To make proper decisions about the scale of a response, an incident commander must be provided timely, accurate information as quickly as possible. It was clear from the incident commander's comments that he lacked the information required to make necessary decisions. These decisions were ultimately delayed until he reached the airport, when he first called a yellow then eventually a red alert. If made earlier, these alerts would have greatly expanded the size of the response and provided earlier notifications to hospitals that injured occupants would be arriving. Video footage indicates that the incident commander's vehicle arrived at the scene at 1151:30, indicating a likely 15- to 20-minute delay in expanding the response based on a lack of specific information about the accident. Although it is not possible to determine exactly what, if any, impact this delay had in the emergency response to this accident, the breakdown in communications between the airport and city dispatch centers resulted in a delay in the incident commander receiving information needed to most effectively respond to the accident.

Communication problems at the scene of a mass casualty event are common and, in fact, should be anticipated and planned for. That is one of the main purposes of the annual disaster drills and monthly RedCap drills conducted at SFO. While SFO did include mutual aid in at least some of its planning drills, the NTSB is nonetheless concerned that the problems discussed above were not identified and addressed before the accident. It is possible that the disaster drills at SFO were either not sufficiently realistic or did not include postdrill debriefs detailed enough to adequately identify the communications problems that occurred during the emergency response to the accident.

Before the accident, the airport had taken steps to address some of the communication issues identified in this accident. For example, in 2012, SFO replaced its radio system in an attempt to improve communications with surrounding mutual aid resources through the establishment of a common interagency frequency. However, that frequency did not perform as intended in this accident because mutual aid responders had not yet installed the required equipment. Additionally, interviews conducted during the investigation suggest larger communications issues at the airport. For example, members of the command staff did not seem to recognize the problems that occurred under their command. Neither the incident commander nor the fire attack supervisor reported any problems with communications after arriving on scene, and the fire attack supervisor stated that relying on face-to-face communications was adequate.

After the accident, SFO contracted with ICF International, a technology, policy, and management consulting company, to examine the airport's response to the accident on multiple levels. In the area of communications, the company made numerous observations and recommendations including that the airport acquire new, more robust, communications alerting equipment; improve personnel training; and develop a communication plan annex to the emergency procedures manual.

SFO has already begun addressing these recommendations. Notably, airport officials informed NTSB investigators that the common interagency frequency is now operational at the airport, allowing mutual aid units to speak directly with SFFD-AB personnel. The NTSB believes that had the recommended changes been made before the accident, the communications difficulties encountered would have been greatly alleviated.

The NTSB concludes that although some of the communications difficulties encountered during the emergency response, including the lack of radio interoperability, have been remedied, others, such as the breakdown in communications between the airport and city dispatch centers, should be addressed. Therefore, the NTSB recommends that the City of San Francisco implement solutions to the communications deficiencies identified in ICF International's after-action report as soon as practicable.

2.8.3.6 Airport Emergency Procedures Manual

Title 14 CFR Part 139.325 requires that each certificated airport develop and maintain an airport emergency plan designed to minimize the possibility and extent of personal injury and property damage on the airport in an emergency. The NTSB noted during the investigation that although SFO had submitted, and the FAA had approved in December 2012, an updated emergency procedures manual, the airport had not yet distributed or trained personnel on the updated manual and was still actively operating with the manual approved by the FAA in December 2008. Although there were no significant changes to the Alert 3 section of the manual in the 2012 revision, this finding warrants increased oversight by the FAA. When considered with other findings in the report regarding the medical response, disaster drills, and communications, the NTSB concludes that the Alert 3 sections of SFO's 2008 and 2012 emergency procedures manuals were not sufficiently robust to anticipate and prevent the problems that occurred in the accident response.

As SFO moves forward with implementing changes from the lessons learned in the accident, the NTSB believes that it is critical for the FAA to proactively engage with the airport. Therefore, the NTSB recommends that the FAA conduct a special inspection of SFO's emergency procedures manual and work closely with the airport to ensure that the airport meets its obligations under Part 139.325.

3. Conclusions

3.1 Findings

1. The following were not factors in the accident: flight crew certification and qualification; flight crew behavioral or medical conditions or the use of alcohol or drugs; airplane certification and maintenance; preimpact structural, engine, or system failures; or the air traffic controllers' handling of the flight.

2. Although the instrument landing system glideslope was out of service, the lack of a glideslope should not have precluded the pilots' successful completion of a visual approach.

3. The flight crew mismanaged the airplane's vertical profile during the initial approach, which resulted in the airplane being well above the desired glidepath when it reached the 5 nautical mile point, and this increased the difficulty of achieving a stabilized approach.

4. The flight crew's mismanagement of the airplane's vertical profile during the initial approach led to a period of increased workload that reduced the pilot monitoring's awareness of the pilot flying's actions around the time of the unintended deactivation of automatic airspeed control.

5. About 200 ft, one or more flight crewmembers became aware of the low airspeed and low path conditions, but the flight crew did not initiate a go-around until the airplane was below 100 ft, at which point the airplane did not have the performance capability to accomplish a go-around.

6. The flight crew was experiencing fatigue, which likely degraded their performance during the approach.

7. Nonstandard communication and coordination between the pilot flying and the pilot monitoring when making selections on the mode control panel to control the autopilot flight director system (AFDS) and autothrottle (A/T) likely resulted, at least in part, from role confusion and subsequently degraded their awareness of the AFDS and A/T modes.

8. Insufficient flight crew monitoring of airspeed indications during the approach likely resulted from expectancy, increased workload, fatigue, and automation reliance.

9. The delayed initiation of a go-around by the pilot flying and the pilot monitoring after they became aware of the airplane's low path and airspeed likely resulted from a combination of surprise, nonstandard communication, and role confusion.

10. As a result of complexities in the 777 automatic flight control system and inadequacies in related training and documentation, the pilot flying had an inaccurate understanding of how the autopilot flight director system and autothrottle interacted to control airspeed, which led to his inadvertent deactivation of automatic airspeed control.

11. If the autothrottle automatic engagement function ("wakeup"), or a system with similar functionality, had been available during the final approach, it would likely have activated and increased power about 20 seconds before impact, which may have prevented the accident.

12. A review of the design of the 777 automatic flight control system, with special attention given to the issues identified in this accident investigation and the issues identified by the Federal Aviation Administration and European Aviation Safety Agency during the 787 certification program, could yield insights about how to improve the intuitiveness of the 777 and 787 flight crew interfaces as well as those incorporated into future designs.

13. If the pilot monitoring had supervised a trainee pilot in operational service during his instructor training, he would likely have been better prepared to promptly intervene when needed to ensure effective management of the airplane's flightpath.

14. If Asiana Airlines had not allowed an informal practice of keeping the pilot monitoring's (PM) flight director (F/D) on during a visual approach, the PM would likely have switched off both F/Ds, which would have corrected the unintended deactivation of automatic airspeed control.

15. By encouraging flight crews to manually fly the airplane before the last 1,000 ft of the approach, Asiana Airlines would improve its pilots' abilities to cope with maneuvering changes commonly experienced at major airports and would allow them to be more proficient in establishing stabilized approaches under demanding conditions; in this accident, the pilot flying may have better used pitch trim, recognized that the airspeed was decaying, and taken the appropriate corrective action of adding power.

16. A context-dependent low energy alert would help pilots successfully recover from unexpected low energy situations like the situation encountered by the accident pilots.

17. The flight attendants acted appropriately when they initiated an emergency evacuation upon determining there was a fire outside door 2R. Further, the delay of about 90 seconds in initiating an evacuation was likely due partly to the pilot monitoring's command not to begin an immediate evacuation, as well as disorientation and confusion.

18. Passengers 41B and 41E were unrestrained for landing and ejected through the ruptured tail of the airplane at different times during the impact sequence. It is likely that these passengers would have remained in the cabin and survived if they had been wearing their seatbelts.

19. Passenger 42A was likely restrained for landing, and the severity of her injuries was likely due to being struck by door 4L when it separated during the airplane's final impact.

20. The dynamics of the impact sequence in this accident were such that occupants were thrown forward and experienced a significant lateral force to the left, which resulted in serious passenger injuries that included numerous left-sided rib fractures and one left-sided head injury.

21. The reasons for the high number of serious injuries to the high thoracic spine in this accident are poorly understood.

22. The release and inflation of the 1R and 2R slide/rafts inside the airplane cabin was a result of the catastrophic nature of the crash, which produced loads far exceeding design certification limits.

23. Clearer guidance is needed to resolve the concern among airport fire departments and individual firefighters that the potential risk of injuring airplane occupants while piercing aircraft structure with a skin-penetrating nozzle outweighs the potential benefit of an early and aggressive interior attack using this tool.

24. Medical buses were not effectively integrated into San Francisco International Airport's monthly preparation drills, which played a part in their lack of use in the initial response to the accident and delayed the arrival of backboards to treat seriously injured passengers.

25. Guidance on task prioritization for responding aircraft rescue and firefighting personnel that addresses the presence of seriously injured or deceased persons in the immediate vicinity of an accident airplane is needed to minimize the risk of these persons being struck or rolled over by vehicles during emergency response operations.

26. The overall triage process in this mass casualty incident was effective with the exception of the failure of responders to verify their visual assessments of the condition of passenger 41E.

27. The San Francisco Fire Department's aircraft rescue and firefighting staffing level was instrumental in the department's ability to conduct a successful interior fire attack and successfully rescue five passengers who were unable to self-evacuate amid rapidly deteriorating cabin conditions.

28. Although no additional injuries or loss of life were attributed to the fire attack supervisor's lack of aircraft rescue and firefighting (ARFF) knowledge and training, the decisions and assumptions he made demonstrate the potential strategic and tactical challenges associated with having nonARFF-trained personnel in positions of command at an airplane accident.

29. Although some of the communications difficulties encountered during the emergency response, including the lack of radio interoperability, have been remedied, others, such as the breakdown in communications between the airport and city dispatch centers, should be addressed.

30. The Alert 3 sections of San Francisco International Airport’s 2008 and 2012 emergency procedures manuals were not sufficiently robust to anticipate and prevent the problems that occurred in the accident response.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the flight crew’s mismanagement of the airplane’s descent during the visual approach, the pilot flying’s unintended deactivation of automatic airspeed control, the flight crew’s inadequate monitoring of airspeed, and the flight crew’s delayed execution of a go-around after they became aware that the airplane was below acceptable glidepath and airspeed tolerances. Contributing to the accident were (1) the complexities of the autothrottle and autopilot flight director systems that were inadequately described in Boeing’s documentation and Asiana’s pilot training, which increased the likelihood of mode error; (2) the flight crew’s nonstandard communication and coordination regarding the use of the autothrottle and autopilot flight director systems; (3) the pilot flying’s inadequate training on the planning and executing of visual approaches; (4) the pilot monitoring/instructor pilot’s inadequate supervision of the pilot flying; and (5) flight crew fatigue, which likely degraded their performance.

4. Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations:

To the Federal Aviation Administration:

Require Boeing to develop enhanced 777 training that will improve flight crew understanding of autothrottle modes and automatic activation system logic through improved documentation, courseware, and instructor training. (A-14-37)

Once the enhanced Boeing 777 training has been developed, as requested in Safety Recommendation A-14-37, require operators and training providers to provide this training to 777 pilots. (A-14-38)

Require Boeing to revise its 777 Flight Crew Training Manual stall protection demonstration to include an explanation and demonstration of the circumstances in which the autothrottle does not provide low speed protection. (A-14-39)

Once the revision to the Boeing 777 Flight Crew Training Manual has been completed, as requested in Safety Recommendation A-14-39, require operators and training providers to incorporate the revised stall protection demonstration in their training. (A-14-40)

Convene an expert panel (including members with expertise in human factors, training, and flight operations) to evaluate methods for training flight crews to understand the functionality of automated systems for flightpath management, identify the most effective training methods, and revise training guidance for operators in this area. (A-14-41)

Convene a special certification design review of how the Boeing 777 automatic flight control system controls airspeed and use the results of that evaluation to develop guidance that will help manufacturers improve the intuitiveness of existing and future interfaces between flight crews and autoflight systems. (A-14-42)

Task a panel of human factors, aviation operations, and aircraft design specialists, such as the Avionics Systems Harmonization Working Group, to develop design requirements for context-dependent low energy alerting systems for airplanes engaged in commercial operations. (A-14-43)

Conduct research that examines the injury potential to occupants in accidents with significant lateral forces, and if the research deems it necessary, implement regulations to mitigate the hazards identified. (A-14-44)

Conduct research to identify the mechanism that produces high thoracic spinal injuries in commercial aviation accidents, and if the research deems it necessary, implement regulations to mitigate the hazards identified. (A-14-45)

Analyze, in conjunction with slide/raft manufacturers, the information obtained in this accident investigation and evaluate the adequacy of slide and slide/raft certification standards and test methods specified in Federal Aviation Administration regulations and guidance materials. If appropriate, modify certification standards and test methods for future slide and slide/raft design based on the results of this evaluation. (A-14-46)

Work with the Aircraft Rescue and Firefighting Working Group and equipment manufacturers to develop and distribute more specific policies and guidance about when, how, and where to use the high-reach extendable turret's unique capabilities. (A-14-47)

Once the minimum staffing level has been developed by the Aircraft Rescue and Firefighting (ARFF) Working Group, as requested in Safety Recommendation A-14-60, amend 14 *Code of Federal Regulations* 139.319(j) to require a minimum ARFF staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers. (A-14-48)

Work with the Aircraft Rescue and Firefighting (ARFF) Working Group to develop and distribute policy guidance and training materials to ensure that all airport and mutual aid firefighting officers placed in command at the scene of an aircraft accident have at least a minimum level of ARFF training. (A-14-49)

Issue a CertAlert to all Part 139 airports to distribute the information contained in the Federal Aviation Administration's (FAA) legal interpretation of 14 *Code of Federal Regulations* 139.319 that requires all personnel assigned to aircraft rescue and firefighting duties to meet the initial and recurrent training and live-fire drill requirements and clarify how the FAA will enforce this regulation. (A-14-50)

Conduct a special inspection of San Francisco International Airport's emergency procedures manual and work closely with the airport to ensure that the airport meets its obligations under Part 139.325. (A-14-51)

To Asiana Airlines:

Reinforce, through your pilot training programs, flight crew adherence to standard operating procedures involving making inputs to the operation of autoflight system controls on the Boeing 777 mode control panel and the performance of related callouts. (A-14-52)

Revise your flight instructor operating experience (OE) qualification criteria to ensure that all instructor candidates are supervised and observed by a more experienced instructor during OE or line training until the new instructor demonstrates proficiency in the instructor role. (A-14-53)

Issue guidance in the Boeing 777 Pilot Operating Manual that after disconnecting the autopilot on a visual approach, if flight director guidance is not being followed, both flight director switches should be turned off. (A-14-54)

Modify your automation policy to provide for more manual flight, both in training and in line operations, to improve pilot proficiency. (A-14-55)

To Boeing:

Revise the Boeing 777 Flight Crew Operating Manual to include a specific statement that when the autopilot is off and both flight director switches are turned off, the autothrottle mode goes to speed (SPD) mode and maintains the mode control panel-selected speed. (A-14-56)

Using the guidance developed by the low energy alerting system panel created in accordance with Safety Recommendation A-14-43, develop and evaluate a modification to Boeing wide-body automatic flight control systems to help ensure that the aircraft energy state remains at or above the minimum desired energy condition during any portion of the flight. (A-14-57)

To the Aircraft Rescue and Firefighting Working Group:

Work with the Federal Aviation Administration and equipment manufacturers to develop and distribute more specific policies and guidance about when, how, and where to use the high-reach extendable turret’s unique capabilities. (A-14-58)

Work with medical and medicolegal professional organizations to develop and distribute guidance on task prioritization for responding aircraft rescue and firefighting (ARFF) personnel that includes recommended best practices to avoid striking or rolling over seriously injured or deceased persons with ARFF vehicles in a mass casualty situation. (A-14-59)

Develop a minimum aircraft rescue and firefighting staffing level that would allow exterior firefighting and rapid entry into an airplane to perform interior firefighting and rescue of passengers and crewmembers. (A-14-60)

Develop and distribute, in conjunction with the Federal Aviation Administration, guidance and training materials to ensure that all airport and mutual aid firefighting officers placed in command at the scene of an aircraft accident have at least a minimum level of aircraft rescue and firefighting training. (A-14-61)

To the City and County of San Francisco:

Routinely integrate the use of all San Francisco Fire Department medical and firefighting vehicles in future disaster drills and preparatory exercises. (A-14-62)

Implement solutions to the communications deficiencies identified in ICF International's after-action report as soon as practicable. (A-14-63)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

CHRISTOPHER A. HART Acting Chairman	**ROBERT L. SUMWALT** Member
	MARK R. ROSEKIND Member
	EARL F. WEENER Member

Adopted: June 24, 2014

Acting Chairman Hart and Members Sumwalt, Rosekind, and Weener filed the following statements.

Board Member Statements

Acting Chairman Christopher A. Hart filed the following concurring statement on July 3, 2014.

It is a tribute to the safety robustness of the commercial aviation system that just one breached safety defense rarely causes injury or damage. This accident, however, was caused by an unfortunate combination of several safety weaknesses, each of which, by itself, is usually innocuous. Of the many safety issues addressed in this report, I would like to touch briefly on three: pilot training, instructor training, and approval of the automation logic.

Pilot Training. It is troubling that, despite having nearly 10,000 hours of flying time, much of which was in airliners, the pilot was uneasy about conducting a visual approach into SFO without an ILS glideslope. Granted, his unease may have resulted in part from the fact that he had less than 40 hours in the airplane (as opposed to the simulator), and he had never done a visual approach in the airplane without a glideslope. Given his unblemished record, however, my concern is the extent to which his unease was a reflection of his training and experience with Asiana—in particular, the training and experience that was based upon a strong preference by Asiana for its pilots to use automation as much as possible.

Although automation has a long history of improving safety and efficiency, too much reliance on automation can have unintended consequences. One unintended consequence is that it caused this highly experienced pilot with an unblemished record to be uncomfortable about manually accomplishing a very basic task—landing on an 11,000 ft runway on a clear day with very little wind. Hence, we issued our recommendation to Asiana about encouraging more manual flying, both in training and in line operations.

Instructor Training. Although the instructor pilot had more than 12,000 hours, including more than 3,200 hours in the Boeing 777, the accident flight was his first flight as an instructor pilot. With more experience as an instructor pilot, he might have been more attentive to the indications that the pilot was “behind” the airplane, and he might have been more alert to the need to give additional guidance to the pilot, as well as the potential need to take control of the airplane.

Those indications became apparent at least 15 miles out on the approach when the airplane first intercepted the localizer, and they were high and fast but the pilot failed to begin immediate corrections. The indications became more serious as they continued the approach and the pilot still had not remedied the exceedances. When the pilot failed to follow Asiana’s approach guidelines, e.g., rate of descent not to exceed 1,000 ft per minute below 1,000 ft, and mandatory go-around if the approach was not stable by the time the airplane has descended to 500 ft, the instructor should have either commanded a go-around or done it himself.

Ideally, the pilot should have let the instructor know about his unease regarding the approach, but he did not; better training of the instructor, such as training with an instructor-observer to observe and counsel the instructor, may have enhanced the instructor’s ability to recognize the pilot’s unease even without the pilot admitting it. Hence, we issued our recommendation to Asiana, to revise their flight instructor operating experience qualification criteria so that instructor candidates are supervised and observed during line training. I hope that other airlines that do not supervise and observe their instructor candidates during line training will take a lesson from this accident and revise their instructor qualification criteria accordingly.

FAA Approval of Automation Logic. The report notes that a 1996 flight test certification report for the Boeing 777 stated that "Per design, when the autopilot is controlling airspeed, the autothrottle automatic engage ["wake-up"] feature is disabled." In 2010, as a result of the flight test certification program for the Boeing 787 (which, according to Boeing, has the same autothrottle "wake-up" feature as the Boeing 777), the primary project pilot, who had about 1,000 hours in Boeing airplanes, including about 500 hours in the Boeing 777, noted that the autothrottle did not function as he expected, and he referred to the failure of the autothrottle to "wake up" under certain circumstances as "less than desirable." Consequently, the FAA required Boeing to add an explanation about the "wake-up" mode in the Boeing 787 AFM. Notably, no such language was required for the Boeing 777 AFM, even though the Boeing 777 "wake-up" feature behaved the same as in the Boeing 787.

EASA also noted problems about the Boeing 787 autothrottle and wrote a "Major Recommendation for Improvement #3" in 2011, noting that the behavior of the system could "look from a pilot's perspective as an inconsistency in the automation behavior of the airplane," and further stating that "the manufacturer would enhance the safety of the product by avoiding [this behavior] in the 'Autothrottle wake up' mode condition." In other words, fixing the problem is a much better remedy than warning about the problem, and what was needed was improved automation logic, not just additional language in the AFM. Hence, we issued our recommendation to the FAA to convene a special certification design review of how the Boeing 777 automatic flight control system controls airspeed.

Inasmuch as this was the first fatal Boeing 777 accident since it was introduced into commercial service nearly two decades ago, we recognize that the autothrottle "wake-up" behavior has not previously led to any accidents or incidents in many millions of flights. Hence, borrowing language from a proposed recommendation that was not adopted by the Board, I trust that the FAA will begin the special certification design review by looking at the extensive existing databases in search of situations in which flight crews of Boeing wide-body aircraft (which share the same autothrottle "wake-up" feature) were uncertain or confused about whether the automatic flight control system was controlling airspeed, particularly during approach. The fact that this confusion about the autothrottle happened in this accident means that it could happen again, albeit probably very rarely; the more that is known and understood about the history of this problem, the greater the likelihood that an appropriate remedy can be developed that is unlikely to create unintended consequences.

Perhaps the ultimate irony of this tragic accident is that if the airplane had encountered low ceiling and visibility conditions upon arriving at SFO, the approach would probably have been largely or fully automatic and would probably have been conducted without incident.

Members Sumwalt and Rosekind joined in this statement.

Member Robert L. Sumwalt filed the following concurring (in part) and dissenting (in part) statement on July 1, 2014.

In the months after this accident, many have asked, “How could an airline crew crash an airplane on a perfectly clear day with calm winds on a visual approach?”

There was uninformed conjecture that placed the crew’s competency in question. As I stated in the board meeting, this accident is not one about crew competency. After all, the pilot flying had nearly 10,000 flight hours and had been a captain and instructor on the Airbus A320. The instructor pilot had 12,000 flight hours, including over 3,000 in the Boeing 777, and was selected from many to join the elite instructor corps of Asiana. Pilots simply don’t make it this far in their careers if they lack competency.

Contrary to what some may believe, this accident is not just another “pilot error” accident. Like most accidents, the causation of this accident is complex and involves the interaction of several elements of the system. It involves a set of circumstances that came together on this day to produce a tragic outcome.

I believe setting the stage for the crash was *expectancy*; the pilot flying *expected* the airplane to do something that it wasn’t designed to do. Specifically, he expected the autothrottle system to provide speed control for him, but unbeknownst to him, the system would not do so while in a HOLD mode.

This pilot was not the only one who didn’t understand this nuance of the automation, and I am convinced that misunderstandings of this system are actually fairly common. For example, somewhere during the pilot flying’s ground school training, a ground instructor supposedly mentioned to him—perhaps in passing—that on three occasions, he had experienced a similar situation where the autothrottle system did not maintain speed. To show that the ground instructor himself did not understand this situation, he described it as an “anomaly.” However, it’s not an “anomaly” at all—it’s the way the system was designed. This represents data point number one in a wider misunderstanding of the system logic.

Data point number two comes in the form of an FAA test pilot. In 2010, this pilot was flying a Boeing 787 on a test flight when he was alarmed to see that the autothrottle did not maintain speed while in FLCH and HOLD. The autothrottle logic on the 787 is essentially the same as the 777, and this pilot had 500 hours in the 777. Why would an experienced FAA test pilot not understand this system logic if it was that clear? He raised his concern throughout the FAA certification chain. Officials with EASA also became concerned. As a result, Boeing added additional and clearer guidance in the Boeing 787 manuals regarding this system logic. But for the Boeing 777—an airplane with the same basic system—nothing was done.

Data points three and onward are less well documented but are no less relevant or important. Before the Board meeting, I asked the head of 777 training for a very large airline how well this autothrottle “failure to wake-up while in HOLD mode” was understood prior to this accident. His answer: not well understood at all.

After the Board meeting, I learned from credible sources that other airlines have noted similar problems. One airline estimated from its data sources that three times a day, pilots at that particular airline experienced the situation faced by the Asiana pilots: pilots expect the autothrottle to provide speed control, but because the system is in HOLD, that protection is not available. Another airline source noted that their Flight Operation Quality Assurance data showed seven such occurrences, including one in which speed decreased 19 knots below V_{ref} before the pilots detected and corrected the situation. Another source stated, "It is true that the HOLD mode is poorly understood by the industry, and absolutely this accident could have happened in any airline."

In spite of the number of anecdotal reports of this misunderstanding of the autothrottle HOLD mode, I am left wondering why the issue was not more widely reported through various data sources. As a former airline pilot myself, I can understand why pilots don't report when automation doesn't act the way they believe it should; after all, having automation do something unexpected, or not do something that was expected, is not terribly uncommon. If they did report it, a technician would likely test it and report "ops checks normal." That may explain why there is little information through self-reporting systems such as Aviation Safety Action Systems or the National Aeronautics and Space Administration's Aviation Safety Reporting System (ASRS).

Perhaps the key to learning of more incidents involving the 777 autothrottle HOLD mode could come from FOQA programs and from the Aviation Safety Information Analysis & Sharing (ASIAS) program. Regrettably, the NTSB's Memorandum of Understanding (MOU) with ASIAS does not allow for querying ASIAS for a non-US air carrier accident.

In the absence of an MOU allowing the NTSB to learn more about the nature of the FLCH HOLD issue, through this statement, I urge the ASIAS Executive Board to search the ASIAS database to look for similar problems. Because some believe that the situation encountered by the crew of Asiana flight 214 was a "one off" event, I urge findings of this ASIAS study to be shared with the NTSB upon completion.

The NTSB Board members unanimously determined that "the complexities of the autothrottle and autopilot flight director systems that were inadequately described in Boeing's documentation and Asiana's pilot training, which increased the likelihood of mode error." This concurring and dissenting statement enumerates some of those complexities and inadequacies.

As it relates to training, the Boeing 777 Flight Crew Training Manual contained a section titled "stall demonstration," which outlined three scenarios. Each was designed to showcase features of the 777 that were intended to protect the aircraft in case, for whatever reason, airspeed becomes too slow. One scenario, for example, demonstrated that if the autopilot is on and airspeed gets too slow, the autopilot's altitude hold mode will disengage and allow the aircraft to pitch over to regain speed. Another scenario demonstrated that if the autothrottles were disconnected, if speed gets too slow, the autothrottles will reactivate ("wake up") and increase speed. While these demonstrations showed how and when the airplane will protect against critically slow speed, they did not demonstrate when the airplane *would not* intervene when speed got too slow—precisely the situation experienced by the crew of Asiana flight 214.

What these demonstrations did, as indicated by the pilot flying's postaccident interview statements, was instill in him a dangerously false belief that no matter what, the airplane would protect against a slow speed situation. The pilot flying told investigators that he was "astonished" that the airplane would do these things to keep him from stalling. I believe this may somewhat explain (but not excuse) why the pilot flying subconsciously relaxed his scan of the airspeed indicator.

From a design perspective, let me first applaud the designers of the 777 for creating an airplane that, indeed, has many safety features to protect against human error. That said, I believe from a pilot's perspective there is something unintuitive about the speed protection logic: when the autothrottles are disconnected, they will wake up when speed gets slow; however, when they are in their normal operating mode in HOLD, the throttles will not wake up to protect speed.

The investigation found that if the autothrottle automatic engagement function (wake-up), or a system with similar functionality, had been available, it would likely have activated and increased power about 20 seconds before impact, which may have prevented the accident.

In spite of the unintuitive design feature from a pilot's perspective, and in spite of the determination that an autothrottle wake up feature would probably have prevented the crash, the majority of the Board voted (3 to 1) against a recommendation proposed by staff and supported vigorously by me to require Boeing to redesign the system.

The gavel had barely dropped to end the Board meeting when Boeing issued a statement saying that it "respectfully disagrees with the NTSB's statement that the 777's auto-flight system contributed to this accident, a finding that [Boeing does] not believe is supported by the evidence." Denial is the enemy of change. Such statements are perhaps issued by public relations personnel intent on protecting their brand, or perhaps posturing against potential litigation. However, for those who are truly interested in making a safe aircraft even safer, my hope is that they will internalize the safety lessons from this report and make the necessary changes through a more error tolerant design.

In making safety improvements, the well-known system safety order of precedence should be followed: the largest potential for safety improvements comes from design and engineering enhancements, while the lowest form of safety improvement comes from training and procedures.[110] Therefore, I hope changes will be made to the aircraft design and not just words added to a manual (although deficiencies in the manuals were certainly noted in this investigation, and wording should be clarified.)

The above remarks are an attempt to explain how the pilot flying may have relied on the aircraft to maintain a safe airspeed. Despite his reliance on the automated system, there is no doubt that he should have monitored airspeed. The investigation found that the pilot flying didn't monitor for 24 seconds, and the instructor pilot didn't monitor for 17 seconds. These were critical errors that were causal to the crash.

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[110] For example, see US Department of Defense, *Standard Practice for System Safety, MIL-STD-882E,* Section 4.3.4 (a) - (e); *US Air Force System Safety Handbook*, Section 3.3; and, *FAA System Safety Handbook*, Section 3.6.

At NTSB's December 2013 public hearing for this accident, a Boeing engineer testified: "So, when we design the airplane, we assume that aircrews are very good at monitoring when it's a critical phase of flight…". This is an assumption that is unsupported by data from accidents, incidents, normal flight operations, and considerable literature and research.

In preparation for this Board meeting, I reviewed 25 accidents—mostly air carrier accidents— in which poor monitoring of the flight path was cited in the accident's causation. Of the 25 accidents reviewed, 17 (including this one) occurred on approach. Of those, six were the result of allowing speed to decrease to unacceptably slow values.

I also reviewed over 100 reports submitted to NASA ASRS—reports where pilots didn't adequately monitor flightpath. Twenty percent of these reports involved cases where pilots didn't sufficiently monitor during the approach.

Line Operations Safety Audit data from over 14,000 observed line operations flights show that between 15 to 20% of flights have poor monitoring/cross-checking performance in at least one phase of flight.

Research studies on pilot monitoring behavior are plentiful, but perhaps one of the most telling research studies was completed in 2000, where the principal researcher was a Boeing flight deck human factors engineer.[111] That study involved observing crews flying full mission simulated flights in a Boeing 747-400 simulator, an aircraft that has flight deck displays and automation similar to the 777. That research revealed that pilots in the study did not often notice autoflight mode changes. The researchers attributed this to pilots failing to monitor and to pilots lacking an understanding of what the automation should be doing.

In short, to assume that pilots are very good at monitoring in a critical phase of flight is, unfortunately, an assumption that is unsupported by data. Instead, it would seem better to assume that pilots will, somewhere during the lifecycle of an aircraft, be ineffective at monitoring important flight path parameters and miss something critical, as did the Asiana flight 214 crew. Through such an assumption, the manufacturer would create additional layers of defense to trap those errors before consequential results occur. One such important layer of defense would be a design change so that autothrottles would wake up and prevent critically low airspeeds, even when the system is in a HOLD mode. I am disappointed that my colleagues did not join me in supporting a recommendation for such a change.

In my opinion, this accident was a systems accident. Yes, the pilots made grave errors in planning and executing the approach, and failed to monitor. However, I believe the pilot flying's failure to monitor may have been precipitated by the false belief that the 777's automation would provide speed control—a perilous error. As the report points out, insufficient flight crew monitoring of airspeed during the approach resulted, in part, from expectancy, increased workload, and automation overreliance.

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[111] Mumaw, R., N. Sarter, C. Wickens, S. Kimball, M. Nikolic, R. Marsh, W. Xu, and W. Xu. (2000). *Analysis of Pilots' Monitoring and Performance on Highly Automated Flight Decks*. (NASA Ames Contract NAS2-99074). Mountain View, CA: NASA Ames Research Center.

I’ve often said that as tragic as a transportation accident is, it is even more tragic to suffer the accident and not learn from it. I hope that lessons learned from this accident can be used to improve safety so that others don’t have to endure what the passengers, crew, and families of the victims have already endured.

Member Mark R. Rosekind filed the following concurring statement on July 3, 2014.

Introduction

On July 6, 2013, a Boeing 777 with Korean registration operating as Asiana Airlines flight 214 was on approach to San Francisco International Airport runway 28L when it struck a seawall. Three of the 307 people on board were fatally injured and 49 received serious injuries, though overall, 98% of those who flew Asiana flight 214 that day were able to self-evacuate successfully after the crash. Despite a catastrophic fire that destroyed the airplane, there was a 99% survival rate. This is extraordinary in modern aviation and reflects many years of advances across a spectrum of innovation that warrants further emphasis.

Safety

While every airplane crash represents failure of some kind, there are significant success stories out of Asiana flight 214 amid the tragic loss of life and injuries suffered. This crash's amazingly high survivability rate reflects years of safety progress in so many areas such as aircraft design and manufacturing, flight crew training, and emergency operations. The entire aviation industry played a role in safety that day, including progress that can be attributed to decades of NTSB research, analysis, investigations, and recommendations. Images of the broken, burned-out airplane fuselage underscore in graphic detail noteworthy advancements in safety engineering saving so many people in a crash that snapped off the Boeing 777's tail and sent a 200-ton aircraft careening across the runway.

Survival

The sheer number of survivors is astonishing to anyone who has seen the video of Asiana flight 214 showing the airplane's violent contact with the seawall, its cartwheel along the runway, and the post-accident fire that consumed the fuselage. While the latest in aviation engineering has produced a resilient aircraft able to withstand significant impact forces, the number of deaths and injuries would have been significantly higher if seatbelts were not available and required. It is no coincidence that two of the three passenger fatalities sustained traumatic injuries as a result of unrestrained ejection from their seats while some of the adjacent passengers wearing seatbelts walked away from the crash.

The critical role of the emergency response personnel at San Francisco International Airport (SFO) and the firefighters from the San Francisco Fire Department cannot be underestimated. Although certain issues regarding communications, triage, and training became evident from the investigation and must be addressed, emergency responders were faced with the extremely rare situation of having to enter a burning airplane to perform rescue operations. Their quick and professional action in concert with a diligent flight crew evacuated the remaining passengers and prevented this catastrophe from becoming much worse. In addition, the emergency response infrastructure and resources at SFO that supported firefighting and recovery after the crash are admirable, significantly exceeding minimum requirements.

The evacuation of an airplane must happen immediately for the best chance to avoid death or injury by fire. A key safety element enabling sufficient time for survival is the development and use of flame-retardant materials for seating, insulation, flooring, and other interior components. Enormous strides have been made during the last decade regarding their flammability, propagation, heat release, and emissions in preventing an immediate outbreak of flames and allowing for a longer period to evacuate people and suppress postcrash fires.

Fatigue

There were nearly a dozen fatigue-related cockpit crew errors throughout the approach, landing, and delayed go-around phases of Asiana flight 214, and these errors involved all three members of the cockpit crew over an extended period of time throughout the accident sequence. The degraded performance associated with sleep disruption and circadian rhythms is well established, with reduced vigilance and attention being classic decrements. Monitoring as expressed by the crew's vigilance and attention would be affected by fatigue as would other basic elements of human performance such as memory, reaction time, and decision-making. The report establishes a solid foundation for fatigue's effects on degraded performance, reduced vigilance, and decreased monitoring across a variety of functions that contributed to the crash.

This accident underscores the importance of acknowledging the distinction between the role of sleep and circadian rhythms, with emphasis on the circadian component and its inevitable biological nature. Sleep disruption was created through acute effects associated with this flight, while the circadian-related performance challenges were associated with operating during the hard-wired and physiologically programmed low-point of the circadian cycle.

Human Performance

Over twenty incorrect actions and inactions leading up to the accident spell out a thorough, comprehensive story of the interrelated complexity of multiple events laying the foundation for the probable cause. Of particular importance is how the execution of divided tasks and an overreliance on automation produced a decrease in monitoring automated technology during the landing sequence. The investigation identified each of these human performance aspects and enables us to understand and differentiate these in detail. Delineating the differential effects of workload, expectancy, surprise, role confusion, mental models of aircraft systems, training, reduced monitoring, and fatigue as each relates to unintended actions or inaction throughout the accident sequence is critical to understanding the probable cause with emphasis on the classic human performance challenge related to the need for "human-centered" integration of automation design, operations, and training.

Acting Chairman Hart and Member Weener joined in this statement.

Member Earl F. Weener filed the following concurring (in part) and dissenting (in part) statement on July 3, 2014.

The investigation of the Asiana Airlines flight 214 accident challenged the Board to reconcile a number of tangible facts with competing views on human performance. The final report, comprehensive in nature, and the probable cause statement reflect the outcome of this challenge. For the most part, as both an aerospace engineer and pilot, I concur with the final report and support the probable cause statement. However, in the pursuit of being comprehensive, I believe the report deemphasizes the significance of the crew's performance as the cause of this accident. As well, I disagree the accident justifies recommendation number 6, a recommendation to the FAA to convene a special certification review (SCR) of the Boeing 777 automatic flight control system (AFCS), but reflects instead a misunderstanding on the Board's part of the purpose and intent of the SCR process.

As stated in the probable cause statement, this accident was caused by the crew's mismanagement of the airplane's descent during the visual approach. In my view, this is the critical finding, and other articulated factors in the statement serve either as examples of mismanagement or as attempts to explain why it occurred. Fundamentally, though, this accident occurred due to crew mismanagement; efforts to deemphasize or excuse the crew's substandard performance in operating the aircraft are not justified by the evidence adduced from the investigation.

The primary responsibility of a pilot (or a two or three pilot crew for that matter), as with other vehicular modes of transportation, is to safely operate the vessel, vehicle, or aircraft. Thus, a pilot bears the responsibility of thoroughly understanding the operation of the aircraft and systems he or she intends to operate. In this case, as the report details, both the pilot flying and the pilot monitoring/instructor pilot were seasoned pilots, both completed the requisite training to execute their responsibilities, and, I would argue, both fully understood their responsibilities as pilots, respectively. However, as the report also details, these pilots missed a number of cues and did not follow company standard operating procedures during the final descent. To characterize this accident as hinging on a single action taken by the pilot flying, such as the unintended deactivation of automatic airspeed control, is simply inaccurate and suggests a lack of understanding of the complexities involved in landing an aircraft. Further, to then suggest the complexity of an operating system excuses or exonerates a pilot from his responsibility to operate the aircraft safely, is incongruent—particularly when this safe operation occurs routinely, every day, using the same operating system logic on multiple models of aircraft all over the world, and has done so for over thirty years.

Undoubtedly, this pilot was confused or did not have a thorough understanding of the AFCS on the airplane, notwithstanding the training he received (including a briefing a few months prior to the accident where the autothrottle HOLD modes were specifically discussed). This is clear from the accident and from the evidence gathered during the investigation. Yet, the accident could have been averted had the crew—both the pilot flying and the pilot monitoring/instructor pilot—properly managed the descent profile from the outset, followed the company's operating procedures with regard to callouts and stable approach criteria, monitored the airspeed, and paid attention to outside visual flight path cues. As well, the result likely would have been different had the pilot flying verbalized his concerns about executing the visual approach and alerted the pilot monitoring/instructor pilot and had the pilot monitoring/instructor pilot sufficiently executed his monitoring and instructing role. The fact is there were numerous opportunities during the descent to prevent this accident from occurring: the crew received multiple cues indicating corrections were necessary to achieve a stable flightpath, and there was sufficient time to execute the corrections during the initial approach. The report's focus on and assertion that AFCS complexity is part of the primary cause of the accident mistakenly detracts from the weaknesses in crew performance. Automation technology is intended to aid flight crews in executing their responsibilities; it is not intended to replace a well-trained and proficient crew. When automation fails or does not react as expected, it remains incumbent upon the crew to be prepared and able to fulfill their responsibility of operating the aircraft safely.

I also disagree with the recommendation to the FAA requesting an SCR of the Boeing 777 AFCS. By design, SCRs are postcertification mechanisms for the FAA to evaluate a potentially unsafe design feature on a previously approved product and so are limited specifically to that product. Historically, the FAA has conducted SCRs on a limited basis and generally as a result of an accident or incident caused by a specific aircraft design feature.

Per the FAA's guidance, an SCR may be initiated after certification requirements are met and the product receives approval or "as service experience dictates." Certification requirements are intended to ensure a product under development will eventually show a satisfactory in-service accident risk. Over time, certification requirements incorporate accumulated knowledge, tested design concepts, and acceptable practices with historically demonstrated satisfactory accident risks. The degree of accident risk of a mature aircraft program is readily demonstrated by its in-service experience. Where in-service experience demonstrates unacceptable accident risk, it is appropriate to examine the certification requirements and processes. Simply put, the decision to undertake an SCR should be data driven.

In the case of the Boeing 777, as of this accident report, the Board has only a single data point concerning the AFCS. However, an examination of the in-service data of the AFCS accumulated over almost two decades would serve to show factually whether or not the system was responsible for unsatisfactory accident/incident performance. Further, because the AFCS is not unique to the 777 model, a more thoughtful approach to determining whether an issue exists would be to provide FAA flexibility to collect and evaluate data from other Boeing models with similar AFCS. As well, it would be prudent to provide FAA flexibility to address an issue, if so determined. Instead, recommendation number 6 limits the SCR solely to the 777 model. For these reasons, I proffered the following revision to the recommendation (although it did not receive the support of a majority of board members):

> Conduct a review of available flight operations data, such as in the Aviation Safety Reporting System (ASRS), Aviation Safety Action Program (ASAP), and Flight Operation Quality Assurance (FOQA), to determine the circumstances of the situations in which flight crews of Boeing wide-body aircraft appeared to be uncertain or confused about whether the automatic flight control system was controlling airspeed, particularly during approach.

The Board is charged with the responsibility of determining accident causes for the purpose of preventing their recurrence and enhancing transportation safety. In this case, the probable cause statement is well supported by the facts, although I believe it is sufficient to identify as the sole primary cause of this accident the crew's mismanagement of the airplane's descent. However, the Board's recommendation to convene an SCR on the basis of a single event occurring in a fleet of aircraft in operation for more than 30 years, without assessing in-service data more broadly, is misguided. If the FAA pursues this recommendation based on one pilot's confusion, we may miss a very real opportunity to enhance safety.

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5. Appendixes

Appendix A: Investigation and Hearing

Investigation

The NTSB was notified about the accident on July 6, 2013. Staff from the NTSB arrived on scene that day and remained there until July 18, 2013, to conduct the field portion of the investigation. Then-Chairman Deborah A.P. Hersman accompanied the team.

In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the KARAIB participated in the investigation as the representative of the State of the Operator. Asiana Airlines and the KOCA participated as technical advisors to the KARAIB.

Parties to the investigation were the FAA, Boeing Company, Pratt and Whitney, Air Cruisers, Honeywell International, and SFFD.

Investigative Hearing

An investigative hearing was held on December 11, 2013, in Washington, DC. All five Board Members participated in the hearing.

The subjects discussed at the investigative hearing included flight deck design concepts and characteristics, pilot training on automated systems and visual approach procedures, pilot awareness in highly automated aircraft, emergency response, and cabin safety. Parties to the investigative hearing were the FAA, Boeing, Asiana Airlines, Asiana Pilot Union, City and County of San Francisco, and Air Cruisers.

Appendix B: Cockpit Voice Recorder Transcript

Transcript of a Honeywell 6022 (980-6022-001) solid-state cockpit voice recorder, serial number CVR120-07983, installed on a Boeing 777 (HL7742), which crashed during landing in San Francisco, California.

LEGEND

CAM	Cockpit area microphone voice or sound source
INT	Intercom
FA	Flight attendant
HOT	Flight crew audio panel voice or sound source
RDO	Radio transmissions from HL7742
TWR	Radio transmission from the airport tower controller
-1	Voice identified as the Pilot Monitoring (PM)
-2	Voice identified as the Pilot Flying (PF)
-3	Voice identified as the jump seat
-?	Voice unidentified
*****	Unintelligible word
#	Expletive
@	Non-pertinent word
( )	Questionable insertion
[ ]	Editorial insertion
{ }	Translated from Korean

Note 1: Times are expressed in Pacific Daylight Time (PDT).

Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.

Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

Note 4: A non-pertinent word, where noted, refers to a word not directly related to the operation, control or condition of the aircraft.

CVR Quality Rating Scale

The levels of recording quality are characterized by the following traits of the cockpit voice recorder information:

Excellent Quality	Virtually all of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate only one or two words that were not intelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.
Good Quality	Most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.
Fair Quality	The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by cockpit noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the CVR system that distorts or obscures the audio information.
Poor Quality	Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high cockpit noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the CVR system that severely distorts or obscures the audio information.
Unusable	Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the CVR system.

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
09:22:28.7	[start of recording]		
Start of Transcript			
10:42:27.9 **CAM-2**	{I will give you a} approach briefing. {current weather is Juliet, variable is six, visibility is one zero mile cloud few is one thousand three hundred scattered is eighteen hundred, temperature seventeen Celsius, dew point is ten degree, and altimeter is twenty nine eighty two. Runway is twenty eight L, and I set approach with localizer. And I will fly through Point Reyes, Papa Yankee Echo, of Golden Gate Six Arrival and when close to San Francisco I will fly using radial three zero three to San Francisco. and when I receive vector of final turn twenty eight left or right. airport field elevation is thirteen feet and transition is one eight zero MSA. North of airport is five thousand one hundred and approach side is four thousand five hundred. Type of approach is localizer and MDA set at four hundred sixty. receiving visual approach at final, maintaining lateral, and I will descend using the V/S to keeping up with vertical when localizer captured. setting go-around altitude three thousand feet in case of missed-approach, and I will ascend following LNAV. it's not necessary for cold temperature and altitude correction. I will use autobrake two for landing and taxi. the landing distance is about six thousand three hundred feet. via Quebec or Kilo and Alpha or Bravo and taxiway Hotel, I will taxi at International Terminal between gate A one and gate A nine following diamond marks on center as I receive the gate number. There is no other information} approach briefing completed, sir.		
10:43:29.8 **CAM-1**	{yeah.}		
10:43:37.1 **CAM-1**	{yeah.}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
10:45:09.0 **CAM-1**	{yeah.}		
10:45:10.6 **CAM-1**	{when you land on 28 left, usually, **exit to taxiway Delta or Tango.}		
10:45:12.9 **CAM-2**	{yeah.}		
10:45:20.5 **CAM-1**	{in normal landing condition, exit through Bravo, then exit to Hotel, Mike, but sometimes they give us direct to Mike.}		
10:45:26.3 **CAM-2**	{yeah.}		
10:45:42.7 **CAM-1**	{getting into Hotel, from Bravo to Hotel, we sometimes receive number two. then before entering Bravo, we need to contact ramp tower.}		
10:46:01.1 **CAM-2**	{understand.}		
10:46:01.3 **CAM-1**	{at that time, please monitor ground. before entering, we receive clearance from ramp tower. through number two, we go Alpha five. usually we are given Alpha five.}		
10:46:04.9 **CAM-2**	{yeah, I got it.}		
10:46:20.8 **CAM-1**	{sometimes, they give us Alpha six, then just follow the instructions.}		
10:46:31.2 **CAM-1**	{if you think you did not hear right or misunderstand ATC either in the air or ground. then you can confirm with ATC before setting MCP in air. when you read back, you are not sure of it, you can ask again to make sure and confirm on the ground. if you are not sure a hundred percent, then stop the aircraft, confirm again before you proceed.}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
10:47:06.7 **CAM-2**	{yes, I will do it.}		
10:47:25.4 **CAM-1**	{I will proceed, descent checklist.}		
10:47:28.0 **CAM-2**	yes sir. descent checklist.		
10:47:29.8 **CAM-1**	recall and notes. check. autobrake two. landing data.		
10:47:35.1 **CAM-2**	VREF one three two, minimum four six zero.		
10:47:38.4 **CAM-1**	VREF one three two, minimum four six zero.		
10:47:46.3 **CAM-1**	approach briefing?		
10:47:47.4 **CAM-2**	completed.		
10:47:49.5 **CAM-1**	low visibility approach required?		
10:47:52.2 **CAM-2**	no.		
10:47:54.2 **CAM-1**	check list completed.		
10:48:58.6 **CAM-1**	{if you have sunglasses, why don't you wear them? but I don't wear them because of depth perception.}		
10:49:11.6 **CAM-2**	{I won't wear them also.}		
10:49:13.9 **CAM-1**	{we usually wear sunglasses to protect eyes.}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
10:49:21.1 **CAM-1**	{I understand that people, who have many outdoor activities, are recommended to wear them to protect eyes. But I can't wear sunglasses. I usually use them while in cruise flight, but always take them off when on approach.}		
10:49:40.8 **CAM-2**	{I even take them off to focus when on approach.}		
10:49:44.3 **CAM-1**	{approaching with wearing sunglasses when I flew seven six seven, I felt a bit uneasy from flare, I don't wear them since then.}		
10:50:12.3 **CAM-1**	{I * *.}		
10:50:44.4 **CAM-2**	{I am wondering how captain @ had a detached cornea.}		
10:50:51.0 **CAM-2**	{Captain @ and other seven three seven captains were working under scorching sun without any problems without wearing sunglasses, and can read up to that old age.}		
10:51:02.7 **CAM-2**	{nowadays, kids are having weak eyes, even my nephew who is sophomore in high school has bad eye sight 0.5.}		
10:51:14.4 **CAM-1**	{my son had third grade of eye sight testing in physical.}		
10:51:21.8 **CAM-2**	{oh, can you get third grade because of eye sight?}		
10:51:25.6 **CAM-1**	{yeah, not exempted unless it is 0.01 like really bad.}		
10:51:27.4 **CAM-2**	{yeah.}		
10:51:33.6 **CAM-1**	{and lately there will be no exemption with only one item, especially bad eye sight, can't make it happen because eye glasses and so on are available.}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
10:51:38.9 **CAM-2**	{aha.}		
10:52:06.6 **CAM-1**	{I don't know whether my son should do Lasik or * *. some recommend to perform and some not. But my nephew, who had really bad eye sight, just did it and he said his life style has been changed since.}		
10:52:23.6 **CAM-2**	{it really depends on how skilfully the doctor corrects the cornea; I mean how the doctor deals with the thickness of it. But it seems they are not operating well. That may be the reason pilots complained after the correction.}		
10:52:43.2 **CAM-2**	{I know it corrects the sight, but there's some risk also. and I was told that Lasik is not recommended to those who have thin corneas.}		
10:52:52.0 **CAM-1**	{humm.}		
10:52:54.2 **CAM-2**	{captain @ who moved to Air Busan had a blocked artery, has high eye pressure always because his cornea is 1.5 thicker than average people.}		
10:53:06.9 **CAM-1**	{aha.}		
10:53:07.5 **CAM-2**	{whenever his physical performed, his eye pressure is always high.}		
10:53:15.5 **CAM-1**	{I see captain @ is in Air Busan.}		
10:53:19.6 **CAM-2**	{yeah, he is a manager in safety management team in Air Busan.}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
10:53:31.1 **CAM-1**	{the company offered him a choice of either staying at a hotel or rent a house. and he chose to rent. the company provided $100,000 deposit for the rental property to accommodate his staying.}		
10:53:47.4 **CAM-1**	{does he fly three two one?}		
10:53:49.5 **CAM-2**	{he had flown seven four seven then changed to three two one because he also had the rating.}		
10:54:08.1 **CAM-1**	{there's no particular reason to stay * * after age sixty.}		
10:54:17.5 **CAM-1**	{the condition is about same or worse.}		
10:54:23.0 **CAM-1**	{comparing Jeju Air and us, first, the physical is tougher. Jeju Air is a bit lenient on physical and give five year verbal extension contract immediately after passing the physical. However our company extends the contract annually, gives a new employee ID, start newly step one, sixty hours guaranteed, and no space available pass. literally everything accumulated is wiped out.}		
10:55:03.0 **CAM-1**	{zone fare at point seventy would not be available also.}		
10:55:08.9 **CAM-2**	{even we don't have that?}		
10:55:10.4 **CAM-1**	{the company says use the annually provided passes. after age sixty, we usually get eight passes annually, which is half of the number of the years we have served.}		
10:55:20.0 **CAM-2**	{eight passes annually?}		
10:55:23.6 **CAM-2**	{so it won't matter international or domestic?}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
10:55:26.1 **CAM-1**	{so the benefit is dramatically diminished. But we still can use them in case we move to Jeju at sixty. we can use Jeju's and * *.}		
		10:55:42.2 **CTR**	Asiana two fourteen descend pilots discretion maintain flight level two four zero.
		10:55:47.4 **UNK**	(confirm Asiana two zero two.)
10:55:49.9 **CAM-1**	talk English.		
		10:55:51.7 **CTR**	negative, Asiana two one four, two fourteen descend pilots discretion maintain flight level two four zero
		10:55:58.0 **RDO-1**	descend flight level two four zero pilot discretion Asiana two one four
10:56:02.1 **CAM-2**	yes sir two four zero pilots discretion.		
10:56:05.8 **CAM-2**	{yes, you have control. I will make PA.}		
10:56:08.6 **CAM-1**	{yeah, wait a moment.}		
10:56:15.6 **CAM-1**	I have ATC and control.		
10:56:17.2 **CAM-2**	yes sir. you have ATC and control.		
10:56:24.9 **CAM-2**	{I will make thirty minutes of arrival time.}		
10:56:29.5 **CAM-1**	{yeah.}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
		10:56:44.3 **RDO-1**	Asiana two one four leaving three niner zero for two four zero.
		10:56:50.6 **CTR**	Asiana two one four roger.
10:57:11.0 **INT-2**	{passenger announcement in Korean.}		
10:57:42.8 **INT-2**	ladies and gentleman, this is your captain speaking. we hope you had a pleasant flight. we are now approaching San Francisco International Airport we'll be landing in about thirty minutes around eleven thirty AM local time. the current weather in San Francisco International Airport is clear temperature is one seven degrees Celsius and sixty two degrees Fahrenheit. we thank you for flying Asiana Airlines member of Star Alliance. enjoy your stay in San Francisco. hope to see you again soon.		
10:58:24.4 **FA**	{passenger announcement in Korean} ladies and gentlemen in a few moments we will be closing our duty free shop to prepare safe landing. if you want to purchase a duty free item now or * flight please contact your cabin crew for more details. and now we end our entertainment system and we * -.		
10:58:28.7 **HOT-2**	I have control sir.		
10:58:30.4 **HOT-1**	you have a controls ahh. {I report to descent immediately as * *.}		
10:58:33.0 **CAM-1**	{then I will report we are descending two four zero. yes we are descending.}		
10:58:36.7 **HOT-2**	check sir.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
10:58:40.2 **HOT-1**	{closing speed window and let's descend VNAV eight two two nine zero.}		
10:58:45.8 **HOT-2**	yes sir.		
10:59:05.8 **CAM-1**	{when did captain @ leave the company?}		
10:59:13.5 **HOT-2**	{I think it's been only about a year.}		
10:59:13.7 **CAM-2**	{it's been about a year.}		
10:59:17.6 **HOT-1**	{coming to annual ground training long ago.}		
10:59:17.7 **CAM-1**	{they were at annual ground school with us.}		
10:59:17.7 **HOT-2**	{ah, at that time, the annual ground school was contracted for Air Busan and I met him there.}		
10:59:21.7 **CAM-2**	{they attended the school as Air Busan pilot. they attended Asiana annual ground school and I met them there while ago.}		
10:59:36.5 **CAM-1**	{captain @, @ -.}		
10:59:36.5 **HOT-1**	{long ago, the pre-selected.}		
		10:59:39.1 **CTR**	Asiana two one four contact Oakland Center one two five point eight five.
		10:59:43.1 **RDO-1**	two five eight five Asiana two one four good day.

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
		10:59:58.4 **RDO-1**	NorCal control good morning Asiana two one four heavy descend flight level two four zero direct point Reyes.
		11:00:05.7 **CTR**	Asiana two fourteen heavy Oakland center cross LOZIT at or maintain one one thousand San Francisco altimeter two niner eight two.
		11:00:12.6 **RDO-1**	ah cross LOZIT one one thousand altimeter two niner eight two.
11:00:18.3 **HOT-2**	cross LOZIT one one thousand set.		
11:00:20.2 **HOT-1**	check sir.		
11:00:39.0 **CAM-1**	{captain @ and three people were good friends, might be an alumni.}		
11:00:39.3 **HOT-1**	{it was a captain @. three were like an alumni.}		
11:00:44.6 **CAM-2**	{do you mean captain @?}		
11:00:45.7 **CAM-1**	{ah is he @?, captain @, @, and there is one more person. right he move to Air Busan.}		
11:00:51.4 **CAM-2**	{they are @, and @ captain @ came to Airbus, Air Busan.}		
11:00:55.6 **HOT-2**	{captain @ move to Air Busan * *.}		
11:01:08.5 **HOT-2**	{captain @, @ had too much herb medicine and his liver numbers are too high.}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:01:17.3 **CAM-1**	{It's absurd it works at Air Busan, but not in my company.}		
11:01:23.0 **HOT-2**	{* his physical had been done at SamSeong general hospital in Ilwon Dong, and he's been cleared there.}		
11:01:30.6 **HOT-1**	{so I mean why it is possible at Air Busan, but not at our company.}		
11:01:39.5 **HOT-1**	{it's really strange.}		
11:01:49.0 **CAM-1**	idle VNAV path.		
11:01:50.6 **CAM-2**	check sir.		
11:01:59.5 **CAM-1**	hold.		
11:02:00.6 **CAM-2**	check.		
11:02:01.5 **CAM-1**	{so, it means working condition of our company is that bad?}		
11:02:01.6 **CAM-1**	{our health gets better because the physical is so tough.}		
11:02:14.5 **CAM-1**	{if thinking the other way, they are passed even the physical condition is not as good at Air Busan.}		
11:02:35.7 **CAM-1**	{small size aircraft was allowed, but not large size aircraft long ago.}		
11:02:39.7 **CAM-2**	yeah.		
11:03:36.1 **CAM-1**	{Is this air ops?}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:03:38.7 **CAM-2**	{Yeah, it is air ops.}		
11:03:39.5 **CAM-2**	I have ATC.		
11:03:40.1 **HOT-1**	{* *.}		
11:03:40.7 **CAM-1**	{I will try contact.}		
11:03:42.3 **CAM-2**	yes sir.		
11:03:42.8 **FA**	{* * * * to help the needy children throughout the world. we appreciate your contribution.}		
11:03:48.3 **CAM-1**	air ops.		
		11:03:49.4 **RDO-1**	good morning Asiana two one four.
		11:03:52.5 **OPS**	* * go ahead Asiana two one four.
		11:03:55.7 **RDO-1**	ETA San Francisco one eight three zero remaining fuel three three decimal one.
		11:04:03.7 **OPS**	copy I have you ETA one eight three zero you guys are going to gate Alpha four.
		11:04:09.7 **RDO-1**	Alpha four thank you.
11:04:19.2 **CAM-1**	{received Alpha four.}		
11:04:21.4 **HOT-2**	yes sir.		
11:04:28.0 **HOT-1**	{it is in the back.}		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:04:28.6 **CAM-1**	{this side.}		
11:04:28.6 **CAM-2**	{yeah.}		
11:04:31.5 **CAM-2**	{yes, it is in the back.}		
11:04:32.9 **CAM-1**	{yeah.}		
11:04:45.7 **HOT-1**	{when you enter, it looks a bit narrow, but it won't matter. there's center line *.}		
11:04:51.8 **HOT-2**	{acknowledged.}		
11:04:55.5 **HOT-1**	{before the center line, first at abeam * *, entering all the way over the * *. at the left side, it won't get caught.}		
		11:05:04.3 **RDO-2**	{acknowledged.}
11:05:19.0 **HOT**	{ATIS information Echo.}		
11:05:50.7 **CAM**	[sound similar to electronic seat adjustment]		
11:05:58.5 **CAM**	[sound similar to electronic seat adjustment]		
11:07:04.0 **HOT-1**	{flying time is about same as to LA.}		
11:07:07.0 **HOT-2**	{yeah.}		
11:07:21.3 **HOT-1**	{I will give a signal first.}		
11:07:22.5 **HOT-2**	yes, sir. approach signal sir.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:07:38.5 **CAM-1**	transition.		
11:07:40.3 **CAM-2**	set QNH two niner eight two.		
11:07:43.0 **HOT-1**	two niner eight two inches set.		
11:07:45.3 **HOT-2**	check.		
11:08:06.7 **CAM-1**	standby.		
11:08:06.8 **CAM-2**	approach checklist sir.		
11:08:06.9 **HOT-1**	stand by ah.		
11:08:07.2 **HOT-2**	approach check * * two niner eight two set * *.		
11:08:08.8 **CAM-3**	approach signal * with altimeter.		
11:08:11.5 **FA**	{we will arrive at San Francisco international airport shortly. please put your seat belt on, and put the seat tray unfold. and please open the window curtain}		
11:08:13.8 **HOT-1**	two niner eight two.		
11:08:13.9 **CAM-1**	two niner eight two is set, checklist complete.		
11:08:16.0 **HOT-1**	checklist complete.		
11:08:17.2 **HOT-2**	check.		
11:08:19.6 **HOT-1**	{announcement sent out.}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:08:20.4 **HOT-2**	yes sir.		
11:08:26.4 **INT**	{passenger announcement in Korean.}		
11:08:36.9 **FA**	we are now making our descent into San Francisco international airport * * leg rest and tray tables in the upright position and open the window shade * overhead bins * * * thank you.		
11:08:39.8 **CAM-1**	{it seems better to give approach signal earlier in long flight.}		
11:08:46.5 **HOT-1**	{long hours working * * * long flight * *.}		
11:08:46.6 **CAM-2**	{ah yeah.}		
11:08:47.9 **CAM-1**	{* * preparing hard and earlier, but it takes longer than thought. they want to start at ten thousand feet if possible in short distance travel because service should be provided.}		
11:09:01.3 **HOT-1**	{long distance has * *.}		
11:09:05.0 **HOT-2**	yeah.		
11:09:15.5 **CAM-1**	{as a beginner, flying small size aircraft, they rush even for making an announcement. it becomes their habit doing it that way. * * small size aircraft in long flight even though they can relax and slow down in the process.}		
11:09:36.7 **HOT-1**	{later it will become really busy when going Kansai or Fukuoka.}		
11:09:41.5 **HOT-1**	{it will be very busy.}		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:10:06.8 **CAM-1**	{I turn off the weather radar.}		
11:10:08.6 **HOT-2**	yes sir weather radar off.		
		11:10:52.7 **CTR**	Asiana two fourteen contact NorCal approach one three three point niner five.
		11:10:56.9 **RDO-1**	three three niner five Asiana two one four good day.
11:10:59.7 **HOT-2**	* sir.		
		11:11:05.6 **RDO-1**	(NorCal) approach good morning Asiana two one four direct LOZIT one one thousand.
11:11:12.0 **CAM**	[sound of double chime]		
		11:11:13.7 **APR**	Asiana two one four heavy NorCal approach depart San Francisco VOR heading one four zero vector visual approach two eight left.
11:11:16.3 **CAM**	[sound of metallic clunks]		
		11:11:19.6 **RDO-1**	after San Francisco heading one four zero visual two eight left?
		11:11:25.6 **APR**	ah two eight left affirmative.
		11:11:27.1 **RDO-1**	thank you.
		11:11:28.6 **RDO-2**	yes sir heading one four zero San Francisco.

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:11:31.3 **HOT-1**	after San Francisco.		
11:11:33.1 **HOT-2**	yes sir.		
11:11:36.4 **CAM-1**	{you don't get rest, do you?}		
11:11:50.4 **CAM-1**	clear left visual approach.		
11:11:52.4 **HOT-2**	yes sir two eight left approach.		
11:12:23.9 **HOT-1**	VNAV ALT.		
11:12:25.4 **CAM-2**	check.		
11:12:33.7 **HOT-1**	{FO @, monitoring well please in the back.}		
11:12:39.6 **CAM-3**	{yes sir.}		
11:12:40.3 **HOT-1**	{let us know immediately if anything strange shows. and we received Alpha four.}		
11:13:05.9 **CAM-1**	{ah, I can see well San Francisco.}		
11:13:10.3 **CAM-1**	{Ahh, well.}		
11:13:12.3 **CAM-1**	{ah. that bridge leads to Oakland.}		
11:13:16.7 **HOT-2**	{is that the Golden Gate?}		
11:13:18.6 **CAM-1**	{the Golden Gate is over there.}		
11:13:20.1 **HOT-2**	yeah.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:13:21.5 **CAM-1**	{this is to Oakland, and it leads to Sacramento, which is capitol of California, and location of University of Berkley.}		
11:13:23.8 **HOT-2**	yeah.		
11:13:30.9 **HOT-2**	ah *		
11:13:36.1 **CAM-1**	{Golden Gate is that side, but can't see it because of clouds.}		
11:13:53.4 **HOT-1**	{the water in the lake.}		
		11:13:55.1 **APR**	Asiana two one four heavy reduce speed to two one zero.
		11:13:57.7 **RDO-1**	ah speed a two one zero Asiana two one four.
11:13:59.7 **HOT-2**	yes sir two one zero set.		
11:14:01.5 **HOT-1**	check.		
11:14:03.6 **CAM-1**	(check two one * set.)		
11:14:07.9 **HOT-1**	{it's the water source of San Francisco.}		
11:14:10.3 **HOT-2**	ah yeah.		
11:14:13.2 **HOT-1**	{there's a golf course over there, which is Crystal Spring golf course. It's pretty good, but we can't get a car nowadays.}		
11:14:16.7 **HOT-2**	yeah.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:14:23.9 **HOT-2**	yeah.		
11:15:13.9 **HOT-1**	{wow, there's no airplane.}		
11:15:20.5 **HOT-1**	{there's no plane on taxiway.}		
11:15:22.5 **HOT-2**	yeah.		
11:15:24.3 **CAM-1**	{they are landing. there is one on two eight left on final, short final.}		
11:15:31.4 **CAM-1**	{one land at two eight right, and the other land at two eight left.}		
11:15:35.5 **HOT-2**	yeah.		
11:15:51.1 **CAM-1**	{that's Oakland.}		
11:15:52.4 **CAM-2**	{yeah.}		
11:16:08.9 **CAM**	[sound similar to electronic seat adjustment]		
11:16:23.3 **HOT-2**	one four zero preset.		
11:16:24.5 **HOT-1**	check.		
11:16:42.6 **CAM-2**	heading select.		
11:16:44.0 **CAM-1**	heading select.		
11:16:48.9 **HOT-1**	San Fran-.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
		11:16:50.3 **APR**	Asiana two one four heavy descend and maintain niner thousand contact approach one three five point sixty five good day.
		11:16:57.7 **RDO-1**	ah descend nine thousand one two five six five Asiana two one four good day.
		11:17:03.0 **APR**	ah just verify one three five point six five.
		11:17:05.8 **RDO-1**	thirty five sixty five thank you.
11:17:07.4 **HOT-2**	yes sir.		
		11:17:07.5 **APR**	thank you have a good day.
11:17:11.6 **HOT-1**	{did I say two five?}		
		11:17:15.1 **RDO-1**	approach good morning Asiana two one four heading one four zero nine thousand speed two one zero.
		11:17:21.4 **APR**	Asiana two one four heavy NorCal approach caution wake turbulence you'll be following a heavy Boeing triple seven.
		11:17:26.9 **RDO-1**	* Asiana two one four.
11:17:29.7 **HOT-2**	sir nine thousand flight level change.		
11:17:31.6 **HOT-1**	check sir.		
11:18:02.3 **CAM-2**	descend * *.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:18:04.8 **CAM-1**	{setting at this, I will keep * *.}		
11:18:05.7 **HOT-1**	*.		
11:18:07.2 **HOT-2**	{thank you.}		
11:18:20.8 **CAM-2**	one zero thousand all lights on sir.		
11:18:23.0 **CAM-1**	check (all lights).		
11:18:51.5 **CAM-1**	speed alt sir.		
11:18:52.5 **CAM-2**	check.		
11:19:05.0 **CAM**	[sound similar to a click]		
11:19:16.5 **HOT-1**	{it's there.}		
11:19:19.6 **HOT-2**	traffic in sight.		
		11:19:25.0 **APR**	Asiana two one four heavy descend and maintain six thousand turn left heading one zero zero.
11:19:29.4 **CAM**	[sound similar to a click]		
		11:19:29.5 **RDO-1**	heading one zero zero descend six thousand Asian two one four.
11:19:31.3 **CAM**	[sound similar to a click]		
11:19:31.7 **CAM**	[sound similar to a click]		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:19:32.9 **CAM**	[sound similar to a click]		
11:19:33.1 **HOT-2**	one zero zero six thousand flight level change.		
11:19:35.1 **HOT-1**	check.		
11:19:41.0 **HOT-1**	hold flight level change speed.		
11:19:42.9 **HOT-2**	check.		
11:20:01.3 **HOT-?**	{*.}		
11:20:03.4 **HOT-1**	{I will set it.}		
11:20:05.8 **HOT-2**	{thank you.}		
11:20:31.2 **CAM**	[sound similar to electronic seat adjustment]		
11:20:38.8 **HOT-1**	{they are coming from both sides same time.}		
		11:20:57.0 **APR**	Asiana two one four heavy descend and maintain four thousand turn left heading zero three zero.
		11:21:01.0 **RDO-1**	heading zero three zero descend four thousand Asiana two one four.
11:21:04.4 **HOT-2**	yes sir zero three zero four thousand.		
11:21:06.3 **CAM-1**	check.		
11:21:06.7 **CAM-2**	speed brake.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:21:11.8 **CAM-1**	heading select.		
11:21:13.3 **CAM-2**	yes, sir.		
		11:21:49.0 **APR**	Asiana two one four heavy San Francisco airport nine or ten o'clock one seven miles do you have it sight?
11:21:53.3 **HOT-2**	yes sir runway in sight.		
11:21:55.1 **HOT-1**	in sight?		
11:21:55.5 **HOT-2**	yes sir runway in sight.		
		11:21:56.2 **RDO-1**	okay runway in sight.
		11:21:57.8 **APR**	Asiana two one four heavy turn left heading three one zero cleared visual approach runway two eight left.
		11:22:02.7 **RDO-1**	cleared heading three one zero cleared visual two eight left Asiana two one four.
11:22:06.5 **HOT-2**	yes three one zero ID normal {I am intercepting} localizer.		
11:22:09.0 **HOT-1**	yes.		
11:22:12.7 **HOT-1**	localizer armed.		
11:22:14.2 **HOT-2**	check, cleared visual approach.		
11:22:17.2 **HOT-1**	check.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:22:45.6 **HOT-2**	{next, three thousand one hundred.}		
11:22:47.1 **CAM-2**	cleared visual approach.		
11:22:48.4 **CAM-1**	check.		
11:22:53.8 **HOT-1**	{since we did not receive HEMAN, but receive DUYET, let's descend slowly to one thousand eight hundred feet, and it's visual.}		
11:22:56.8 **HOT-2**	{yes} yes sir {I will set to one thousand eight hundred.}		
11:23:03.1 **HOT-1**	{because} clear visual {is given.}		
11:23:04.0 **HOT-1**	yes sir.		
11:23:05.2 **HOT-1**	localizer capture.		
11:23:06.5 **HOT-2**	check, flaps one sir.		
11:23:08.9 **HOT-1**	speed check flaps one set.		
11:23:16.4 **HOT-2**	speed one nine two set.		
		11:23:17.3 **APR**	Asiana two one four heavy reduce speed to one eight zero maintain that till five mile final there's traffic behind and to the right that does have you in sight.
		11:23:23.7 **RDO-1**	localizer speed one eighty * final five mile * * Asiana two one four.

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:23:30.7 **CAM-2**	speed one eight zero.		
11:23:31.8 **CAM-1**	check.		
11:23:32.9 **HOT-2**	flaps five.		
11:23:36.0 **HOT-1?**	{* *.}		
11:23:42.4 **CAM-2**	flaps five sir.		
11:23:43.5 **CAM-1**	speed check.		
11:23:44.7 **CAM-1**	flaps five.		
11:23:46.7 **CAM-1**	set.		
11:23:47.8 **HOT-2**	check.		
11:23:49.5 **CAM-1**	{* *.}		
11:23:53.2 **HOT-2**	{yeah, I am descending now.}		
11:23:54.4 **HOT-1**	yeah.		
11:23:58.0 **HOT-1**	V/S.		
11:23:58.8 **HOT-2**	one thousand.		
11:24:00.9 **HOT-1**	check.		
11:24:32.2 **CAM-3**	to one eight zero five miles.		

TIME and SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	TIME and SOURCE	AIR-GROUND COMMUNICATION CONTENT
11:24:34.3 **CAM-1**	{Uhh?}		
11:24:34.4 **HOT-1**	ah ah ah one eight zero.		
11:24:35.0 **CAM-3**	one eight zero five miles.		
11:24:36.0 **CAM-2**	huh?		
11:24:36.8 **CAM-3**	* one eight zero.		
11:24:37.9 **HOT-2**	okay one eight zero five miles.		
11:24:50.6 **HOT-2**	okay gear down sir.		
11:24:52.0 **HOT-1**	gear down.		
11:24:53.1 **CAM-1**	{this seems a little high.}		
11:24:53.3 **CAM**	[sound of increased background noise]		
11:24:55.2 **CAM-2**	{yeah.}		
11:24:55.6 **CAM-1**	{this should be a bit high}		
11:24:58.9 **HOT-2**	{do you mean it's too high?}		
11:24:59.6 **HOT-1**	*.		
11:25:02.0 **CAM-2**	{I will descend more.}		
11:25:13.1 **FA**	[passenger announcement made in Korean]		

TIME and **SOURCE**	**INTRA-COCKPIT COMMUNICATION** **CONTENT**	TIME and **SOURCE**	**AIR-GROUND COMMUNICATION** **CONTENT**
11:25:23.0 **CAM-1**	{* * *.}		
11:25:29.0 **CAM-1**	ok.		
11:25:31.2 **CAM-1**	one thousand.		
		11:25:36.1 **APR**	Asiana two one four heavy contact San Francisco tower one two zero point five.
		11:25:39.4 **RDO-1**	* * * five Asiana two one four good day.
11:25:43.4 **HOT-2**	(missed) approach three thousand * *.		
11:25:50.3 **CAM-?**	(down flaps five).		
		11:25:56.0 **RDO-1**	ah tower good morning Asiana two one four final seven miles south two eight left.
11:26:01.1 **HOT-2**	flaps (twenty).		
11:26:02.2 **CAM-1**	flaps five ahh.		
11:26:04.9 **CAM-1**	flaps twenty.		
11:26:05.9 **CAM-2**	yeah.		
11:26:12.6 **CAM-2**	flaps thirty.		
11:26:14.8 **CAM-1**	speed check flaps thirty (sir).		
11:26:15.1 **HOT-1**	check.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:26:21.2 **HOT-1**	{* * speed. speed one three seven.* * one thousand speed. speed one three seven.}		
11:26:21.2 **CAM-1**	speed * *.		
11:26:24.6 **CAM**	[sound of click]		
11:26:27.6 **CAM**	[sound of click]		
11:26:28.3 **CAM-1**	flaps thirty.		
11:26:29.5 **HOT-2**	* sir *.		
11:26:32.5 **CAM-1**	flight director.		
11:26:34.0 **CAM-2**	check.		
11:26:35.7 **CAM-1**	speed.		
11:26:36.8 **CAM-2**	target speed one three seven.		
11:26:40.4 **CAM-2**	flight director off.		
11:26:41.3 **CAM-1**	okay.		
11:26:43.4 **CAM**	[sound of knock]		
11:26:44.0 **CAM-1**	{it's high.}		
11:26:52.2 **CAM-1**	one thousand.		
11:26:54.2 **CAM-2**	check.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:26:58.6 **CAM-3**	sink rate sir.		
11:26:59.1 **HOT-2**	yes sir.		
		11:26:59.5 **RDO-1**	tower Asiana two one four short final.
11:27:05.1 **CAM-3**	sink rate sir.		
11:27:06.1 **HOT-1**	cleared to land {?}		
11:27:07.3 **CAM-?**	{(sink rate.)}		
		11:27:07.5 **TWR**	Asiana two one four heavy San Francisco tower runway two eight left cleared to land.
11:27:10.7 **CAM**	* * * *.		
		11:27:10.8 **RDO-2**	cleared to land two eight left Asiana two one four.
11:27:14.3 **CAM-1**	okay.		
11:27:15.5 **CAM**	five hundred. [electronic voice]		
11:27:16.6 **HOT-2**	landing checklist.		
11:27:16.8 **CAM**	minimums, minimums. [electronic voice]		
11:27:17.5 **CAM-1**	landing checklist complete cleared to land.		
11:27:19.8 **HOT-1**	on glide path sir.		
11:27:21.2 **CAM-2**	check.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:27:32.3 **CAM**	two hundred. [electronic voice]		
11:27:33.6 **CAM-1**	{it's low.}		
11:27:34.8 **CAM-2**	yeah.		
11:27:36.0 **HOT-?**	*		
11:27:38.2 **CAM**	[sound similar to electronic seat adjustment]		
11:27:39.3 **CAM**	[sound of quadruple chime]		
11:27:41.6 **CAM**	one hundred. [electronic voice]		
11:27:42.8 **CAM-1**	speed.		
11:27:44.0 **CAM-?**	speed * *.		
11:27:45.8 **CAM**	fifty. [electronic voice]		
11:27:46.4 **CAM**	[sound similar to stick shaker lasting for approximately 2.24 seconds]		
11:27:46.6 **CAM**	forty. [electronic voice]		
11:27:47.3 **CAM**	thirty. [electronic voice]		
11:27:47.8 **HOT-1**	oh # go around.		
11:27:48.6 **CAM**	twenty. [electronic voice]		
11:27:49.5 **HOT-2**	go around.		

TIME and SOURCE	**INTRA-COCKPIT COMMUNICATION CONTENT**	**TIME and SOURCE**	**AIR-GROUND COMMUNICATION CONTENT**
11:27:49.6 **CAM**	ten. [electronic voice]		
11:27:50.3 **HOT-?**	oh.		
11:27:50.3 **CAM**	[sound similar to impact]		
11:27:51.9 **HOT**	[sound similar to telephone dial tone]		
11:27:54.3 **CAM**	[sound of quadruple chime]		
11:27:55.4 **INT-?**	ah what's happening over there?		
11:27:55.9 **CAM**	[sound of quadruple chime]		
11:27:57.8 **CAM**	[sound of quadruple chime]		
11:28:00.2 **CAM**	{sound of quadruple chime]		

End of Transcript

11:28:01.9 [end of recording]

COMMENTS OF THE REPUBLIC OF KOREA TO THE NATIONAL TRANSPORTATION SAFETY BOARD'S DRAFT REPORT CONCERNING THE INVESTIGATION OF THE ACCIDENT INVOLVING ASIANA AIRLINES FLIGHT 214

Prepared and submitted by:

AVIATION AND RAILWAY
ACCIDENT INVESTIGATION BOARD

June _16, 2014

I. Overall Comment

- ARAIB believes that this accident is one of a series of recent accidents caused by a failure of the pilots to recognize unexpected operations of the autothrottle system.

- ARAIB is deeply concerned that the Report fails to engage in in-depth investigation and to address the issue of a deficiency in the low-speed alert and speed protection of the B777 automation system, particularly as it was a key agenda in the investigative hearing. The NTSB and ARAIB's joint investigative efforts have been focused on this very issue, so it comes as a surprise that the issue was only dealt with superficially in the Report and not as a probable cause of the accident.

- ARAIB recognizes that a deficiency in the automation system related to speed protection has been a major cause of several recent aviation accidents. In this respect, international standards need to be developed and implemented to improve aviation safety.

II. B777 automation system

A. Inconsistencies in the airspeed protection feature and inadequacy of the low-speed alert

1. Failure to maintain proper airspeed has been a major cause of several recent aviation accidents.

   a) In response to four recent accidents that involved a failure to maintain proper airspeed, the U.S. Federal Aviation Administration ("FAA") released a safety policy statement in 2011 and the European Aviation Safety Agency ("EASA") stated that an inconsistency in the automation behavior has been in the past a major contributing factor to aviation accidents. The Dutch Safety Board ("DSB") recommended Boeing, along with other manufacturers, to improve a low-speed alert by introducing a unique, immediate alarming sound as a part of the alert system.

   Four accidents that involved a failure to maintain airspeed:

(1) Thomsonfly Ltd, Boeing Model 737-300, near Bournemouth, United Kingdom on September 23, 2007
(2) Empire Airlines, Model ATR-42-300, in Lubbock, Texas on January 27, 2009
(3) Colgan Air, de Havilland Model DHC-8-400, in Clarence Center, New York on February 12, 2009
(4) Turkish Air, Boeing Model 737-800, in Amsterdam, Netherlands on February 25, 2009

FAA Policy No PS-ANM-25-16 (2011)

This policy statement is necessary to address a safety vulnerability, as evidenced in the following four recent incidents and accidents that involved the failure to maintain proper airspeed:

Thomsonfly Ltd, Boeing Model 737-300, near Bournemouth, United Kingdom on September 23, 2007—This incident involved deceleration after the flightcrew did not notice the autothrottle failure or the autothrottle disengagement. The flightcrew allowed the airspeed to decrease 20 knots below Vref before they initiated recovery. After multiple stick shaker activations and an aerodynamic stall, the flightcrew eventually regained control, and the airplane landed safely.

Empire Airlines, Model ATR-42-300, in Lubbock, Texas on January 27, 2009 — This accident involved a deceleration to stick shaker and autopilot disconnect following a flap anomaly. The probable cause was the flightcrew's failure to monitor and maintain a minimum safe airspeed while executing an instrument approach in icing conditions, which resulted in an aerodynamic stall at low altitude.

Colgan Air, de Havilland Model DHC-8-400, in Clarence Center, New York on February 12, 2009 — This accident involved decelerating to a low speed, which activated the stall warning while on approach. The probable cause of this accident was the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover. The flightcrew's failure to monitor airspeed also contributed to this accident.

Turkish Air, Boeing Model 737-800, in Amsterdam, Netherlands on February 25, 2009 — This accident involved a radio altimeter anomaly that led to an inappropriate autothrottle thrust reduction. The flightcrew failed to recognize the airspeed decay and the pitch increase *until the moment the stick shaker was activated. Subsequently, the approach-to-stall recovery procedure was not executed properly, causing the airplane to stall and crash.*

b) The FAA issued *Alerts for Excursions Outside Acceptable Margins* and *Reliability of Protection/Alerts*, respectively, with respect to a low-speed alert and speed protection function.

> *FAA Policy No PS-ANM-25-16 : Reliability of Protection/Alerts.*
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> *The reliability of the low-speed protection or alert required by § 25.1329(h) must meet the requirement of § 25.1309(b)(2). Failure of the low-speed protection or alert required by § 25.1329(h), which would reduce the capability of the airplane or the ability of the crew to cope with adverse operational conditions, must be improbable.*
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> *AC 25.1329(h)*
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> *(2) Compliance with § 25.1329(h). Standard stall warning and high-speed alerts are not always timely enough for the flight crew to intervene to prevent unacceptable speed excursions during FGS operation. The intent of § 25.1329(h) is for the FGS to provide a speed protection function for all operating modes, so that the airspeed can be safely maintained within an acceptable margin of the speed range of the normal flight envelope.*

2. FAA AC 25.1329(h) specifies that it intends to ensure “a speed protection function for all operation modes.” However**, the B777 did not provide a speed protection in HOLD mode.**

3. FAA AC 25.1322-1 sets out that a low-speed alert “should be a time-critical warning” level alert that “gives the flight crew immediate awareness without further reference to other flight deck indications.” Contrary to the requirement, **the B777 low-speed alert was a caution that did not require immediate pilot actions, and generated a master beeper that sounds identical to more than 60 other problems on the aircraft.**

FAA Policy No PS-ANM-25-16 : Alerts for Excursions Outside Acceptable Margins.

> *If a low-speed alert is used as the means of compliance with § 25.1329(h), the alert should ensure that the flightcrew is immediately aware of any excursions beyond an acceptable margin from the speed range of the normal flight envelope.*

> *In accordance with § 25.1322(b), this alert must be a caution or a warning. Since automatic flight control presupposes that the flightcrew will not have their hands on the controls, aural and visual indications are presumably the essential attention-getting senses required by § 25.1322(c)(2).*
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> *In addition, the alert should be time-critical for warnings and for cautions, and be consistent with the elements of the related time-critical warning in accordance with AC 25.1322-1.*
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> *AC 25.1322-1 b.*
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> *Time-Critical Warning Alerts. Some warnings may be so time-critical for the safe operation of the airplane that general alerts such as a master visual alert and a master aural alert may not provide the flightcrew with immediate awareness of the specific alerting condition that is commensurate with the level of urgency of flightcrew response necessary. In such cases, warning elements dedicated to specific alerting conditions should be provided that give the flightcrew immediate awareness without further reference to other flight deck indications. Examples of such time-critical warnings include reactive windshear and ground proximity.*
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> *The alerting elements for time-critical warnings should include:*
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> - *Unique voice information or unique tone, or both, for each alerting condition, and;*
> - *Unique visual alert information in each pilot's primary field of view for each alerting condition.*

4. The EASA stated in its Debrief Note Ex 14-1 that the loss of speed protection in certain automation modes on the B787 can be a contributing factor to an accident. EASA characterized the automation inconsistency as "a strong contributor to aviation accidents" which must be improved upon.

> *Autothrottle Wake-Up, speed protection feature: The "autothrottle wake up" feature has been considered by the certification team as a system improving significantly the safety of the aircraft to be certified. It protects the aircraft not only against stall but also against low energy states, anticipating on the stick shaker triggering. Unfortunately there are on the B787 (as well as some other previous Boeing models) at least two automation modes (FLCH in descent and VNAV speed in descent, with ATHR on HOLD) for which the "Autothrottle Wake up" function is not operative and therefore does*

> *not protect the aircraft. Although the certification team accepts that this "Autothrottle wake up" feature is not required per certification requirements, these two exceptions look from a pilot's perspective as an inconsistency in the automation behavior of the airplane. Inconsistency in automation behaviors has been in the past a strong contributor to aviation accidents. The manufacturer would enhance the safety of the product by avoiding exceptions in the "Autothrottle wake up" mode condition.*

5. In its Final Report on Turkish Airlines Flight B737-800's crash at Amsterdam Schiphol Airport in Netherlands on February 25, 2009 - **the accident very similar to Asiana Flight 214** - the DSB recommended Boeing to "assess" an auditory low-speed warning signal and, if shown effective, "mandate its use." In response, Boeing issued a Service Bulletin 737-34A2292 in April 2012, which instructed an electronic voice based low-speed alert which clearly enunciating "airspeed low" be installed on the B737 aircrafts within 12 months of issuance.

> *Boeing, FAA and EASA should assess the use of an auditory low-speed warning signal as a means of warning the crew and - if such a warning signal proves effective - mandate its use.*

6. Although the FAA, EASA and DSB had recommended Boeing to improve the design of the low-speed alert and speed protection logic on its aircrafts, Boeing failed improved the B777, which shares the same autothrottle operation and design as the B787. Boeing did not heed to these recommendations. As a result, at least four past accidents were attributable to the aircraft's failure to protect airspeed and to give a timely and distinct low-speed alert.

B. Improper function of the low-speed alert

1. A low-speed alert, a quadruple chime, enunciated between 12 to 11 seconds prior to impact. Moreover, when the alert sounded it was just a general "caution" chime, which is used to signify more than 60 other problems on the aircraft. Unlike higher priority "warning" alerts, a general "caution" does not require immediate crew action.

2. The quadruple master chime is indistinguishable and under extraordinarily high workload, it would have increased the heavy pilot workload and caused confusion amongst the crew. Within 4 seconds after the master chime sounded, the PM pushed the thrust levers. On the accident flight, if a more direct aural

alert, such as an electronic voice clearly enunciating “low airspeed” was provided to the crew, they would have reacted immediately to such alert.

3. About 4 seconds after the alert sounded and 7 seconds prior to impact, the PM pushed the throttles forward to execute a go-around. About 3 seconds after the PM’s action and 4 seconds prior to impact, the stick shaker - a low-speed warning - activated.

4. The simulation study indicated that the accident flight had adequate performance capability to accomplish a go around initiated no later than 11 to 12 seconds prior to ground impact. If a smaller tolerance is built in to the simulation, a go-around initiated 1 to 2 seconds earlier may have prevented impacting the seawall.

5. If the low-speed alert was a “warning” which requires immediate crew action or a more direct aural alert, such as an electronic voice clearly enunciating “low airspeed,” the crew response time would have been shorter and the crew could have increased power earlier so that impacting the seawall could have been prevented.

6. Inadequacy of the B777 low-speed alert is attributable to the crew’s delayed execution of a go-around and confusion, which could have prevented the decaying airspeed had it warned the flight crew in time to permit a timely response from the pilots, and could have prevented the impact as a last resort in the safety features embedded in the aircraft.

C. Conclusions

1. **The B777 did not provide adequate airspeed protection. Although the FAA recommends that airspeed protection be maintained in all flight modes, the B777 did not provide the necessary protection in HOLD mode.**

2. **The B777’s low-speed alert was inadequate.**

   Although Boeing had improved the B737-800 low-speed alerts by introducing a unique aural cue for immediate pilot awareness, the low-speed alert of B777, which shares a similar logic, remains unchanged. The level of urgency of the low-speed alert on the B777 remains unchanged - it is not a warning, but a caution, which does not require immediate crew action. As it stands, the low speed caution alert is too late to provide the crew a window of opportunity to correct the developing low speed situation.

3. **Boeing’s failure to comply with previous recommendations to improve the**

design of the B777

As a result of four recent accidents involving a failure to maintain airspeed - a significant safety concern that is directly relevant to Asiana flight 214 - the FAA, EASA and DSB had recommended Boeing to improve the low airspeed alert and the airspeed protection features of its aircrafts. Boeing neither implemented any corrective measures to the B777 (which share the same automation system design and logic as the previous accident flights), nor provided a revised training material or issued notice to the B777 operators.

Had Boeing complied with these recommendations, improved the speed control systems of its aircrafts and informed the airlines with respect to the automation inconsistencies in its aircrafts, the accident could have been averted.

III. ADDITIONAL CONTRIBUTING FACTOR

ARAIB determines that additional Contributing Factor to the accident is "Inadequacy of the B777's low airspeed alert and inconsistencies in the airspeed protection function"

IV. ADDITIONAL RECOMMENDATIONS

Despite several recent aviation accidents, inadequate measures have been taken by international regulatory organizations to improve aviation safety.

In response to four recent accidents that involved a failure to maintain proper airspeed, the FAA, EASA and DSB stated that an inconsistency in the automation behavior has been in the past a major contributing factor to aviation accidents and strongly encouraged the manufacturer to improve its automated system. Boeing, however, did not heed this recommendation. While Boeing made passive changes to certain aircraft type, it did not take proactive measures to improve the automated system, including a low-speed alert, across its aircraft types, despite the fact they share the same automation issue.

ICAO should require all large commercial aircraft manufacturers to (1) install a more direct and distinct low-speed alert that permits a timely response from the pilots, and (2) improve the automation system to provide adequate speed protection in all modes.