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SPECIAL DOUBLE ISSUE

Preparing for Last-minute Runway Change, Boeing 757 Flight Crew Loses Situational Awareness, Resulting in Collision with Terrain

On their approach to Cali, Colombia, the flight crew selected a direct course to the ROMEO nondirectional beacon (NDB), believing that they were selecting the ROZO NDB. According to the Colombia Aeronautica Civil accident investigation report, the incorrect flight management system entry led the airplane to turn toward Bogota, Colombia, which was 212 kilometers (132 miles) to the northeast.

FSF Editorial Staff

The crew of an American Airlines (AA) Boeing 757-223, Flight 965, was transitioning from cruise flight to a very high frequency omnidirectional radio range (VOR)/distance measuring equipment (DME) instrument approach to Runway 19 at the Alfonso Bonilla Aragon International Airport (SKCL), Cali, Colombia, when the aircraft collided with a mountain 53 kilometers (33 miles) northeast of the CALI VOR.

The two flight crew members, six cabin crew members and 151 passengers were killed. Five passengers survived the Dec. 20, 1995, accident, but one of them later died as a result of injuries sustained in the accident. The aircraft was destroyed.

The accident occurred at night in visual meteorological conditions (VMC).

The official report of the Aeronautica Civil of the Republic of Colombia said that "the probable causes of this accident were: (1) the flight crew's failure to adequately plan and execute the approach to Runway 19 at SKCL, and their inadequate use of automation; (2) failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them of the inadvisability of continuing the approach; (3) the lack of situational awareness of the flight crew regarding vertical navigation, proximity to terrain and the relative location of critical radio aids; [and] (4) failure of the flight crew to revert to basic radio navigation at the time when the FMS [flight management system]-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight."

The report also said that "contributing to the cause of the accident were: (1) the flight crew's ongoing efforts to expedite their approach and landing in order to avoid potential delays; (2) the flight crew's execution of the GPWS [ground-proximity warning system] escape maneuver while the speedbrakes remained deployed; (3) FMS logic that dropped all intermediate fixes from the display(s) in the event of execution of a direct routing; [and] (4) FMS-generated navigational information that used a different naming convention from that published in navigational charts.”

Flight 965 was a regularly scheduled passenger flight from Miami (Florida, U.S.) International Airport (MIA) to SKCL. The flight crew arrived at the American Airlines MIA operations office about one hour before the scheduled departure time of 1640 hours local time. “The operations base manager later stated that both the captain and first officer were in his office about 40 minutes before the required check-in time, and appeared to be in good spirits,” the report said.

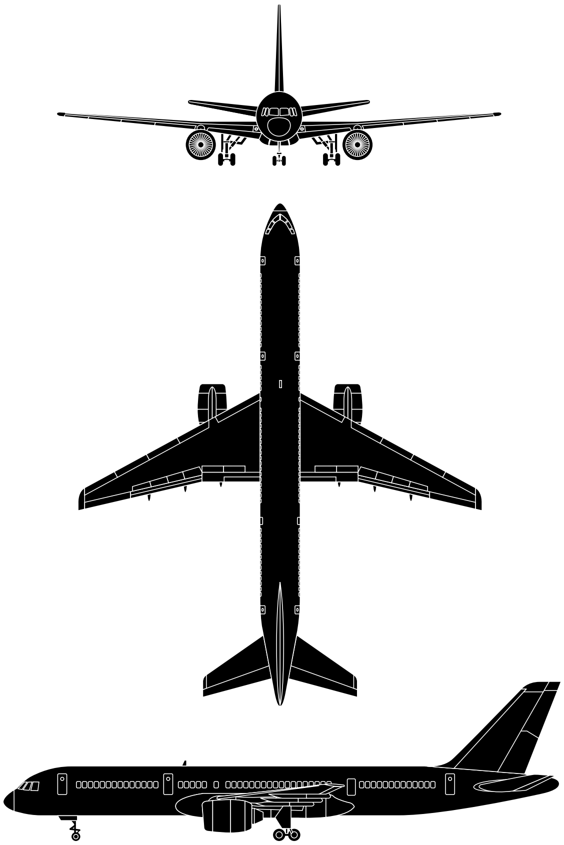
The flight was delayed at the gate for about 34 minutes to accommodate connecting passengers and baggage. “The flight departed the gate at 1714, and then experienced another ground delay of one hour and 21 minutes that the flight dispatcher stated was related to gate congestion due to airport traffic,” the report said. “[Flight] 965 departed MIA at 1835, with an estimated time en route to Cali of three hours, 12 minutes.”

Flight 965’s route “was from MIA through Cuban airspace, then through Jamaican airspace and into Colombian airspace, where the flight was re-cleared by Barranquilla Air Traffic Control Center (Barranquilla Center) to proceed from KILER intersection direct to BUTAL intersection,” the report said. “The flight then passed abeam Cartagena [VOR] (CTG). Bogota Center subsequently cleared the flight to fly direct from BUTAL to the TULUA VOR [ULQ].”

When the flight passed BUTAL intersection, “Bogota Center again cleared the flight from its present position to ULQ, and told the flight to report when they were ready to descend,” the report said. At 2110, the crew obtained the Cali weather from the AA system operations control center via the onboard aircraft communications addressing and reporting system (ACARS).

The crew was given the following weather observation for Cali, reported at 2000 hours local time: scattered clouds at 518 meters (1,700 feet) and 3,050 meters (10,000 feet), visibility more than 10 kilometers (six miles), surface wind from 160 degrees at four knots, temperature 23 degrees C (73 degrees F) and dew point 18 degrees C (64 degrees F).

En route, the flight crew discussed the crew rest requirements for the cabin crew members. Because of the flight’s delayed departure from MIA, the captain was concerned that the cabin attendants would not have the U.S. Federal Aviation Administration (FAA)-required rest period before the crew’s scheduled departure time the following morning.



Boeing 757

The Boeing 757-200 series is a medium-range airliner designed to carry 186 passengers in a typical mixed-class configuration. The B-757 can accommodate up to 239 passengers in charter service, putting its capacity between that of the Boeing 737-400 and the Boeing 767. A longer range version and a freighter configuration of the B-757 are also available.

The B-757-200 is powered by two turbofan engines mounted in underwing pods.Engine pairs for the B-757 are provided by Pratt & Whitney (PW 2037 or PW 2040) and Rolls-Royce (535 series). The engines differ slightly in their static thrust.

The aircraft has a maximum takeoff weight of 104,325 kilograms (230,000 pounds) and engine thrust is rated between 170 kilonewtons (38,200 pounds) and 197.1 kilonewtons (43,100 pounds). At maximum takeoff weight with 186 passengers, the B-757 has a range of between 5,222 kilometers (2,820 nautical miles) and 5,519 kilometers (2,980 nautical miles), depending on the engine installed. The B-757 has a top speed of Mach 0.86 and a normal cruising speed of Mach 0.80 and has an initial cruising altitude of about 12,000 meters (40,000 feet).

The two-pilot cockpit of the B-757 has a computerized, fully integrated flight management system (FMS) that provides automatic guidance and control of the aircraft from immediately after takeoff to final approach and landing. The FMS controls navigation, guidance and engine thrust to ensure that the aircraft flies the most efficient route and flight profile.

Source: *Jane’s All the World’s Aircraft*

As they prepared to descend from cruise, the captain told the first officer, who was the pilot flying, " … If you'd keep the speed up in the descent … it would help us too, okay?"

At 2126:20, Bogota Center cleared the flight to descend from its cruising altitude of flight level (FL) 370 (11,285 meters [37,000 feet]) down to FL 240 (7,320 meters [24,000 feet]).

During the descent, the captain radioed American Airlines operations at Cali, and reported the flight's estimated arrival time. The operations officer issued the gate parking assignment for the flight and said that Runway 1 was in use at Cali.

At 2131:53, the crew reported to Bogota Center that the aircraft was level at FL 240, and the controller told the crew to expect a lower altitude in two minutes.

About two minutes later, the first officer said to the captain, "Well, if she [the Bogota Center controller] doesn't let us down in a little while, she's goin' to put me in a jam here." The captain then called Bogota Center and requested a lower altitude. The flight was cleared down to FL 200 (6,100 meters [20,000 feet]).

"At 2134:04, the flight was instructed to contact Cali Approach Control (Approach)," the report said. When the captain contacted Cali Approach, the controller requested the flight's DME distance from the CALI VOR. The captain replied that they were 63 DME (117 kilometers [63 nautical miles]) from CALI VOR.

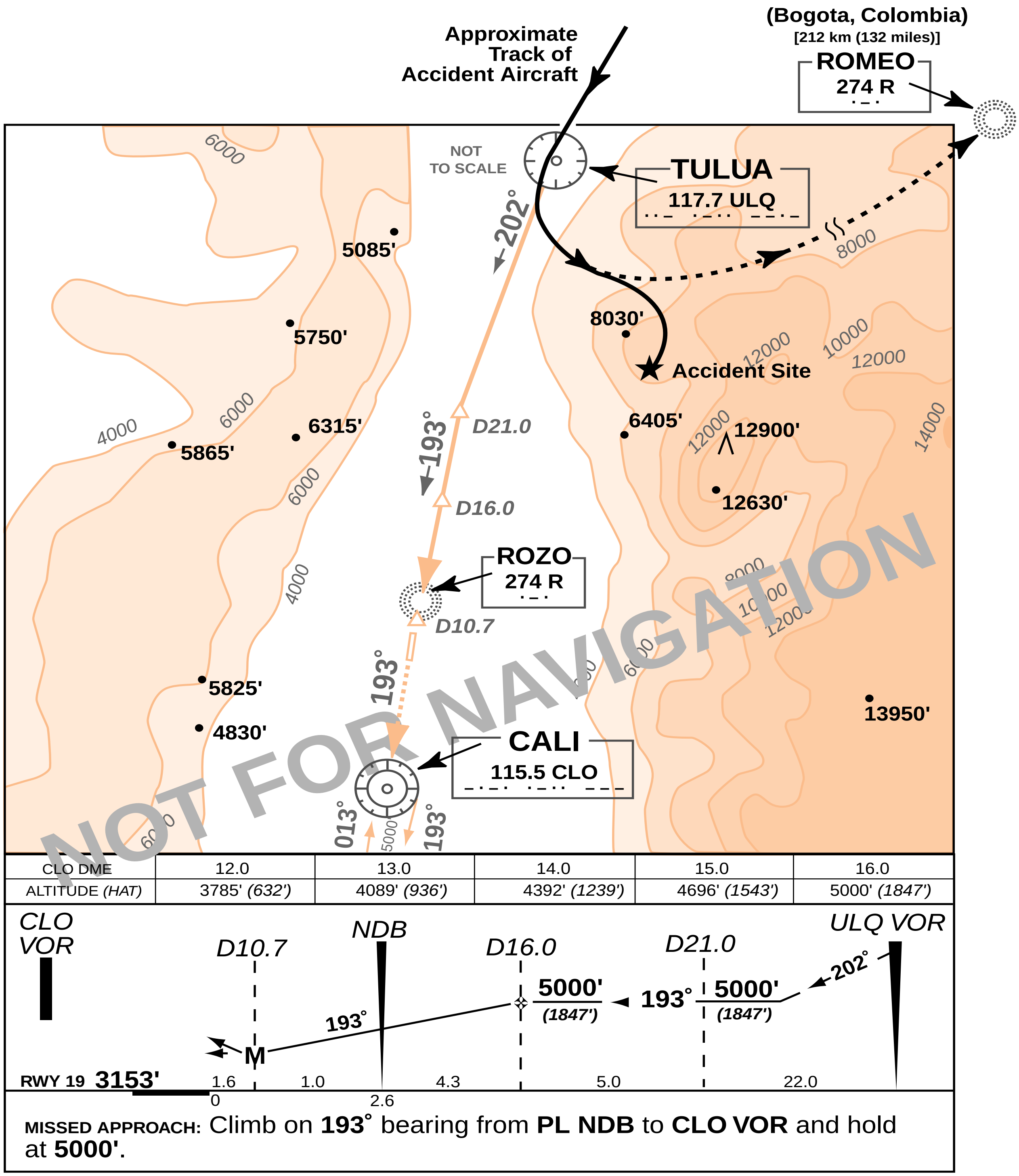
The controller then cleared the flight to the CALI VOR, to descend to 4,575 meters (15,000 feet), and to report the TULUA VOR. When the captain read back the clearance, he said, "Okay, understood. Cleared direct to CALI VOR. Uh, report TULUA and altitude one five, that's fifteen thousand … . Is all that correct, sir?" The controller replied, "Affirmative."

The captain then told the first officer he had entered a direct route to the CALI VOR in the FMS. (For details of the B-757 FMS, see "The Boeing 757 Flight Management System," page 22.)

At 2136:31, Cali Approach asked the crew if they were able to approach and land on Runway 19. After a brief discussion with the first officer, the captain replied that they would accept the approach to Runway 19, but would need a lower altitude immediately. The controller then cleared the flight for the VOR/DME instrument approach to Runway 19 (Figure 1, page 4),

After the aircraft struck trees on the east side of a mountain ridge, the main wreckage of Flight 965 came to rest on the west side about 122 meters to 152 meters (400 feet to 500 feet) from the top. (Photo: Reuters/Claudia Daut/Archive Photos)

VOR/DME Approach to Runway 19, Cali, Colombia, on Dec. 20, 1995



VOR = very high frequency omnidirectional radio range
DME = distance measuring equipment

Source: Colombia Aeronautica Civil

Figure 1

the ROZO One Arrival, and again instructed the crew to report the TULUA VOR.

The captain acknowledged the clearance and said, "Will report the VOR … ." The controller once again instructed the crew to report the TULUA VOR, which the captain acknowledged.

The flight crew discussed which fix they should navigate to next. The captain said, "I gotta give you to TULUA first of all. You, you wanna go right to CAL, er to TULUA?"

The first officer said, "Uh, I thought he said the ROZO One arrival?"

The captain said, "Yeah he did. We have time to pull that out(?) … ."

After the sound of rustling pages was heard on the cockpit voice recorder (CVR), the captain said, " … ROZO … there it is."

After the discussion, the captain asked Cali Approach if the flight could proceed direct to the ROZO nondirectional beacon (NDB) and execute the ROZO One arrival. The controller replied, "Affirmative, take the ROZO One … ." After the captain acknowledged, the controller told him to report TULUA, and the 21 DME (39 kilometers [21 nautical miles]) fix at 1,525 meters (5,000 feet).

(The airplane's flight data recorder [FDR] showed that the flight passed TULUA during this exchange and "began to turn left of the cleared course and flew on an easterly heading [of 100 degrees] for approximately one minute," the report said. "Then the airplane turned to the right, while still in the descent.")

At 2138:39, Cali Approach asked the flight for a position report, which the captain reported as 38 DME (70 kilometers [38 nautical miles]) from the CALI VOR.

Immediately following the exchange with Cali Approach, the first officer asked the captain, "Uh, where are we … ."

At one point, the crew apparently realized they had passed TULUA and the first officer asked, " … So you want a left turn back around to ULQ?" The captain responded that they should "press on," and told the first officer to "come to the right" and proceed to the CALI VOR.

At 2140:01, the captain told Cali Approach that they were "thirty-eight [nautical] miles" north of CALI VOR, and asked if they should proceed to TULUA and execute the ROZO One arrival to Runway 19. The controller replied that they could use Runway 19, and asked for their altitude and DME from

Search and rescue personnel were notified that Flight 965 was missing at 2150 hours, but it was not until after the wreckage was sighted at 0630 the next morning that search teams reached the site by helicopter. (Photo: Reuters/Henry Romero/ Archive Photos)

CALI. The captain reported they were 37 DME (69 kilometers [37 nautical miles]) from CALI, and at 3,050 meters.

The cockpit conversation suggested that the crew was still experiencing difficulty getting oriented to the TULUA VOR on the FMS display. The first officer finally said, "I don't want TULUA. Let's just go to the [Runway 19] extended centerline … ."

At 2141:02, Cali Approach asked the crew to report their altitude, which the captain reported as 2,745 meters (9,000 feet). The controller then asked for their distance from CALI. Before the captain could respond, the aircraft's GPWS sounded, "Terrain, terrain, whoop, whoop."

Shortly thereafter, the sound of the autopilot-disconnect warning could be heard on the CVR. The GPWS continued to alarm, and the aircraft stick shaker could be heard.

"The FDR showed that the flight crew added full power and raised the nose of the airplane, [but] the spoilers (speedbrakes) that had been extended during the descent were not retracted," the report said. "The airplane entered

Cockpit Voice Recorder Transcript, American Airlines Flight 965, Dec. 20, 1995

2134:40	**RDO-1**:	Cali Approach, American nine six five.
2134:44	**APR**:	American niner six five, good evening. go ahead.
2134:47	**RDO-1**:	ah, buenos noches senior, American nine six five leaving two three zero, descending to two zero zero. go ahead sir.
2134:55	**APR**:	the uh, distance DME from CALI?
2134:57	**RDO-1**:	the DME is six three.
2134:59	**APR:**	roger, is cleared to CALI VOR, uh, descend and maintain one, five thousand feet. altimeter three zero zero two … .
2135:09	**HOT-2**:	one five.
2135:09	**APR**:	… no delay expect for approach. report uh, TULUA VOR.
2135:14	**RDO-1**:	OK, understood. cleared direct to CALI VOR. uh, report TULUA and altitude one five, that's fifteen thousand three zero … zero … two. is that all correct sir?
2135:25	**APR**:	affirmative.
2135:27	**RDO-1**:	thank you.
2135:28	**HOT-1**:	I put direct CALI for you in there.
2135:29	**HOT-2**:	OK, thank you.
2135:44	**HOT-2**:	two fifty below ten here?
2135:47	**HOT-1**:	yeah.
2136:18	**CAM**:	[sound of single chime similar to seat belt switch being activated]
2136:20	**PA-1**:	uh, flight attendants please prepare for landing, thank you.
2136:24	**HOT-1**:	I sat 'em down and …
2136:27	**APR**:	* niner six five, Cali.
2136:28	**PA-1**:	niner.
2136:29	**RDO-1**:	niner six five, go ahead please.
2136:31	**APR**:	* sir the wind is calm. are you able to approach runway one niner.
2136:36	**HOT-1**:	would you like to shoot the one nine straight in?
2136:38	**HOT-2**:	uh yeah, we'll have to scramble to get down. we can do it.
2136:40	**RDO-1**:	uh yes sir, we'll need a lower altitude right away though.

into the regime of stick-shaker stall warning, nose-up attitude was lowered slightly, the airplane came out of stick-shaker warning, nose-up attitude then increased and stick shaker was reentered."

The airplane struck trees on the east side of a mountain at an altitude of 2,714 meters (8,900 feet) mean sea level (MSL). It then "continued over a ridge near the summit and impacted and burned on the west side of the mountain ... ," the report said. "The elevation of the top of the ridge was about [2,745 meters (9,000 feet)] MSL."

The report described the accident scene: "The initial impact area was marked by an area of broken trees, followed by a swath where the trees had been essentially flattened or uprooted. The area of uprooted trees began about [76 meters (250 feet)] below the top of the ridge. The initial impact swath was oriented along a heading of about 220 degrees.

"Wreckage that was found at the beginning of the wreckage path included thrust-reverser parts, a fan cowling, an APU [auxiliary power unit] tail cone, flap jackscrews, an engine fire bottle, the FDR and a small section of wing. The pattern of broken trees indicated that the airplane initially struck at a high nose-up attitude.

"The main wreckage came to rest on the west side of the ridge, about [122 meters to 153 meters (400 feet to 500 feet)] from the top. In addition to the engines, the largest portion of wreckage included the cockpit, a section of center fuselage about [11 meters (35 feet)] long, the CVR, aviation electronics (avionics) boxes, a section of the aft fuselage and a portion of the wing center section. ...

"There was limited postimpact fire, where the main fuselage came to rest."

The CVR recording ended at 2141:28. Search and rescue personnel were notified that the flight was missing at 2150. "The initial sighting of the accident was made by a helicopter at 0630 [the following morning]," the report said. "Search teams arrived by helicopter to the accident within a few minutes of the sighting. ...

"The body of the first officer was recovered on the first day after the accident. The body of the captain was retrieved from the accident on the third day after the accident. The cause of death of each was determined to be blunt force trauma. ...

"The characteristics and magnitude of the impact and subsequent destruction of the airplane indicated that the accident was nonsurvivable. However, five passengers initially survived the crash, having sustained serious injuries. One died later in the hospital.

"Postmortem examination of the occupants indicated that the characteristics of the fatal ... injuries varied according to the location of the persons in the crashed airplane. All of the injuries were consistent with deceleration trauma of different intensity consistent with the aircraft's impact and breakdown pattern."

Investigators reviewed the maintenance records of the accident aircraft and found "no malfunctions or outstanding maintenance items on the airplane prior to its departure from MIA … ," the report said. "In addition, there was no record of repetitive navigation or flight control system anomalies."

The weight-and-balance for the accident flight was reviewed and found to be within limits for both takeoff and landing.

The captain, 57, was hired by AA in 1969. His career at AA began as a flight engineer on the Boeing 727, and he later flew as captain on the B-727, B-757 and Boeing 767. The captain had 13,000 hours of flight time, with 2,260 hours in the B-757/767. He held a first-class medical certificate, with the limitation to wear corrective lenses for distant vision and to wear glasses to correct for near vision.

"The captain completed annual line checks, administered by an AA FAA-approved check airman, on Nov. 9, 1995 (domestic) and on Dec. 9, 1995 (international)," the report said. "In the line check on Dec. 9, 1995, he flew as captain on AA 965 from MIA to SKCL. Including flights to SKCL on Dec. 9 and Dec. 14, 1995, the captain flew a total of 13 times into Cali before the accident flight."

The report noted: "The captain was described by his colleagues as a nonsmoker, avid tennis player, in exemplary health and respected for his professional skills, including his skill in communicating with crew members and passengers. Company records contained numerous letters from passengers and company employees that reflected outstanding and courteous performance."

The first officer, 39, was hired by AA in 1986 as a flight engineer on the B-727. During his career at AA, he was a first officer on the B-727, the McDonnell Douglas MD-11, B-757 and B-767. The first officer had approximately 5,800 hours of flight time, with 2,286 hours in the B-757/767. He also held a first-class medical certificate with no limitations.

"The first officer attended the AA five-day qualification and recurrence course, and satisfactorily completed the required annual simulator check on Nov. 27, 1995," the report said. "The first officer had never flown into Cali. However, he had flown to other destinations in South America as an internationally qualified B-757/767 first officer."

The report also said: "The first officer was described by his colleagues as professionally competent, and appropriately assertive as a flight crew member. …

2136:43	**APR**:	roger. American nine six five is cleared to VOR DME approach runway one niner. ROZO number one, arrival. report TULUA VOR.
2136:52	**RDO-1**:	cleared the VOR DME to one nine, ROZO One arrival. will report the VOR, thank you sir.
2136:58	**APR**:	report uh, TULUA VOR.
2137:01	**RDO-1**:	report TULUA.
2137:03	**HOT-1**:	I gotta give you to TULUA first of all. you wanna go right to CAL, er to TULUA?
2137:09	**HOT-2**:	uh, I thought he said the ROZO One arrival?
2137:10	**HOT-1**:	yeah, he did. we have time to pull that out(?) …
2137:11	**CAM**:	[sound similar to rustling pages]
2137:12	**HOT-1**:	… and, TULUA One … ROZO … there it is.
2137:25	**HOT-1**:	yeah, see that comes off TULUA.
2137:27	**HOT-2**:	OK.
2137:29	**HOT-1**:	can American Airlines uh, nine six five go direct to ROZO and then do the ROZO arrival sir?
2137:36	**APR**:	affirmative. take the ROZO One and runway one niner, the wind is calm.
2137:42	**RDO-1**:	all right ROZO, the ROZO One to one nine, thank you, American nine six five.
2137:46	**APR**:	(thank you very much) … report TULUA and eeh, twenty-one miles, ah, five thousand feet.
2137:53	**RDO-1**:	OK, report TULUA twenty-one miles and five thousand feet, American nine uh, six five.
2137:59	**HOT-2**:	OK, so we're cleared down to five now?
2138:01	**HOT-1**:	that's right, and … off ROZO … which I'll tune here.
2138:26	**HOT-1**:	see what I get.
2138:27	**HOT-2**:	yeah.
2138:28	**HOT-1**:	… at twenty-one miles at five thousand's part of the approach, okay?
2138:31	**HOT-2**:	OK.
2138:33	**HOT-1**:	off ULQ, so let me put ULQ in here, seventeen seven cause I want to be on raw data with you.
2138:39	**APR**:	American niner six five, distance now?

2138:42	**RDO-1**:	uuuh, what did you want sir?
2138:45	**APR**:	distance DME.
2138:46	**HOT-1**:	OK the distance from uh, CALI is uh, thirty-eight.
2138:49	**HOT-2**:	uh where are we …
2138:49	**APR**:	roger.
2138:52	**HOT-2**:	we goin' out to …
2138:54	**HOT-1**:	let's go right to uh, TULUA first of all, OK?
2138:58	**HOT-2**:	yeah, where we headed?
2138:58	**HOT-1**:	seventeen seven, ULQ uuuh, I don't know what's this ULQ? what the, what happened here?
2139:04	**HOT-2**:	manual.
2139:05	**HOT-1**:	let's come to the right a little bit.
2139:06	**HOT-2**:	… yeah he's wantin' to know where we're headed.
2139:07	**HOT-1**:	ULQ. I'm goin' to give you direct TULUA.
2139:10	**HOT-2**:	OK.
2139:10	**HOT-1**:	… right now.
2139:11	**HOT-1**:	OK, you got it?
2139:13	**HOT-2**:	OK.
2139:14	**HOT-1**:	and …
2139:18	**HOT-1**:	it's on your map. should be.
2139:19	**HOT-2**:	yeah, it's a left uh, left turn.
2139:22	**HOT-1**:	yeah, I gotta identify that # though I …
2139:25	**NAV-1**:	[sound of Morse code (for) VC, "dit dit dit dah, dah dit dah dit"]
2139:25	**HOT-1**:	OK, I'm gettin' it. seventeen seven. just doesn't look right on mine. I don't know why.
2139:29	**NAV-1**:	[sound of Morse code, similar to ULQ, "dit dit dah dit dah dit dit dah dah dit dah dit"]
2139:30	**HOT-2**:	left turn, so you want a left turn back around to ULQ.
2139:32	**HOT-1**:	nawww … hell no, let's press on to …
2139:35	**HOT-2**:	well we're, press on to where though?
2139:37	**HOT-1**:	TULUA.
2139:39	**HOT-2**:	that's a right u u.
2139:40	**HOT-1**:	where we goin'? one two … come to the right. let's go to CALI. first of all, let's, we got # up here didn't we.

"AA provided additional ground school instruction to all flight crew members who were to begin operations into Latin America," the report said. " ... The airline also distributed to [pilots] a Jeppesen-sized reference guide devoted exclusively to the hazards and demands of flying into Latin America. The training and reference guide were not required by [U.S.] Federal Aviation Regulations (FARs)."

In the analysis of this accident, the report said, "there was no evidence of failures or malfunctions in the airplane, its components or its systems. Weather was not a factor in this accident. Both crew members were properly qualified and certificated to operate the airplane on this flight … . No evidence was found that either crew member was experiencing a behavioral or physiological impairment at the time that could have caused or contributed to the accident."

The investigation focused on why the flight crew proceeded off course and continued descending into an area of mountainous terrain, the role of the Cali Approach controller, the design of the B-757 speedbrakes, and AA procedures and training for executing a GPWS escape maneuver.

The Cali airport "is located in a long, narrow valley oriented north to south," the report said. "Mountains extend up to [4,270 meters (14,000 feet)] MSL to the east and west of the valley. The airport is located approximately [12 kilometers (7.5 miles)] north of CLO [VOR], at an elevation of [964 meters (3,162 feet)] MSL."

In reviewing the accident flight crew's preparation for the approach into Cali, investigators studied the CVR transcript and found no "details of an approach briefing into Cali, and investigators were unable to determine whether or how detailed a flight crew approach briefing took place before the beginning of recorded information," the report said.

Investigators determined that the airplane's FMS had been programmed for the instrument landing system (ILS) approach to Runway 1 at Cali. As a result, investigators believed, the flight crew had initially expected to navigate to the CALI VOR (located 14 kilometers [8.6 miles] south of Runway 1), execute the published course reversal at the VOR and proceed inbound on the ILS to Runway 1.

The expectation to fly the ILS was also "based on the experience of AA pilots operating into Cali, where almost all landings had been on Runway 1 … ," the report said. In addition, the flight crew had been advised by the AA operations office at Cali that Runway 1 was in use.

The report said: "As a result of the decision to accept a straight-in approach to Runway 19, the flight crew needed to accomplish the following actions expeditiously:

- "Locate, remove from its binder and prominently position the chart for the approach to Runway 19;

- "Review the approach chart for relevant information, such as radio frequencies, headings, altitudes, distances and missed-approach procedures;

- "Select and enter data from the airplane's [FMS] computers regarding the new approach;

- "Compare information on the VOR DME Runway 19 approach chart with approach information displayed from FMS data;

- "Verify that selected radio frequencies, airplane headings and FMS-entered data were correct;

- "Recalculate airspeeds, altitudes, configurations and other airplane control factors for the selected points on the approach;

- "Hasten the descent of the airplane because of the shorter distance available to the end of [the] new runway; [and,]

- "Monitor the course and descent of the airplane, while maintaining communications with air traffic control (ATC)."

The report said: "The evidence of the hurried nature of the tasks performed and the inadequate review of critical information between the time of the flight crew's acceptance of the offer to land on Runway 19 and the flight's crossing the initial approach fix, ULQ, indicates that insufficient time was available to fully or effectively carry out these actions. Consequently, several necessary steps were performed improperly or not at all and the flight crew failed to recognize that the airplane was heading towards terrain, until just before impact. Therefore, Aeronautica Civil believes that flight crew actions caused this accident."

In reviewing the flight crew's lack of situational awareness regarding the navaids and terrain during their descent, investigators also found that "the flight crew's situation[al] awareness was further compromised by a lack of information regarding the rules which governed the logic and priorities of the navigation database in the FMS," the report said.

For example, "the captain established the flight path that initially led to the deficiency in situation[al] awareness by misinterpreting the Cali Approach controller's clearance to proceed to CALI, given at 2134:59, as a clearance 'direct to' CALI," the report said. The captain's readback of "cleared direct to CALI VOR, report Tulua" received an affirmative response from the controller.

2139:45	**HOT-2**:	yeah.
2139:46	**HOT-1**:	go direct ... C ... L ... O. how did we get # up here?
2139:54	**HOT-1**:	come to the right, right now, come to the right, right now.
2139:56	**HOT-2**:	yeah, we're, we're in a heading select to the right.
2139:59	**RDO-1**:	[sound of click]
2140:01	**RDO-1**:	and American uh, thirty-eight miles north of CALI, and you want us to go TULUA and then do the ROZO uh, to uh, the runway, right? to runway one nine?
2140:11	**APR**:	***, you can * landed, runway one niner, you can use, runway one niner. what is (you) altitude and (the) DME from CALI?
2140:21	**RDO-1**:	OK, we're thirty-seven DME at ten thousand feet.
2140:24	**HOT-1**:	you're OK. you're in good shape now.
2140:25	**APR**:	roger.
2140:26	**HOT-1**:	we're headin'…
2140:27	**APR**:	report (uh) five thousand and uh, final to one one, runway one niner.
2140:28	**HOT-1**:	we're headin' the right direction, you wanna …
2140:32	**HOT-1**:	# you wanna take the one nine yet?
2140:34	**HOT-1**:	come to the right, come come right to CA CALI for now, OK?
2140:35	**HOT-2**:	OK.
2140:40	**HOT-1**:	it's that # TULUA I'm not getting for some reason.
2140:44	**HOT-1**:	see I can't get, OK now, no, TULUA's # up.
2140:48	**HOT-2**:	OK. Yeah.
2140:49	**HOT-1**:	but I can put it in the box if you want it.
2140:52	**HOT-2**:	I don't want TULUA. let's just go to the extended centerline of uh …
2140:55	**HOT-1**:	which is ROZO.
2140:56	**HOT-2**:	ROZO.
2140:56	**HOT-1**:	why don't you just go direct to ROZO then, all right?
2140:58	**HOT-2**:	OK, let's …
2140:59	**HOT-1**:	I'm goin' to put that over you.
2141:00	**HOT-2**:	… get some altimeters, we're out of uh, ten now.

“The captain’s readback was technically correct because he stated that he was to report TULUA, thus requiring him to report ‘crossing’ the fix first,” the report said. “However, the CVR indicates that the captain then executed a change in the FMS-programmed flight path to proceed ‘direct to’ the CALI VOR. In so doing, he removed all fixes between the airplane’s present position and CALI, including TULUA, the fix they were to proceed towards.”

Investigators found no evidence “that either pilot recognized that ULQ had been deleted from the display until they were considerably closer to CALI, and were in fact past ULQ at that time,” the report said. “Consequently, largely as a result of this action, the flight crew crossed the initial approach fix, ULQ, without realizing that they had done so and without acknowledging the crossing to the controller.”

The report said: “The logic of the FMS that removed all fixes between the airplane’s present position and the ‘direct to’ fix compromised the situational awareness of the flight crew … . Since the initial certification of the FMS on the B-757/767, the Boeing Co. has developed and implemented a change to the B-757 software that allowed such fixes to be retained in the display. However, this retrofit, part of a product improvement package for the airplane, had not been incorporated into the accident airplane.”

The accident flight crew was “experienced in the airplane, and [was] described as proficient in the use of the FMS by their peers,” the report said. “Yet, most likely because of the self-induced time pressure and continued attempts to execute the approach without adequate preparation, the flight crew committed a critical error by executing a change of course through the FMS without verifying its effect on the flight path.”

Investigators found evidence that “either the captain or the first officer selected and executed a direct course to the identifier ‘R,’ in the mistaken belief that R was ROZO as it was identified on the approach chart,” the report said.

In the wreckage of the accident airplane, investigators recovered circuit cards from the airplane’s FMS that contained nonvolatile memory. These components, along with portions of the airplane’s FMS and flight management computer (FMC), were shipped to Honeywell Air Transport Systems (the equipment manufacturer) for examination.

When power was applied to the FMC and its memory was restored, the FMC-planned route for the accident flight was displayed. The navigational fixes displayed showed the flight proceeding from ULQ to CLO, then via the ILS to Runway 1. The FMC also displayed a modification to the stored route.

Tests were then conducted using a B-757 fixed-base simulator, and an FMS bench-type simulator. “Several different displays

2141:01	**HOT-1**:	all right.
2141:02	**APR**:	niner six five, altitude?
2141:05	**RDO-1**:	nine six five, nine thousand feet.
2141:10	**APR**:	roger, distance now?
2141:15	**CAM-4**:	terrain, terrain, whoop, whoop…
2141:17	**HOT-1**:	oh #.
2141:17	**CAM**:	[sound similar to autopilot disconnect warning starts.]
2141:18	**HOT-1**:	… pull up baby.
2141:19	**CAM-4**:	… pull up, whoop, whoop, pull up.
2141:20	**CAM**:	[sound similar to aircraft stick shaker]
2141:20	**HOT-2**:	it’s OK.
2141:21	**CAM-4**:	pull up.
2141:21	**HOT-1**:	OK, easy does it, easy does it.
2141:22	**CAM**:	[sound similar to autopilot disconnect warning and sound similar to aircraft stick shaker stops.]
2141:23	**HOT-2**:	(nope)
2141:24	**HOT-1**:	up baby …
2141:25	**CAM**:	[sound similar to aircraft stick shaker starts and continues to impact]
2141:25	**HOT-1**:	… more, more.
2141:26	**HOT-2**:	OK.
2141:26	**HOT-1**:	up, up, up.
2141:27	**CAM-4**:	whoop, whoop, pull up.
2141:28	end of recording	

HOT	=	Crew member hot microphone voice or sound source
RDO	=	Radio transmission from accident aircraft
CAM	=	Cockpit area microphone voice or sound source
APR	=	Radio transmission from Cali Approach Control
PA	=	Transmission made over aircraft public address system
-1	=	Voice identified as captain
-2	=	Voice identified as first officer
-?	=	Voice unidentified
*	=	Unintelligible word
#	=	Expletive
( )	=	Questionable insertion
[ ]	=	Editorial insertion
…	=	Pause

Source: Colombia Aeronautica Civil

were used to replicate the flight-path and routing information that was recovered from the accident FMC nonvolatile memory at Honeywell Systems, and the accident flight's arrival, descent, approach phase and attempted escape maneuver were replicated as closely as possible on the fixed-base simulator," the report said.

The study found that "neither the Boeing fixed-base simulator, nor the [FMS] simulator could be back-driven with the data obtained directly from the accident airplane's FDR," the report said. "Instead, data obtained from the FDR and nonvolatile memory data from the FMC were input into both simulators, to replicate the flight as closely as possible from [101 kilometers (63 miles)] north of CLO to and including the escape maneuver."

The study found that "calling up 'R' on the CDU [central display unit] displayed a series of waypoints and their coordinates," the report said. "They were located north and south of the equator, and ordered from top to bottom of the display by their distance from the airplane. 'ROMEO,' a nondirectional ... beacon (NDB) in the city of Bogota, was the first and closest waypoint displayed. 'ROZO,' which was also an NDB, was not displayed, and entering 'R' would not call up Rozo. Rozo could only [be] called up by spelling out ROZO on the CDU."

The report said: "The simulations found that when R was entered into the CDU, a white dashed line pointed off the map display towards the east-northeast. When R was 'executed,' the airplane turned towards R (in the city of Bogota), and the white dashed line turned to a solid magenta colored line on the display."

"The CVR indicates that the flight crew became confused and attempted to determine their position through the FMS. "

As a result, the crew could not have known "without verification with the EHSI [electronic horizontal situation indicator] (see "The Boeing 757 Flight Management System," page 22) display or considerable calculation that instead of selecting Rozo, they had selected the ROMEO beacon, located near Bogota, some [212 kilometers (132 miles)] east-northeast of CALI," the report said. "Both beacons had the same radio frequency, 274 kilohertz, and had the same identifier 'R' provided in Morse code on that frequency.

"In executing a turn toward ROMEO rather than ROZO, the flight crew had the airplane turn away from CALI and towards mountainous terrain to the east of the approach course, while the descent continued. At this time, both pilots also attempted to determine the airplane's position in relation to ULQ, the initial approach fix."

The report said: "Neither flight crew member was able to determine why the navaid was not where they believed it should be, and neither noted [or] commented on the continued descent. The CVR indicates that the flight crew became confused and attempted to determine their position through the FMS."

Investigators found that "because of rules governing the structure of the FMS database, ROZO, despite its prominent display as 'R' on the approach chart, was not available for selection as 'R' from the FMS, but only by its full name," the report said. "The evidence indicates that this information was not known by the flight crew of [Flight] 965."

Investigators also determined that "considerable additional differences existed in the presentation of identical navigation information between that on the approach charts and that in the FMS database, despite the fact that the same company supplied the data to both," the report said.

"The Jeppesen Sanderson Co. [said] that software inputs that are provided by contract to operators of FMS-equipped aircraft are made in accordance with the guidelines of ARINC-424 [see "Aeronautical Radio Inc. (ARINC)," page 18], Chapter 7, 'Naming Conventions,' [which] establishes the coding rules of identifiers and name fields when government source data does not provide these identifiers or names within the rules established by International Civil Aviation Organization (ICAO) Annex 11. As stated by the Jeppesen Sanderson senior vice president, flight information and technology, in a subsequent letter to the president of the investigation:

"'An important item to remember is that all of Jeppesen's navigation data is entered into our database using the ARINC-424 Aeronautical Database Specifications standard. This standard is the result of an effort that began in 1973 and has been continuously updated and is now in its 14th revision. The ARINC spec is a set of rules that has been established by industry, airlines, avionics manufacturers, FAA, ICAO ... and others to ensure agreement in concept of using aeronautical information in automated systems worldwide.

"'As one of the first considerations, databases cannot accept duplicate information. There cannot be two names for the same item. Specifically, the ROMEO NDB uses the letter R for its identifier. The ROZO NDB also uses the same letter R for its identifier. The letter R was assigned to both of these navaids by the Colombian government.

"'Both of these navaids are within the same country and therefore have the same ICAO identifier. For en route facilities, the combination of both the NDB identifier *and* [emphasis in original] the ICAO code is normally adequate to provide uniqueness for entering data in the database.

"'When entering navaid information into the database, the navaid identifier is used as the key identifier. This means that the letter R is the default value for the ROMEO NDB and the ROZO NDB. Since the Bogota city and airport is larger than Cali, the larger airports are entered sequentially at the beginning to satisfy the greatest [number] of users. The letter R was entered for the ROMEO NDB as the 'key' to the navaid. Therefore, when using most FMSs, entering the letter R when in Colombia will call up the ROMEO NDB since it is the identifier for the ROMEO NDB.

"'When the ROZO NDB was entered into the database, the letter R was attempted, but the computer rejected the letter R since it had already been used for the ROMEO NDB. According to the ARINC 424 standards, when a duplicate exists, the *name* of the NDB can be used as the identifier for entry into the database. In the case of ROZO, since the name is four letters or less, the complete name of ROZO was used as the identifier.'"

The investigation revealed that "although the differences between the presentation of the same information could be confusing, and the selection of ROMEO instead of ROZO can be understood according to the logic of the FMS, the fact remains that one of the pilots of [Flight] 965 executed a direct heading to ROMEO in violation of AA's policy of requiring flight crew members of FMS-equipped aircraft to verify coordinates and to obtain approval of the other pilot before executing a change of course through the FMS," the report said.

The report said: "The failure to verify and to obtain verbal approval for the execution of the course to 'R' occurred primarily because of the self-induced pressure of the pilots of [Flight] 965 to execute the approach without adequate time being available."

"This accident demonstrates that merely informing crews of the hazards of over-reliance on automation and advising them to turn off the automation is insufficient and may not affect pilot procedures when it is needed most," the report said.

Investigators reviewed the use of crew resource management (CRM) by the accident flight crew. The report said that even though AA conducted superior CRM training, "the CRM of the [accident] crew was deficient, as neither pilot was able to recognize the following:

- "The use of the FMS was confusing and did not clarify the situation;
- "Neither [pilot] understood the steps necessary to execute the approach, even while trying to execute it;
- "Numerous cues were available that illustrated that the initial decision to accept Runway 19 was ill-advised and should be changed;
- "They were encountering numerous parallels with an accident scenario they had reviewed in recent CRM training; [and,]
- "The flight path was not monitored for over a minute just before the accident."

The report said, "Although the accident flight crew articulated misgivings several times during the approach, neither pilot displayed the objectivity necessary to recognize that they had lost situation[al] awareness and effective CRM."

"The air traffic controller also stated that the request from the flight to fly direct to the TULUA VOR … made no sense to him. He said that his fluency in nonaviation English was limited, and he could not ask them to elaborate on the request."

The investigation reviewed the Cali Approach facility and the services it provided. "At the time of the accident, the Cali Approach Control facility was located in the control tower at SKCL," the report said. "The approach controller was located in a small cab [2.4 meters to three meters (eight feet to 10 feet)] from the tower controller. Flight progress strips were used to keep track of aircraft that were inbound or outbound from the airport, or traversing the Cali airspace. Radar coverage and radar services were not available."

On two separate occasions, investigators interviewed the Cali Approach controller who had handled the accident flight and attempted to determine whether the differences in the native languages between the controller and the accident flight crew could have resulted in a misunderstanding that caused the accident.

When first interviewed, the controller told investigators "that there were no language difficulties in the communications between himself and the accident flight crew," the report said.

During a second interview, however, "when asked a specific question regarding his opinion about the effects the difference in native languages between the accident flight crew and approach control may have had, he stated that he would have asked the pilots of [Flight] 965 more detailed questions regarding the routing and the approach if the pilots had spoken Spanish," the report said. "He stated that he believed that his comprehension of the pilot's transmission was satisfactory, and that the pilot also understood him."

The controller told investigators that, "in a nonradar environment, it was unusual for a pilot to request to fly from his or her present position to the arrival transition," the report said. "The air traffic controller also stated that the request from the flight to fly direct to the TULUA VOR, when the flight was [38 nautical miles] north of CALI [south of TULUA VOR] made no sense to him. He said that his fluency in nonaviation English was limited, and he could not ask them to elaborate on the request."

The controller said that "he restated the clearance and requested [the accident flight's] position relative to the CALI VOR," the report said. "He believed that the pilot's response, that [Flight] 965 was [69 kilometers (37 nautical miles)] from CALI, suggested that perhaps the pilot had forgotten to report passing the TULUA VOR.

"The controller further stated that had the pilots been Spanish-speaking, he would have told them that their request made little sense, and that it was illogical and incongruent. He said that because of limitations in his command of English he was unable to convey these thoughts to the crew."

The report said that the controller's "training, experience and guidance under the applicable rules in the nonradar environment of Cali would have made it unlikely for him to solicit the necessary information from the flight crew of [Flight] 965 that would [have] enabled him or the flight crew to recognize the precarious nature of their flight path. Consequently, Aeronautica Civil concludes that the Cali controller neither caused nor contributed to the cause of this accident."

Investigators reviewed the actions of the flight crew following the GPWS warning that occurred 13 seconds before the aircraft collided with the mountain. "FDR data from [Flight] 965 showed that within two seconds of the GPWS warning, the engines began to accelerate from flight idle at a rate of change consistent with a rapid advancement of the throttles," the report said. "The speedbrakes were not retracted."

During the investigation, a study was conducted of the performance of Flight 965 following the GPWS warning. The study indicated that "if the flight crew had retracted the speedbrakes one second after initiating the escape maneuver, the airplane could have been climbing through a position that was [46 meters (150 feet)] above the initial impact point," the report said. " ... Because the airplane would have continued to climb and had the potential to increase its rate-of-climb, it may well have cleared the trees at the top of the ridge."

The report said that "if the speedbrakes had been retracted upon initiation of the escape maneuver and if the pitch attitude had been varied to perfectly maintain the stick-shaker activation angle, the airplane could have been climbing through a position that was [92 meters (300 feet)] above the initial impact point."

Investigators reviewed both Boeing's and American Airlines' training materials regarding the use of the speedbrakes on the B-757. "Boeing's B-757 flight crew training manual provides one method of monitoring the status of speedbrake deployment," the report said. "The manual states that 'the captain should keep his right hand on the speedbrake lever whenever [the speedbrakes] are used in flight. This will preclude leaving the speedbrakes extended.' AA does not have a similar procedure."

The report said: "Furthermore, neither the Boeing operations manual addressing terrain avoidance nor the AA operating manual addressing GPWS escape procedures [discusses] the need to stow the speedbrakes to extract maximum performance from the airplane during an escape maneuver."

"Boeing engineers state that, for the B-757, automatic retraction of the speedbrakes in a go-around maneuver may result in unwanted pitch excursions."

The B-757 incorporates an automatic speedbrake feature that when activated with the airplane on the ground stows any extended spoiler panels when either thrust lever is advanced from flight idle. "However, advancing the thrust levers in flight has no effect on deployed speedbrakes," the report said.

"In addition, flight crews would receive an amber center panel speedbrake light and an amber engine-indicating and crew-alerting system (EICAS) SPEED BRAKES EXT message, master caution light and chime when a speedbrake fails to retract. The speedbrakes remained extended [on the accident airplane] and the CVR did not record the chime, which indicates that the crew did not attempt to retract the speedbrakes."

Investigators reviewed other large jet transport aircraft and found 37 aircraft types that "do not have an automatic speedbrake-stowing feature when full forward thrust is used, while at least eight jet airplanes, including one corporate jet, the Airbus A330 [and Airbus] A340, Fokker F-28 and [Fokker] F-100 airplanes have such a feature," the report said.

The report noted that "the fly-by-wire airplanes have enhancements to the pitch-control system to compensate for the automatic retraction of the speedbrakes. In addition, Boeing engineers state that, for the B-757, automatic retraction of the speedbrakes in a go-around maneuver may result in unwanted pitch excursions.

"If the speedbrakes are stowed as the throttles advance, the airplane would pitch down due to the aerodynamic effects of stowing the speedbrakes. The pilot would likely pull back on the control column to regain the desired pitch attitude as the engines began to spool up. The pilot effort and the increasing thrust could result in an undesirable upward pitch excursion."

Investigators reviewed the FAA's oversight of AA's operations in South America. "During postaccident interviews, FAA personnel indicated that AA conducted about 1,870 of the 7,200 weekly operations at MIA, and that en route surveillance of operations into South America were often conducted by airworthiness inspectors who were already traveling to Latin America to perform facility inspections," the report said.

Investigators found that "airworthiness inspectors would plan and conduct en route inspections on flights to South America, inspect the facility at the destination and conduct en route inspections on the return trip," the report said. "Inspections were planned in this manner to reduce the FAA expenses associated with overseas travel.

"During interviews, FAA personnel verified that operations inspectors, who perform cockpit en route checks, are given different FAA training than airworthiness inspectors. Airworthiness inspectors specialize in maintenance matters, and are not qualified flight crew operational evaluators."

"The flight crew had insufficient time to prepare for the approach to Runway 19 before beginning the approach."

Investigators reviewed the pertinent International Civil Aviation Organization (ICAO) standards regarding en route inspections of air carriers. The applicable ICAO standard states, in part: "Ideally, a CAA [civil aviation authority] inspector should be at least as qualified as the personnel to be inspected or supervised," the report said. "To carry out in-flight inspections, a CAA inspector should not only be qualified in the type of aircraft used, but also possess appropriate route experience."

The report said: "Aeronautica Civil believes that deficiencies in FAA surveillance of [AA's operations into Cali] were present, but that these deficiencies did not adversely affect the performance of the flight crew or the safety of [Flight] 965."

As a result of its investigation, the Aeronautica Civil published the following findings:

- "The pilots were trained and properly certified to conduct the flight. Neither was experiencing behavioral or physiological impairment at the time of the accident;
- "[AA] provided training in flying in South America that provided flight crews with adequate information regarding the hazards unique to operating there;
- "The AA [Flight] 965 flight crew accepted the offer by the Cali approach controller to land on Runway 19 at SKCL;
- "The flight crew expressed concern about possible delays and accepted an offer to expedite their approach into Cali;
- "The flight crew had insufficient time to prepare for the approach to Runway 19 before beginning the approach;
- "The flight crew failed to discontinue the approach despite their confusion regarding elements of the approach and numerous cues indicating the inadvisability of continuing the approach;
- "Numerous important differences existed between the display of identical navigation data on approach charts and FMS-generated displays, despite the fact that the same supplier provided AA with the navigational data;
- "The AA [Flight] 965 flight crew was not informed or aware of the fact that the 'R' identifier that appeared on the approach (ROZO) did not correspond to the 'R' identifier (ROMEO) that they entered and executed as an FMS command;
- "One of the [Flight] AA 965 pilots selected a direct course to the ROMEO NDB believing that it was the ROZO NDB, and upon executing the selection in the FMS permitted a turn of the airplane towards ROMEO, without having verified that it was the correct selection and without having first obtained approval of the other pilot, contrary to AA's procedures;
- "The incorrect FMS entry led to the airplane departing the inbound course to Cali and turning it towards the city of Bogota. The subsequent turn to intercept the extended centerline of Runway 19 led to the turn towards high terrain;
- "The descent was continuous from FL 230 until the crash;
- "Neither pilot recognized that the speedbrakes were extended during the GPWS escape maneuver, due to the

lack of clues available to alert them about the extended condition;

- “Considering the remote, mountainous terrain, the search and rescue response was timely and effective;
- “Although five passengers initially survived, this is considered a nonsurvivable accident due to the destruction of the cabin;
- “The Cali approach controller followed applicable ICAO and Colombian air traffic control rules and did not contribute to the cause of the accident;
- “The FAA did not conduct the oversight of AA flight crews operating into South America according to the provisions of ICAO document 8335, parts 9.4 and 9.6.33;
- “AA training policies do not include provision for keeping pilots’ flight training records, which indicate any details of pilot performance; [and,]
- “AA includes the GPWS escape maneuver under section 13 of the flight instrument chapter of the Boeing 757 flight operations manual and Boeing Commercial Airplane Group has placed the description of this maneuver in the nonnormal procedures section of their flight operations manual.”

The Aeronautica Civil determined that the probable causes of the accident were:

- “The flight crew’s failure to adequately plan and execute the approach to Runway 19 at SKCL and their inadequate use of automation;
- “Failure of the flight crew to discontinue the approach into Cali, despite numerous cues alerting them to the inadvisability of continuing the approach;
- “The lack of situational awareness of the flight crew regarding vertical navigation, proximity to terrain, and the relative location of critical radio aids; [and,]
- “Failure of the flight crew to revert to basic radio navigation at the time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight.”

The Aeronautica Civil listed as contributing to the cause of the accident:

- “The flight crew’s ongoing efforts to expedite their approach and landing in order to avoid potential delays;
- “The flight crew’s execution of the GPWS maneuver while the speedbrakes remained deployed;
- “FMS logic that dropped all intermediate fixes from the display(s) in the event of execution of a direct routing; [and,]
- “FMS-generated navigational information that used a different naming convention from that published in navigational charts.”

As a result of its investigation, the Aeronautica Civil made 17 recommendations to the FAA. The most significant recommendations were:

- “Develop and implement standards for the portrayal of terminal environment information on FMS/EFIS displays that match, as closely as possible, the portrayal of that information on approach charts;
- “Evaluate all FMS-equipped aircraft and, where necessary, require manufacturers to modify the FMS logic to retain those fixes between [the] airplane’s position and one the airplane is proceeding towards, following the execution of a command to the FMS to proceed direct to a fix;
- “Require airlines to provide pilots through CRM and flight training with the tools to recognize when the FMC becomes an obstacle to the proper conduct of the flight, and correctly evaluate when to discontinue the use of the FMC and revert to basic radio navigation;
- “Require that all approach and navigation charts used in aviation graphically portray the presence of terrain that [is] located near airports or flight paths;
- “Require pilots operating FMS-equipped aircraft to have open and easily accessible the navigation charts applicable to each phase of flight before each phase is reached;
- “Encourage manufacturers to develop and validate methods to present accurate terrain information on flight displays as part of a system of early ground-proximity warning. (Enhanced GPWS);

The Aeronautica Civil recommended that the FAA “require that all approach and navigation charts used in aviation graphically portray the presence of terrain that [is] located near airports or flight paths. ”

- “Require Jeppesen Sanderson Co. to inform airlines operating FMS-equipped aircraft of the presence of each difference in the naming or portrayal of navigation information on FMS-generated and approach chart information, and require airlines to inform their pilots of these differences, as well as the logic and priorities employed in the display of electronic FMS navigation information;

- “Evaluate the curricula and flight-check requirements used to train and certificate pilots to operate FMS-equipped aircraft, and revise the curricula and flight-check requirements to assure that pilots are fully knowledgeable in the logic underlying the FMS or similar aircraft computer system before being granted airman certification to operate the aircraft;

- “Perform en route inspections of U.S. carriers operating into Latin America in compliance with standards according to the provisions of [the] ICAO … ;

- “Evaluate the Boeing procedure for guarding the speedbrake handle during periods of deployment, and require airlines to implement the procedure if it increases the speed of stowage or decreases the likelihood of forgetting to stow the speedbrakes in an emergency situation;

- “Evaluate the dynamic and operational effects of automatically stowing the speedbrakes when high power is commanded and determine the desirability of incorporating on existing airplanes automatic speedbrake retraction that would operate during wind-shear and GPWS escape maneuvers, or other situations demanding maximum thrust and climb capability;

- “Require that newly certified transport category airplanes include automatic speedbrake retraction during wind shear and GPWS escape maneuvers, or other situations demanding maximum thrust and climb capability;

- “Develop a mandatory CFIT [controlled-flight-into-terrain] training program that includes realistic simulator exercises that are comparable to the successful wind-shear and rejected-takeoff training programs;

- “Evaluate the CFIT escape procedures of air carriers operating transport category aircraft to ensure that the procedures provide for the extraction of maximum escape performance and ensure that those procedures are placed in operating sections of the approved operations manuals;

- “Alert pilots of FMS-equipped airplanes to the hazard of commonly identified navigation stations when operating outside the United States;

- “Review the pilot training record keeping systems of airlines operated under [FARs] Parts 121 and 135 to determine the quality of the information contained therein, and require the airlines to maintain appropriate information on the quality of pilot performance in training and checking programs; [and,]

- “Evaluate the possibility of requiring that flight crew–generated inputs to the FMC be recorded as parameters in the FDR in order to permit investigators to reconstruct pilot-FMS interaction.”

The Aeronautica Civil made the following recommendations to the ICAO:

- “Urge the member states to encourage [their] pilots and air traffic controllers to strictly adhere to ICAO standards [of] phraseology and terminology in all radio telecommunications between pilots and controllers;

- “Evaluate and consider the adoption of the recommendations produced by the CFIT Task Force that has been created under the initiative of the Flight Safety Foundation; [and,]

- “Establish a single standard worldwide that provides ... unified criteria for the providers of electronic navigational databases used in flight management systems.”

The Aeronautica Civil made the following recommendations to AA:

- “Review the guidelines for ensuring that the flight crew preparation rendered by the training given at the flight training academy is maintained throughout the different operational pilot bases by standardizing the evaluation criteria of the different pilots; [and,]

- “Address the analysis of flight crew performance in flight crew training records in order to reinforce CRM and the individual aspects of flight training programs.”♦

Editorial note: This article was adapted from *Controlled Flight into Terrain, American Airlines Flight 965, Boeing 757-223, N651AA, near Cali, Colombia, December 20, 1995.* The report was prepared by the Aeronautica Civil of the Republic of Colombia, and was translated into English. The 101-page report contains appendices and illustrations.

Other Parties' Submissions to the Official Accident Investigation Report

Representatives from American Airlines (AA), the Allied Pilots Association (APA, the union that represents AA flight crews) and the Boeing Commercial Airplane Group were parties to the accident investigation. The following summarizes the party submissions that were made to the Colombia Aeronautica Civil and the U.S. National Transportation Safety Board regarding the investigation, insofar as they added to or differed from the Aeronautica Civil report.

American Airlines

Aids to navigation. AA reviewed the difficulty experienced by the accident flight crew in locating the ROZO nondirectional beacon (NDB) in the flight management computer (FMC) database. In its comments, AA said that "selecting 'R' provides the pilots [with a list of] 12 navigational aids, listed ... according to distance from the airplane, with the closest listed first, next closest second, and so forth. ROZO was not one of the navigational aids listed in the 'R' category. ROMEO, which was [212 kilometers (132 miles)] northeast, was the first navigational aid listed. In the FMC navigational database, the identifier for ROZO is 'ROZO.'"

"To understand the significance of these mismatched naming conventions, one can compare ROZO to other navaids in the vicinity of Cali. To select CALI VOR, its identifier (CLO) is entered. To select TULUA VOR, its identifier (ULQ) is entered. To select BUENAVENTURA VOR, its identifier (BUN) is entered. And to select the fix the crew obtained in error, ROMEO NDB Bogota, its identifier (R) is entered.

"But to select ROZO NDB, its name must be entered. ROMEO and ROZO appear[ed] on their respective charts in exactly the same way, a box identifier with the name above and the frequency and identifier in the box. ... Yet, one appear[ed] in the database by identifier and the other by its name."

The AA report continued, "The differences in charts and [computer] displays result from two different sets of standards for charts and electronic data. Approach charts are driven by the individual country's procedure for that approach. The country defines the fixes and names them as [it sees] fit, presumably within ICAO [International Civil Aviation Organization] limits. These are then displayed on charts using the Jeppesen format and standards, or those of any other chart provider.

"Navigation data bases are governed by a set of conventions (ARINC 424) [see "Aeronautical Radio Inc.," page 18] that have been developed and revised over a 23-year period. These standards govern the selection of fixes to be displayed for any procedure and provide a convention for naming fixes.

"Applied to approaches, these [ARINC] standards lead to several relevant points. ... ROZO is not displayed because it is used only as a step-down fix," the AA report said. "Fixes that are used solely for step-downs are eliminated in the [FMC] database in order to prevent 'snaking' of the final approach course and clutter of the display. …

"This process results in the end users, the pilots, being presented with a real-time transition task in a high-workload phase of the flight. Even if the pilot fully understands the fix selection and naming conventions, he or she must still translate between what is in the chart and what is displayed by the FMC display. Pilot translation between charted and displayed information for an approach is a significant source of distraction, workload and potential error. Either the database should match the chart, or the chart should include fix names as displayed in the navigational data."

AA accessed the database of a B-757 simulator and selected seven navigational aid identifiers beginning with the letter "R." The results showed that "none of these selections provided ROZO as a choice," the AA report said. "These navigational aids are only identified on the FMC waypoint pages by their latitude and longitude.

"Therefore, the only way to ensure that the navigational aid sought by the pilot is the one displayed to the pilot, as his requested selection, is for the pilot to compare the displayed vs. desired waypoint latitude and longitude. The geographic latitude/longitude coordinates do not appear on the approach charts. ...

"Runway changes ... increase workload by requiring pilots to locate new charts, retune navaids, reidentify navaids, brief the new approach and reset minimums bugs," the report said. "Making such changes on an FMC-equipped aircraft greatly increases workload. ...

"The disadvantage lies in prioritizing the time and steps necessary the change the FMC against the immediate need to control the course of the aircraft and prepare the pilots and navigational radios to fly the approach."

AA training emphasizes that entries into automated flight systems be verified immediately. "An input entered into an autoflight system, an FMC entry or an autopilot-command selection must be cross-checked against its

Aeronautical Radio Inc. (ARINC)

ARINC is an international corporation whose principal stockholders are airlines, air transport companies and aircraft manufacturers.

ARINC operates a system of domestic and overseas aeronautical land radio stations, fulfills systems requirements to accomplish ground and airborne compatibility, allocates and assigns radio frequencies to meet those needs, and coordinates standard airborne communications and electronic systems.♦

result," the AA report said. "In this case, preparing for the approach was given higher priority. The most significant pilot role in this accident surrounds this misplaced priority. In a moment of task saturation, both pilots gave priority to the wrong task."

The AA report said, "From the beginning of the (left) turn off course until the first officer called for 'altimeters' just prior to the GPWS [ground-proximity warning system] warning, neither crew member specifically mentioned terrain. Though the captain communicated some concern with the situation when directing a turn to the right, and the first officer expressed at least frustration in proposing they set aside ULQ and fly to the [Runway] 19 centerline, neither pilot intervened to change the vertical path of the aircraft.

"Well documented in human factors literature is the basic human tendency to focus on prominently displayed or readily available information identified as 'figure' over less prominent or [less] available information identified as 'ground.' Attention is brought to bear on objects or information that capture our focus.

"In this [accident] situation, course information is prominently displayed on navigation displays and arrival and approach charts. Terrain information (beyond simple peaks) is displayed only on the area chart, which would tend to be set aside when initiating an arrival. Attention is more readily drawn to desired course than to terrain to be avoided. Navigation displays may have exacerbated this tendency by increasing the salience of course information without a corresponding increase in terrain display.

"A second well-documented human tendency is to escalate commitment to, rather than abandon, a course of action when difficulties are encountered. Among pilots flying ... automated aircraft this can be manifested in attempts to correct an 'automation-induced' deviation by manipulating the automated system, rather than the controls of the aircraft. ... They could instead revert to a lower level of automation, including hand flying. ... There is great motivation to understand why the autoflight system did not work as expected and to make it perform.

"The misprioritization of preparing for the approach over cross-checking the result of direct 'R' may reflect an inappropriate use of, and level of trust in, flight path automation. The crew of Flight 965 trusted enough in the function of the FMC and their understanding of it to turn away to set up the new approach.

"In the subsequent 60 seconds, the aircraft turned [more than] 90 degrees, and was already (unknown to the crew) substantially off course. In this short period of time, the crew momentarily lost their awareness of where they were and where they wanted to be."

Communications. AA investigators reviewed the communications between Cali Approach and the accident flight. "At 2134:59, Cali Approach … issued the following clearance to [Flight] 965: 'Roger, is cleared to CALI VOR uh descend and maintain one five thousand feet, altimeter three zero zero two … no delay expect for approach report uh TULUA VOR,'" the AA report said. "This clearance was not consistent with the ICAO Document 4444, *Rules of Air Traffic and Air Traffic Services* … . Those references advise that in order to be valid a clearance should have a route of flight such as via a route and/or reporting point(s), via a flight planned route or via an arc or a DME [distance measuring equipment] station."

At 2138:45, Cali Approach requested Flight 965's distance from CALI, which the crew reported as 38 DME (70 kilometers [38 nautical miles]). "During this period of time, the controller was using the telephone normally located at the supervisor's desk, which was to the right and about [1.8 meters (six feet)] from his control position," the AA report said.

"According to Aeronautica Civil's ATC [air traffic control] transcript, at 2138:50, the controller acknowledged Flight 965's transmission that they were at 38 DME; simultaneously, as quoted from the ATC tape transcript, the following events occurred: 'Background music and rhythmic tapping.' Nonpertinent telephone conversation, initiated by the Cali controller at 2139:48, ended at 2140:03, concurrent with 'we're' in the next [AA] transmission."

Commenting on the language difficulties between the accident flight crew and the Cali Approach controller, the AA report said that "insufficient language ability played a role in the crew's and controller's understanding of the clearance direct to CLO [Cali] and in the controller's inability to communicate that some of [Flight] 965's reports and requests were not understood. ...

"The controller was concerned about some of the position reports. CLO DME readings of [70 kilometers and 69 kilometers (38 nautical miles and 37 nautical miles)] are south of [TULUA] ... . One minute and 35 seconds had elapsed in which the airplane reported covering only one mile. However, the controller reported that he could not formulate his concerns into English to communicate them to the crew. …

"Given the miscommunications between the captain and controller during the final minutes of the flight, one must question whether the language requirements and phraseology used under ICAO standards provide pilots and controllers with enough common language for both to participate in problem-solving."

Ground-proximity warning system (GPWS) escape maneuver. The AA report commented on the crew's action following the GPWS warning: "The first officer, who was the pilot flying, responded to the GPWS terrain warning within one second. He pitched the airplane nose-up at a rate of three [degrees] to four degrees per second to a 20-degree attitude and disconnected the autopilot. Approaching 20 degrees pitch attitude, the angle-of-attack triggered the stick shaker.

"With autothrottles engaged in the speed mode, the throttles advanced. The EPR [engine-pressure ratio] commands reached the thrust-limit target of 1.752 EPR after approximately six seconds elapsed time. At impact, after 9.2 seconds elapsed time, the actual engines EPRs only attained 1.182 and 1.348 for the left and right engine respectively. ...

"At 20 degrees pitch attitude, the first officer 'honored' the stick shaker by pushing forward on the yoke. This action lowered the angle-of-attack sufficiently to stop the stick shaker. Subsequently, the first officer pitched the nose up again into and through stick-shaker angle-of-attack and on to stall angle-of-attack. The pitch attitude peaked at 31 degrees. This sequence of events clearly demonstrated the inadequacy of the stick shaker as the primary indicator for angle-of-attack. …

"Prior to impact, the aircraft had been descending at a rate of approximately [458 meters (1,500 feet)] per minute, negative six degrees [angle of attack], three degrees pitch attitude and a calculated airspeed of [444 kilometers per hour (kph) (240 knots)]. It had gone from a 20-degree bank right turn, through wings level and on to 13-degree bank left turn moments before impact. The airplane reached a pitch attitude of 31 degrees and angle-of-attack of 14 degrees (nose-up) during the escape maneuver. ... During the escape maneuver, the airspeed decreased to [346 kph (187 knots)].

The AA report reviewed the effects of the deployed speedbrakes on the crew's ability to avoid a collision with terrain: "The performance group's report showed that stowing the speedbrakes and using the stick shaker as an angle-of-attack indicator may provide an additional altitude gain of approximately [46 meters (150 feet)] … . However, the structures group survey stated that initial tree strikes began approximately [76 meters (250 feet)] below the ridgeline. Therefore, the stowage of the speedbrakes alone would not have allowed the airplane to avoid the mountain.

"The performance group study did show that if the speedbrakes were stowed and the airplane was flown at constant stick-shaker optimum angle-of-attack, it would have achieved an additional gain of about [92 meters (300 feet)], which would have been sufficient to clear the ridgeline and the trees. In this study, the 'math pilot' is effectively using an angle-of-attack indicator to maintain maximum coefficient of lift.

"The installation of a functional, user-friendly, angle-of-attack indicator in all transport category airplanes, in combination with training, would enable pilots to extract maximum available performance from their airplane. This would be equally valuable in all escape maneuvers, regardless of the initiator. ...

"All transport category airplanes already have angle-of-attack systems installed. Therefore, this recommendation involves no new technology; it merely suggests that angle-of-attack, the most significant indication of any wing's performance, be presented to the pilot in a usable form."

The AA report commented on the need for the development of an enhanced ground-proximity warning system (EGPWS): "Depending on altitude and terrain gradient, EGPWS would as much as double the warning time in seconds relative to the current GPWS. The most significant factor influencing climb performance and altitude gain is time, prior to potential terrain impact, that the escape maneuver starts. Combined with GPS [global positioning system] to drive its navigational database, it is a dramatic improvement over its predecessor. It has been demonstrated to [AA] and is being actively pursued."

Wreckage and impact information. The AA report commented on the location of the accident site in the Aeronautica Civil accident report: "The closest known coordinates [of the accident site] are based on a [GPS] position on the west side of the mountain ridge derived by the [AA] team. This position does not exactly agree with other positions from a variety of sources; nor has it been possible to positively correlate that GPS position with a topographical map.

"Therefore, the exact latitude and longitude of the initial impact with the trees on the east side of the mountain is not known. Based on limited time on the scene and difficult weather and terrain conditions, the wreckage diagram in the structures report is abbreviated and should not be considered complete."

In its report, AA said that the probable causes of the accident were: "(1) inadequacies of the [accident aircraft] FMC's navigational database, and failure of those responsible to ensure that the database matched conventional published/charted information and reflected ARINC 424 advisories; (2) the flight crew's failure to perceive the FMC-initiated turn away from the intended routing; and (3) the approach controller's inadequate English-language abilities and his inattention during a critical phase of the approach.

"Contributing to the causes of the accident were: (1) lack of radar coverage; (2) approach control clearances that were not in accordance with ICAO standards; (3) the flight crew's increased task overload caused by the unexpected change in the assigned runway for the approach; and (4) the manufacturer's/vendor's overconfidence in FMC technology and the resultant influence passed onto pilots regarding the FMC's capabilities."

AA, based on its participation in the accident investigation, recommended:

- "That FAA [the U.S. Federal Aviation Administration] develop requirements for the installation of a functional angle-of-attack indicator in all transport category airplanes. This should become a certification requirement for all future airplanes and a retrofit for existing fleets;

- "That FAA develop requirements for the installation of [EGPWS] on all transport category airplanes. This should become a certification requirement for all future ... airplanes and a retrofit for existing fleets;

- "That ICAO remind member countries to follow established air traffic control guidelines regarding complete and proper clearances. ICAO should also encourage states to ensure [that the] controller's command of the English language is adequate to provide a safe environment;

- "That FAA ensure that the responsible parties review the navigational database protocols to establish a system in which ARINC 424 naming conventions match conventional charting practices;

- "That FAA require terrain contouring on arrival and approach charts;

- "That FAA require waypoint coordinates to be listed on approach charts;

- "That FAA and industry review current training standards/requirements to ensure an appropriate mix of automation skills and basic aviation abilities;

- "That FAA and equipment manufacturers make software changes to dramatically lower the tasking inherent with programming the FMC for a runway/approach change. Technology being used in new generation airplanes such as the Boeing 777 should be made available to operators of earlier generation FMS [flight management system]-equipped fleets; [and,]

- "That FAA and manufacturers ensure that vendors of navigational databases implement the ARINC 424 advisory dated Aug. 16, 1993, establishing 'terminal' and 'secondary' files for identically named navigational aids in the same geographical area."

Allied Pilots Association

In its comments regarding the investigation, the APA report said: "Areas of concern to APA are the relatively slow response times of the engines to accelerate to maximum power and the nondetermination of the input to power-lever movement. … APA requests that the acceleration rate of the engines, at conditions Flight 965 was operating under during the GPWS escape maneuver, be investigated to ensure the engines met design certification requirements."

Communications. The APA report commented on the workload encountered by the accident flight crew: "APA submits the following additional information giving evidence of crew task saturation during the arrival: There were 38 radio transmissions either received or made by the crew in the six-and-one-half minutes between the time they checked in with Cali Approach … and the receipt of the GPWS warning."

NAVAID Selection. The APA report noted that the captain might have encountered a mechanical difficulty when selecting the TULUA VOR frequency: "When tuning the VOR to 117.7, it is quite possible that the captain did tune the radio to the desired frequency, but due to wear of the selector knob detents the frequency 'jumped' to 116.7. This is corrected by reselecting the correct frequency. Regardless of how the frequency of 116.7 became tuned in the captain's VOR, the resultant presentation on his navigational display would be the same and APA concurs with AA's assessment of the situation."

GPWS escape maneuver. The APA report commented on AA findings regarding the use of an angle-of-attack indicator for maximum performance during a GPWS escape maneuver: "APA fully supports AA's position on the inadequacy of the stick shaker in representing the angle-of-attack where the maximum coefficient of lift is attained. In order to extract the maximum available performance from our aircraft a functional, accurate angle-of-attack indicator coupled with a properly trained crew is required."

APA also commented on whether the accident flight crew might have been able to clear the terrain had the speedbrakes been retracted when the GPWS escape maneuver was initiated: "APA does not support any speculation on the capability of the aircraft to have cleared the ridge in another configuration. … There was no survey taken of the accident; all dimensions and heights are at best only rough estimates. Any conclusions drawn from [theoretical studies] should only be applied to a generic situation and not to the specific case of Flight 965."

Radar. APA commented on the accident flight crew's transition from a radar environment while en route to the nonradar environment of Cali Approach. "As the crew was transiting from Bogota Center's airspace into Cali Approach's airspace, there was never an advisory of 'radar contact lost.'

"It is quite possible that the [first officer] was unaware they were not in radar contact. Evidence of this fact is presented on the CVR transcript at time 2139:06 when in response to the captain's statement of 'Let's come to the right a little bit,' the [first officer] said, 'Yeah, he's wantin' to know where we're heading.' This indicates the [first officer] believed the controller was following their flight on radar. This theory is supported by the fact this was the [first officer's] first flight into Cali."

The APA made the following recommendations based on its participation in the investigation:

- "Pilots should receive more hands-on training in GPWS escape maneuvers while in unusual configurations. Training should include recoveries from nose-high/low-airspeed attitudes. It is also recommended that pilots receive more training in the support role the pilot not flying plays in the GPWS escape maneuver, e.g., 'coaching' the pilot flying with radio altimeter, airspeed and VSI [vertical speed indicator] readings, checking the aircraft configuration, etc. Training should also be expanded on GPWS maneuvers in high-density airspace and the possibility of false GPWS warnings;

- "The FAA should mandate [that] the GPWS escape maneuvers be a required item on annual pilot recurrent checks;

- "Pilots should receive more training in human factors effects of automation, especially concerning when it is proper to utilize different levels of automation to efficiently complete tasks at hand. More training should be conducted in the hazards associated with the resultant complacency that develops from flying automated aircraft;

- "If one pilot is flying in raw data, the other pilot should be in the MAP mode;

- "If the aircraft is flying in LNAV [lateral navigation], then one pilot should be in the MAP mode;

- "Pilots should receive more training in basic aerodynamics. [AA] has developed an excellent advanced aircraft-maneuvering program which incorporates aerodynamic-principle reviews and recovery from unusual attitudes. APA recommends that this type of program be established at all airlines;

- "Pilots should receive more training on maintaining altitude awareness in all phases of flight. Training should include the immediate consideration for climbing whenever navigational position is in doubt, especially when operating in the vicinity of mountainous terrain. Pilots should also receive additional training on operations in nonradar environments, specifically the need to ensure their own terrain clearance if operating off-airways when proceeding direct;

- "Pilots should receive more training in radar-altimeter awareness; e.g., a callout of 'radar altimeter alive' would alert the other pilot that the aircraft is approaching terrain;

- "Pilots should receive more training in FMS failures during line-oriented flight training (LOFT) scenarios. LOFT scenarios should also include placing the crew in situations that require exercising their situational awareness and decision-making skills;

- "Airlines should review division-specific qualifications for applicability to operations, specifically the establishment of 'division within a division' qualifications. For example, pilots who have been operating in the Atlantic/European operations area should not be allowed to operate in the South American operations area without having entered that area within a specific time frame or completing additional training;

- "Airlines should review crew resource management (CRM) training programs to ensure they address time and risk management, decision making and situational awareness prioritization;

- "Airlines should require that approach briefings include terrain awareness;

- "The FAA should review the certification requirements for engine spool-up time for aircraft situations such as [that encountered by] Flight 965; [and,]

- "The FAA should examine the benefits and feasibility of a throttle quadrant switch to automatically retract speedbrakes at high-throttle-lever positions and installation of a conspicuous 'speedbrake extended' advisory light that illuminates regardless of system altitude/configuration logic."

The Boeing 757 Flight Management System

The Boeing 757 flight management system (FMS) helps the pilot control the aircraft's lateral and vertical flight path. The FMS's primary functions are automatic navigation, optimization of in-flight performance and automatic fuel monitoring.

The flight management computer (FMC), manufactured by Honeywell Air Transport Systems, combines three elements: (1) flight plan information entered by the pilot, (2) information received from supporting systems and (3) information stored in its memory. From this information, the computer calculates the airplane's present position and the pitch, thrust and roll commands necessary to achieve an optimum flight profile.

The FMC sends commands to the autothrottles, to the autopilot and to the moving map display (see MAP mode, below). FMC commands are also sent to the flight director, which is used by the pilot to select the operating modes for the autothrottle and the autopilot.

The following definitions are paraphrased from the *Boeing 757 Operations Manual.*

Autothrottle — Automatically advances or retards power for climb, cruise, descent and approach in accordance with programmed or manual computer inputs.

CDI (course deviation indicator) — Shows actual track and its relationship to programmed course.

DIRECT TO — Selection of this function on the FMC highlights the active (destination) waypoint but removes all intervening waypoints from the FMC display.

EADI (electronic attitude-direction indicator) — Shows conventional airplane attitude indications (angle of bank, pitch); flight director commands; deviation from ILS localizer, glide slope and selected approach airspeed; and pitch limit.

EPR (engine pressure ratio) — The ratio of the turbine discharge total pressure to the turbine inlet total pressure. The EPR is used to set turbine engine power, much as manifold pressure is used to measure power output in a piston engine.

ESHI (electronic horizontal situation indicator) — Can be used in instrument landing system (ILS) or VOR mode. In VOR mode, the display shows a magnetic compass rose with CDI. In ILS mode, glide slope and azimuth to touchdown point are displayed.

FLCH (flight level change) — When selected, maintains existing airspeed and selected thrust for climb or idle thrust descent.

HDG SEL (heading select) — Allows the pilot to manually steer the aircraft by entering a magnetic compass heading into the computer.

LNAV (lateral navigation) — Generates computer steering commands to take the aircraft from its present position to the active waypoint. The LNAV mode is deactivated when HDG SEL is selected.

MAP mode — Displays flight information against a moving map of the actual area being traversed. Information displayed includes track, heading, wind, routes, distance to waypoint and estimated time of arrival. MAP mode is used for most phases of flight.

NAVAID button — Allows display of navigational fixes that are not on the programmed route.

VNAV (vertical navigation) — Accepts preprogrammed vertical flight profile for climb, descent and level-off. Sends commands to autothrottle system.

Vertical speed mode — Used by the pilot to select a computer-controlled constant rate of climb or descent. When vertical speed mode is selected, VNAV is deactivated.

VOR (Very high frequency omnidirectional radio range) — When VOR mode is selected, the pilot manually tunes the desired radio frequency.♦

Boeing

A simulation of the accident flight's ground track and descent was conducted using data from the FMC recovered at the accident. Based on this simulation, Boeing provided a detailed analysis of the crew actions required to duplicate the descent. These actions were correlated with digital flight data recorder (DFDR) data from the accident aircraft. The following summarizes the Boeing analysis.

Before starting their descent into Cali, the crew selected the instrument landing system (ILS) approach to Runway 1 on the FMC. The modifications made on the FMC suggested that they had briefed for the ILS approach. "No other arrival or departure procedures were selected for the remainder of the flight," the Boeing report said. "The ILS approach to Runway 1 and the associated missed approach to ROZO remained in the FMC and, with the appropriate map scale selected, were available for view on the EHSI [electronic horizontal situation indicator] MAP page for the remainder of the flight." (See "The Boeing 757 Flight Management System," above, for an explanation of terms.)

AA procedures require that, below flight level (FL) 250 (7,625 meters [25,000 feet]), "one pilot should monitor VOR raw data on the EHSI, while the other pilot may monitor the MAP display," the Boeing report said. "Later in the flight, the crew appeared to have problems locating the ULQ VOR; therefore, it is uncertain which VOR, if any, may have been selected for raw data."

When Cali Approach cleared the crew to the CALI VOR, the captain read back, "Cleared direct to CALI VOR." The captain then executed the DIRECT TO function on the FMC, and the ULQ VOR disappeared from view on the map display. "Had the crew wished to view the FMC-generated position of the ULQ VOR at this point, or any subsequent point, the NAVAID button could have been selected on the EHSI control panel and a cyan ULQ VOR symbol would have appeared on the EHSI MAP display," the Boeing report said.

When the flight was approximately abeam of the ULQ VOR, one of the crew called up the "R" list from the navigational database. The first entry on this list was for the ROMEO NDB, located 219 kilometers (136 miles) northeast of the accident flight's position. One of the crew executed this entry, "which caused a curved dotted white line to be drawn on the MAP display," the Boeing report said. "Additionally, a scratch pad message 'insufficient fuel' and a northeasterly bearing to 'R' would have appeared … . This modification was executed, although crew coordination of this action was not apparent on the CVR."

The airplane then entered a left turn, and "it is uncertain whether either pilot recognized the aircraft had been commanded to turn left," the Boeing report said. "Indications that the airplane was in a left turn would have included the following: the EHSI MAP display (if selected) with a curved path leading away from the intended direction of flight; the EHSI VOR display, with the CDI [course deviation indicator] displaced to the right, indicating the airplane was left of the direct CALI VOR course; the EADI [electronic attitude-direction indicator] indicating approximately 16 degrees of bank; and all heading indicators moving to the right. ... The captain appeared to have problems interpreting the location of the ULQ VOR."

When the aircraft was at 4,118 meters (13,500 feet) and on a heading of approximately 110 degrees, the "heading select" mode was engaged, and the airplane rolled out of the left turn and began a turn to the right. "If an EHSI had been selected in the VOR mode, the displayed CDI would have shown the airplane heading approximately 90 degrees away from the original direct CALI VOR 195 course," the Boeing report said.

At this point, "ULQ was entered in the [FMC] and executed," the Boeing report said. "The first officer remarked to the captain about turning left to Tulua, and the airplane rolled out of the right turn and began a turn to the left … . The captain said, 'Let's press on.'

"After further discussion, the airplane began a 20-degree bank HDG SEL turn to the right. The actual heading selected … is unknown; however, based on the rollout initiated just prior to the GPWS warning, it can be inferred that it was approximately 230 degrees, which would have coincided with a heading toward ROZO."

One of the crew then entered "R" into the FMC. "This entry was not executed, so ULQ remained the FMC-active waypoint," the Boeing report said. "The effect of this action on the EHSI MAP would have been a dotted white line curving to the left toward 'R' for ROMEO. A portion of the magenta line depicting the direct course to ULQ may have been visible, depending on the selected map size. Had the direct 'R' been executed, no turn towards 'R' would have occurred, since the airplane was still in HDG SEL … ."

The Boeing report said, "As the airplane started to roll out of a 20-degree bank HDG SEL right turn, the vertical speed mode of the autopilot was selected … . It is unknown why this action was taken. However, it resulted in the thrust levers moving slightly off the idle stops.

"Immediately thereafter, the GPWS terrain warning sounded. The crew initiated a prompt and aggressive terrain-avoidance maneuver: turning off the autopilot while pushing the thrust levers full-forward, and rapidly increasing pitch attitude.

"The crew left the autothrottle engaged and the speedbrakes deployed full-up during the maneuver. DFDR data [indicate] that the engine parameters increased on the maximum acceleration schedule, consistent with the thrust levers being manually advanced at the beginning of the escape maneuver; however, the engines had insufficient time to reach full thrust prior to impact."

As a result of its participation in the investigation, Boeing made the following additional recommendations:

- "Manufacturers, airlines and regulatory agencies should develop a process to identify and rectify incorrect navaid database and ground-position information to allow full use of FMS map displays within the certified limitations of the approved airplane flight manual; [and,]
- "ICAO and regulatory authorities should review controller's handbooks and training to [ensure] a standardized worldwide definition of the terms 'to' and 'direct to' consistent with the functionality of FMC-equipped airplanes."♦

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