Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River
US Airways Flight 1549
Airbus A320-214, N106US
Weehawken, New Jersey
January 15, 2009

Accident Report

NTSB/AAR-10/03
PB2010-910403

National Transportation Safety Board

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National
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Safety Board

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Abstract: This report describes the January 15, 2009, accident involving the ditching of US Airways flight 1549 on the Hudson River about 8.5 miles from LaGuardia Airport, New York City, after an almost complete loss of thrust in both engines following an encounter with a flock of birds. The 150 passengers, including a lap-held child, and 5 crewmembers evacuated the airplane by the forward and overwing exits. One flight attendant and four passengers were seriously injured, and the airplane was substantially damaged.

Safety issues discussed in this report include in-flight engine diagnostics, engine bird-ingestion certification testing, emergency and abnormal checklist design, dual-engine failure and ditching training, training on the effects of flight envelope limitations on airplane response to pilot inputs, validation of operational procedures and requirements for airplane ditching certification, and wildlife hazard mitigation. The report also discusses survival-related issues, including passenger brace positions; slide/raft stowage; passenger immersion protection; life line usage; life vest stowage, retrieval, and donning; preflight safety briefings; and passenger education. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration, the U.S. Department of Agriculture, and the European Aviation Safety Agency.

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Abbreviations

AC	advisory circular
ACM	airport certification manual
AFA	Association of Flight Attendants
agl	above ground level
AHAS	Avian Hazard Advisory System
AIM	aeronautical information manual
ANU	airplane nose-up
AOA	angle-of-attack
APHIS	Animal and Plant Health Inspection Service
APM	aircrew program manager
APU	auxiliary power unit
AQP	Advanced Qualification Program
ARS	airport surveillance radar
ARTS	automated radar terminal system
ASOS	automated surface observing system
ASRS	Aviation Safety Reporting System
ATC	air traffic control
ATCT	air traffic control tower

ATP	airline transport pilot
BEA	Bureau d'Enquêtes et d'Analyses
BRDB	bird-ingestion rulemaking database
CAM	cockpit area microphone
CAMI	Civil Aerospace Medical Institute
CASS	Continuing Analysis and Surveillance System
CBA	class B airspace
CFM	CFM International
CFR	*Code of Federal Regulations*
cg	center of gravity
CIMS	Citywide Incident Management System
CLT	Charlotte Douglas International Airport
CMO	Certificate Management Office
CQT	continuing qualification training
CRM	crew resource management
CSN	cycles since new
CVR	cockpit voice recorder
DGAC	Direction Générale de L'Aviation Civile
EASA	European Aviation Safety Agency
ECAM	electronic centralized aircraft monitor

EMS	emergency medical services
EOW	extended overwater
ERAU	Embry-Riddle Aeronautical University
EST	eastern standard time
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FAC	flight augmentation computer
FADEC	full-authority digital engine controls
FCOM	flight crew operating manual
FDNY	Fire Department of New York
FDR	flight data recorder
FL	flight level
FOM	flight operations manual
fps	feet per second
FR	frame
FWC	flight warning computer
GE	General Electric Company
GPWS	ground proximity warning system
Hg	mercury
HPC	high-pressure compressor

HPT	high-pressure turbine
IDG	integrated-drive generator
IGV	inlet guide vane
IMF Lille	Institut de Mécanique des Fluides de Lille
JAA	Joint Aviation Authorities
JAR-E	*Joint Aviation Regulations*–Engines
JFK	John F. Kennedy International Airport
KCAS	knots calibrated airspeed
kts	knots
LGA	LaGuardia Airport
LPC	low-pressure compressor
LPT	low-pressure turbine
MAC	mean aerodynamic chord
msl	mean sea level
N_1	engine fan
N_2	engine core
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NIMS	National Incident Management System
NPRM	notice of proposed rulemaking

NTSB	National Transportation Safety Board
NY and NJ	(Port Authority of) New York and New Jersey
NYPD	New York Police Department
NY WW	New York Waterway
OEM	Office of Emergency Management
OGV	outlet guide vane
PA	public address
PF	pilot flying
PFD	primary flight display
PH	pilot handbook
PIT	Pittsburgh International Airport
PM	pilot monitoring
POI	principal operations inspector
psi	pounds per square inch
PST	Pacific standard time
QRH	quick reference handbook
QT	qualification training
RAT	ram air turbine
SFO	San Francisco International Airport
SIC	second-in-command

Snecma Société Nationale d'Étude et de Construction de Moteurs d'Aviation

S/N serial number

SNPRM supplemental NPRM

TC type certificate

TCAS traffic collision avoidance system

TEB Teterboro Airport

TEM threat and error management

TLM time limits manual

TM training manual

TRACON Terminal Radar Approach Control

TSO technical standard order

USAPA U.S. Airline Pilots Association

USCG U.S. Coast Guard

USDA U.S. Department of Agriculture

VGV variable guide vane

WHA wildlife hazard assessment

WHMP wildlife hazard management plan

WPD Weehawken Police Department

Executive Summary

On January 15, 2009, about 1527 eastern standard time, US Airways flight 1549, an Airbus Industrie A320-214, N106US, experienced an almost complete loss of thrust in both engines after encountering a flock of birds and was subsequently ditched on the Hudson River about 8.5 miles from LaGuardia Airport (LGA), New York City, New York. The flight was en route to Charlotte Douglas International Airport, Charlotte, North Carolina, and had departed LGA about 2 minutes before the in-flight event occurred. The 150 passengers, including a lap-held child, and 5 crewmembers evacuated the airplane via the forward and overwing exits. One flight attendant and four passengers were seriously injured, and the airplane was substantially damaged. The scheduled, domestic passenger flight was operating under the provisions of 14 *Code of Federal Regulations* Part 121 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was the ingestion of large birds into each engine, which resulted in an almost total loss of thrust in both engines and the subsequent ditching on the Hudson River. Contributing to the fuselage damage and resulting unavailability of the aft slide/rafts were (1) the Federal Aviation Administration's (FAA) approval of ditching certification without determining whether pilots could attain the ditching parameters without engine thrust, (2) the lack of industry flight crew training and guidance on ditching techniques, and (3) the captain's resulting difficulty maintaining his intended airspeed on final approach due to the task saturation resulting from the emergency situation.

Contributing to the survivability of the accident was (1) the decision-making of the flight crewmembers and their crew resource management during the accident sequence; (2) the fortuitous use of an airplane that was equipped for an extended overwater flight, including the availability of the forward slide/rafts, even though it was not required to be so equipped; (3) the performance of the cabin crewmembers while expediting the evacuation of the airplane; and (4) the proximity of the emergency responders to the accident site and their immediate and appropriate response to the accident.

The safety issues discussed in this report relate to the following: in-flight engine diagnostics, engine bird-ingestion certification testing, emergency and abnormal checklist design, dual-engine failure and ditching training, training on the effects of flight envelope limitations on airplane response to pilot inputs, validation of operational procedures and requirements for airplane ditching certification, and wildlife hazard mitigation. The report also discusses survival-related issues, including passenger brace positions; slide/raft stowage; passenger immersion protection; life line usage; life vest stowage, retrieval, and donning; preflight safety briefings; and passenger education. Safety recommendations concerning these issues are addressed to the FAA, the U.S. Department of Agriculture, and the European Aviation Safety Agency.

1. Factual Information

1.1 History of Flight

On January 15, 2009, about 1527 eastern standard time (EST),[1] US Airways flight 1549, an Airbus Industrie A320-214, N106US, experienced an almost total loss of thrust in both engines after encountering a flock of birds and was subsequently ditched on the Hudson River about 8.5 miles from LaGuardia Airport (LGA), New York City, New York. The flight was en route to Charlotte Douglas International Airport (CLT), Charlotte, North Carolina, and had departed LGA about 2 minutes before the in-flight event occurred. The 150 passengers, including a lap-held child, and 5 crewmembers evacuated the airplane via the forward and overwing exits. One flight attendant and four passengers received serious injuries, and the airplane was substantially damaged. The scheduled, domestic passenger flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 on an instrument flight rules flight plan. Visual meteorological conditions prevailed at the time of the accident.[2]

The accident flight was the last flight of a 4-day trip sequence for the flight and cabin crewmembers[3] and the second flight of the day in the accident airplane. The flight crew flew from Pittsburgh International Airport (PIT), Pittsburgh, Pennsylvania, to CLT on a different airplane and then flew the accident airplane from CLT to LGA. The flight crew reported that the flight from CLT to LGA was uneventful.

According to the cockpit voice recorder (CVR) transcript, at 1524:54, the LGA air traffic control tower (ATCT) local controller cleared the flight for takeoff from runway 4. At this time, the first officer was the pilot flying (PF), and the captain was the pilot monitoring (PM). According to the accident flight crew and CVR and flight data recorder (FDR) data, the takeoff and initial portion of the climb were uneventful.

At 1525:45, the LGA ATCT local controller instructed the flight crew to contact the New York Terminal Radar Approach Control (TRACON) LGA departure controller. The captain contacted the departure controller at 1525:51, advising him that the airplane was at 700 feet[4] and climbing to 5,000 feet. The controller then instructed the flight to climb to and maintain 15,000 feet, and the captain acknowledged the instruction.

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[1] Unless otherwise noted, all times in this report are EST based on a 24-hour clock.

[2] The National Transportation Safety Board's (NTSB) public docket for this accident investigation is available online at <http://www.ntsb.gov/info/foia_fri-dockets.htm>.

[3] This was the first trip sequence that the captain and first officer had been paired to fly together.

[4] Unless otherwise noted, all altitudes are reported as height above mean sea level (msl).

According to the CVR transcript, at 1527:10.4, the captain stated, "birds." One second later, the CVR recorded the sound of thumps and thuds followed by a shuddering sound. According to FDR data, the bird encounter occurred when the airplane was at an altitude of 2,818 feet above ground level (agl) and a distance of about 4.5 miles north-northwest of the approach end of runway 22 at LGA. At 1527:13, a sound similar to a decrease in engine noise or frequency began on the CVR recording. FDR data indicated that, immediately after the bird encounter, both engines' fan and core (N_1 and N_2, respectively) speeds started to decelerate. (See section 1.16.1.1 for more information about the airplane's performance during the accident sequence.)

At 1527:14, the first officer stated, "uh oh," followed by the captain stating, "we got one rol- both of 'em rolling back." At 1527:18, the cockpit area microphone (CAM) recorded the beginning of a rumbling sound. At 1527:19, the captain stated, "[engine] ignition, start," and, about 2 seconds later, "I'm starting the APU [auxiliary power unit]."[5] At 1527:23, the captain took over control of the airplane, stating, "my aircraft."

At 1527:28, the captain instructed the first officer to "get the QRH [quick reference handbook] loss of thrust on both engines."[6] At 1527:33, the captain reported the emergency situation to the LGA departure controller, stating, "mayday mayday mayday…this is…Cactus fifteen thirty nine hit birds, we've lost thrust in both engines, we're turning back towards LaGuardia."[7] The LGA departure controller acknowledged the captain's statement and then instructed him to turn left heading 220°.

At 1527:50, the first officer began conducting Part 1 of the QRH ENG DUAL FAILURE checklist (Engine Dual Failure checklist), stating, "if fuel remaining, engine mode selector, ignition," and the captain responded, "ignition." The first officer then stated, "thrust levers confirm idle," and the captain responded, "idle." About 4 seconds later, the first officer stated, "airspeed optimum relight. three hundred knots. we don't have that," and the captain responded, "we don't."[8]

At 1528:05, the LGA departure controller asked the captain if he wanted to try to land on runway 13 at LGA if it was available, and the captain responded, "we're unable. we may end up in the Hudson [River]." The rumbling sound that the CVR started recording at 1527:18 ended at 1528:08. At 1528:14, the first officer stated, "emergency electrical power…emergency generator not online." At 1528:19, the captain stated, "it's online." The first officer then stated, "ATC [air

[5] The APU provides an additional source of electrical power for the airplane.

[6] See section 1.17.1.2 for more information about the US Airways QRH Engine Dual Failure checklist and appendix C for the entire checklist.

[7] The "mayday, mayday, mayday" portion of the captain's statement was not transmitted to the air traffic controller because another pilot was transmitting on the same frequency at the same time. The NTSB notes that the flight number was 1549 not 1539.

[8] FDR data indicated that the maximum airspeed reached by the airplane after the bird ingestion was 214 knots (kts), which was below the optimum minimum airspeed of 300 kts for an engine windmill relight.

traffic control] notify." At 1528:25, the captain stated, "The left one's [engine] coming back up a little bit."

At 1528:31, the LGA departure controller stated that it was going to be "left traffic for runway three one," and the captain responded, "unable." At 1528:36, the traffic collision avoidance system (TCAS) on the airplane transmitted, "traffic traffic."[9] At 1528:46, the controller stated that runway 4 at LGA was available, and the captain responded, "I'm not sure we can make any runway. Uh what's over to our right anything in New Jersey maybe Teterboro?"[10] The controller replied, "ok yeah, off your right side is Teterboro Airport [TEB]." Subsequently, the departure controller asked the captain if he wanted to try going to TEB, and the captain replied, "yes."

At 1528:45, while the captain was communicating with ATC, the first officer stated, "FAC [flight augmentation computer] one off, then on." Fifteen seconds later, the first officer stated, "no relight after thirty seconds, engine master one and two confirm."[11] At 1529:11, the captain announced on the public address (PA) system, "this is the Captain, brace for impact." At 1529:14.9, the CVR recorded the ground proximity warning system (GPWS) warning alert, "one thousand."[12] At 1529:16, the first officer stated, "engine master two, back on," and the captain responded, "back on."

At 1529:21, the CVR recorded the LGA departure controller instructing the captain to turn right 280° and stating that the airplane could land on runway 1 at TEB. At the same time, the CVR recorded the first officer asking the captain, "is that all the power you got? (wanna) number one? Or we got power on number one." In response to the controller, the captain stated, "we can't do it." In response to the first officer, the captain stated, "go ahead, try [relighting] number 1 [engine]." FDR data indicated that engine master switch 1 was moved to the OFF position at 1529:27. The departure controller then asked the captain which runway at TEB he would like, and the captain responded, "we're gonna be in the Hudson."

At 1529:36, the first officer stated, "I put it [the engine master switch] back on," and the captain replied, "ok put it back on…put it back on." At 1529:44, the first officer stated, "no relight," and the captain replied, "ok let's go put the flaps out, put the flaps out." At 1529:53, the LGA departure controller stated that he had lost radar contact with the airplane, but he continued

[9] According to ATC data, the alert was caused when the airplane passed close above a helicopter operating in the area. At 1528:59, the TCAS transmitted, "monitor vertical speed," and, 6 seconds later, it transmitted, "clear of conflict." For more information about this traffic conflict, see section 1.10.3.2.

[10] FDR data indicated that the bird strike occurred about 9.5 miles east-northeast of the approach end of runway 4 at Teterboro Airport.

[11] At this point, the first officer was conducting the steps of the Engine Dual Failure checklist required if no engine relight had occurred after 30 seconds; the steps included turning the engine master switches 1 and 2 to OFF and then waiting 30 more seconds before turning the switches back to ON.

[12] The airplane was equipped with a GPWS, which contained both GPWS and enhanced GPWS functions. From 1529:14.9 to 1530:40.1, the two systems transmitted a total of 15 alerts, including altitude alerts and the following: "too low, terrain;" "too low, gear;" "terrain, terrain, pull up;" and "caution terrain."

trying to communicate with the captain, stating, "you also got Newark airport off your two o'clock in about seven miles."[13] See figure 1 for the flight track of the airplane.

Figure 1. Flight track of the airplane.

At 1530:01, the first officer stated, "got flaps out," and, at 1530:03, stated, "two hundred fifty feet in the air." He then stated, "hundred and seventy knots…got no power on either one? Try the other one?" The captain responded, "try the other one." At 1530:16, the first officer stated, "hundred and fifty knots," and, at 1530:17, stated, "got flaps two, you want more?" The captain replied, "no, let's stay at two," and then asked the first officer, "got any ideas?" The first officer responded, "actually not."

At 1530:24, the GPWS issued a "terrain, terrain" warning followed by "pull up," which repeated to the end of the CVR recording. At 1530:38 The first officer then stated, "switch?"[14]

[13] Radar coverage is line-of-sight from the radar antenna to the airplane. If the airplane descends low enough to have the line-of-sight obstructed by buildings or other obstructions, radar contact will be lost.

[14] The first officer was referring to the cabin emergency notification switch, which provides a signal to the cabin crewmembers indicating that an emergency has occurred.

The captain replied, “yes.” At 1530:41.1, the GPWS issued a 50-foot warning.[15] The CVR recording ended at 1530:43.7., the captain stated, “we’re gonna brace.”

Within seconds after the ditching on the Hudson River, the crewmembers and passengers initiated evacuation of the airplane. Subsequently, all of the occupants were evacuated from the airplane and rescued by area responders. (See sections 1.15.5 and 1.15.6 for information about the emergency evacuation and response, respectively.) Figure 2 shows the airplane occupants on the wings and in the slide/rafts after the evacuation.

Figure 2. A photograph showing the airplane occupants on the wings and in the slide/rafts after the evacuation.

[15] The NTSB had difficulty determining whether this callout was “fifty” or “thirty.” According to FDR data, the last recorded radio altitude before this callout was 33 feet (at 1530:41.26). The next recorded radio altitude was 20 feet (at 1530:41.26). The radio altitude is measured by the radio altimeter in the airplane, which provides the distance between the airplane and the ground directly below it.

1.2 Injuries to Persons

Table 1. Injury chart.

Injuries	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	0	0	0	0	0
Serious	0	1	4	0	5
Minor	0	0	95	0	95
None	2	2	51	0	55
Total	2	3	150	0	155

Note: Title 49 CFR 830.2, "Definitions," states that a minor injury is any injury that does not qualify as a fatal or serious injury. The regulation defines a serious injury as any injury that (1) requires hospitalization for more than 48 hours, starting within 7 days from the date that the injury was received; (2) results in a fracture of any bone, except simple fractures of fingers, toes, or the nose; (3) causes severe hemorrhages or nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns or any burns affecting more than 5 percent of the body surface.

1.3 Damage to Airplane

The airplane was substantially damaged.

1.4 Other Damage

No other damage occurred as a result of this accident.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 57, was hired by Pacific Southwest Airlines on February 25, 1980.[16] Before this, he flew McDonnell Douglas F-4 airplanes for the U.S. Air Force. At the time of the accident, he held a single- and multi-engine airline transport pilot (ATP) certificate, issued August 7, 2002, with type ratings in A320, Boeing 737, McDonnell Douglas DC-9, Learjet, and British Aerospace AVR-146 airplanes. The captain held a first-class Federal Aviation Administration (FAA) airman medical certificate, dated December 1, 2008, with no limitations.

[16] Pacific Southwest Airlines merged with USAir Group in 1988. The company was renamed US Airways Group in 1997.

According to US Airways records, the captain had accumulated 19,663 total flight hours, including 8,930 hours as pilot-in-command, 4,765 hours of which were in A320 airplanes. He had flown 155, 83, 39, and 5 hours in the 90, 60, and 30 days, and 24 hours, respectively, before the accident flight. The captain's last A320 line check occurred on December 27, 2007; his last recurrent ground training occurred on February 19, 2008; and his last proficiency check occurred on February 21, 2008. A search of FAA records revealed no accident or incident history, enforcement action, pilot certificate or rating failure, or retest history. A search of the National Driver Register found no record of driver's license suspension or revocation.

The captain stated that he was in excellent health, that he was not taking any prescription medications at the time of the accident, and that he had not taken any medications that might have affected his performance in the 72 hours before the accident. He stated that he drank occasionally but that he had not drunk any alcohol in the week and a half before the accident. The captain reported no major changes to his health, financial situation, or personal life in the last year. A US Airways first officer who had flown with the captain on a six-leg trip sequence in December 2008 described him as exceptionally intelligent, polite, and professional.

1.5.1.1 The Captain's 72-Hour History

From December 31, 2008, to January 11, 2009, the captain was off duty at his home in the San Francisco, California, area. The captain stated that, when he was off duty, he typically went to sleep about 2300 and woke about 0700 Pacific standard time (PST). He stated that he typically needed about 8 hours of sleep to feel rested.

On January 12, the captain began a 4-day trip sequence with the first officer. He stated that they departed CLT at 1806 and arrived at San Francisco International Airport (SFO), San Francisco, California, at 2119 PST.[17] He stated that he spent the evening at home and that he went to sleep about 2300 PST.

On January 13, the captain awoke about 0700 PST and ate breakfast. He stated that he left his house about 1100 PST and arrived at SFO about 1220 PST. The flight departed SFO about 1315 PST and arrived at PIT about 2100. The captain stated that the total layover time in Pittsburgh was about 10 hours. He added that he did not recall what time he went to bed.

On January 14, the captain awoke about 0510 and ate breakfast. He stated that the quality of his sleep the previous night was good or average and that, although he did not get 8 hours of sleep, he was "ok" and felt "normal." The flight crew flew from PIT to LGA and then back to PIT. The captain stated that the total layover time in Pittsburgh was long. He added that he went for a walk around town, ate dinner, answered some e-mails, and went to bed about 2200.

[17] The captain commuted from SFO to CLT to start the 4-day trip sequence via a morning commercial flight, which arrived in CLT the afternoon of the first day of the trip sequence.

On January 15, the captain awoke about 0640. He stated that the quality of his sleep the previous night was good and that he felt rested. The captain ate breakfast at PIT. The captain's first flight departed PIT at 0856 and arrived at CLT at 1055, at which point the flight crew changed to the accident airplane. The captain stated that he did not get anything to eat in CLT. The flight departed CLT at 1154 and arrived at LGA at 1423. The captain stated that, because they had a quick turnaround at LGA, he purchased a sandwich to eat on the airplane after departure.

1.5.2 The First Officer

The first officer, age 49, was hired by US Airways on April 7, 1986. At the time of the accident, he held a multiengine ATP certificate, issued December 31, 2008, with type ratings in A320,[18] Boeing 737, and Fokker 100 airplanes. The first officer held a first-class FAA airman medical certificate, dated October 7, 2008, with the limitation that he "must wear corrective lenses." The first officer stated during postaccident interviews that he was wearing corrective lenses at the time of the accident.

According to US Airways records, the first officer had accumulated 15,643 total flight hours, including 8,977 hours as second-in-command (SIC). The first officer had 37 hours in A320 airplanes, all as SIC. He had flown 124, 55, 37, and 5 hours in the 90, 60, and 30 days, and 24 hours, respectively, before the accident flight. The first officer's last line check on the A320 occurred on January 8, 2009, and his last proficiency check occurred on December 31, 2008. A search of FAA records revealed no accident or incident history, enforcement action, pilot certificate or rating failure, or retest history. A search of the National Driver Register found no record of driver's license suspension or revocation.

The first officer stated that he was in good health, that he was not taking any prescription medications at the time of the accident, and that he had not taken any medications that might have affected his performance in the 72 hours before the accident. He stated that he had not drunk alcohol in the last 10 years. The first officer reported no major changes to his health, financial situation, or personal life in the last year. A US Airways check airman who had flown with the first officer for the first officer's operating experience in January 2009 described him as a very good pilot.

1.5.2.1 The First Officer's 72-Hour History

From January 9 through 11, 2009, the first officer was off duty at his home in Madison, Wisconsin. He stated that he typically needed about 7 hours of sleep to feel rested.

[18] The first officer received his initial A320 type rating on December 31, 2008.

On January 12, the first officer began the 4-day trip sequence with the captain.[19] He stated that, after arriving at SFO from CLT at 2119 PST on January 12, he went to sleep about 2300 PST. The first officer could not recall when he awoke on January 13, but he stated that he felt rested. He stated that the layover in Pittsburgh was less than 8 hours and that he did not recall what time he went to bed.

On January 14, the first officer awoke about 0510. He stated that, after flying from PIT to LGA and then back to PIT, the pilots had a long layover in Pittsburgh. He stated that he did not recall when he went to bed. On January 15, the first officer awoke about 0640. He stated that he felt rested and that the quality of his sleep was good. He stated that he did not eat breakfast, which was typical for him. The first officer stated that, after the flight arrived at CLT, he ate at the airport. He stated that after they arrived at LGA, he got off the airplane and performed a walk around. He stated that they had a quick turn at LGA because the flight had arrived late.

1.5.3 The Flight Attendants

Flight attendant A, age 51, was located at the aft-facing, forward jumpseat (outboard). She received her initial ground training on June 22, 1982; her initial extended overwater (EOW)[20] training on August 20, 1990; and her last recurrent training on January 31, 2008. Flight attendant B, age 58, was located at the forward-facing, "direct-view" jumpseat (aft, center aisle). She received her initial ground training on September 15, 1970; her initial EOW training on September 18, 1989; and her last recurrent training on July 17, 2008. Flight attendant C, age 57, was located at the aft-facing, forward jumpseat (inboard). She received her initial ground training on February 27, 1980; her initial EOW training on October 17, 1989; and her last recurrent training on January 31, 2008.

1.6 Airplane Information

1.6.1 General Information

Airbus, the manufacturer of the A320 airplane, is headquartered in Toulouse, France. The A320-100/200 series airplanes were type certificated for operation in the United States by the FAA under a bilateral airworthiness agreement between the United States and French governments. The FAA approved the A320 type certificate (TC) on December 15, 1988. The A320-214 model was approved on December 12, 1996.

[19] The first officer commuted from Madison to CLT to start the 4-day trip sequence via a morning commercial flight, which arrived in CLT the afternoon of the first day of the trip sequence.

[20] Title 14 CFR 1.1, "General Definitions," defines EOW operations, with respect to aircraft other than helicopters, as operations over water at a horizontal distance of more than 50 miles from the nearest shoreline.

The manufacture of the accident airplane was completed by June 15, 1999. The airplane was delivered new to US Airways and was put on its Part 121 operating certificate on August 3, 1999. At the time of the accident, the airplane had accumulated 25,241 total flight hours and 16,299 total cycles.[21] The airplane's last major maintenance inspection was conducted when the airplane had accumulated 24,912 flight hours.

According to the weight and balance manifest provided by US Airways,[22] the airplane departed LGA with a takeoff weight of 151,510 pounds,[23] which was below the maximum limitation takeoff weight of 151,600 pounds. Assuming a fuel burn of 1,500 pounds during the climb to 3,000 feet and descent at idle thrust, the airplane's weight when it was ditched on the Hudson River was estimated to be about 150,000 pounds. The corresponding center of gravity (cg) was 31.1 percent mean aerodynamic chord (MAC), which was within the takeoff cg limits of between 18.1 and 39.9 percent MAC.

The airplane was configured with 12 first-class passenger seats; 138 economy-class passenger seats; two cockpit flight crew seats; two cockpit observer seats; and five retractable flight attendant jumpseats. Two wall-mounted, aft-facing jumpseats were located at the left, forward passenger door (1L); a bulkhead-mounted, forward-facing jumpseat was located in the aft aisle; and wall-mounted, aft-facing jumpseats were located on each side of the aft galley.

1.6.2 Airspeed Displays

The airplane was equipped with two primary flight displays (PFD), one located on each pilot's instrument panel. On the left side of each PFD was an airspeed scale with a grey background and a fixed yellow reference line and triangle. A white scale was overlaid on, and moved in front of, the background and reference line and triangle, indicating airspeed. In addition to the airplane airspeed, the following characteristic and protection speeds, in part, were presented on the airspeed scale (see figure 3):

- Green dot speed, which is the airspeed that provides the best lift over drag ratio. If a pilot maintains this airspeed, the airplane will have the maximum range for glided flight. Green dot speed is represented by a green circle on the right side of the airspeed tape.

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

[22] US Airways used a computerized weight and balance system that included, in part, a takeoff performance system, which was used as the primary tool to ensure that an airplane's structural loading limits, takeoff weight limits, and center of gravity limits were not exceeded for a particular flight.

[23] The takeoff weight included 29,250 pounds of passenger weight, 22,100 pounds of fuel, and 2,910 pounds of cargo and baggage. The calculation assumed a taxi fuel burn of 750 pounds.

- F speed, which is used as a target speed on approach (not the final approach speed) when the airplane is in CONF 2 or CONF 3.[24] F speed is represented by an "F" on the airspeed scale.

- V_{LS}, which is the lowest selectable airspeed providing an appropriate margin to the stall speed. V_{LS} is represented by the top of an amber strip along the airspeed scale and is computed by the FAC based on aerodynamic data.

- α PROT, which is the alpha-protection speed. α PROT is represented by the top of a black and amber strip along the airspeed scale. The alpha-protection speed corresponds to the angle-of-attack (AOA) at which the alpha-protection mode (see section 1.6.3) becomes active. It varies according to airplane weight and configuration.

- α MAX, which is the maximum AOA speed. α MAX is represented by the top of a red strip along the airspeed scale. Maximum AOA speed corresponds to the maximum AOA that may be reached in pitch normal law (see section 1.6.3) and varied according to airplane weight and configuration.

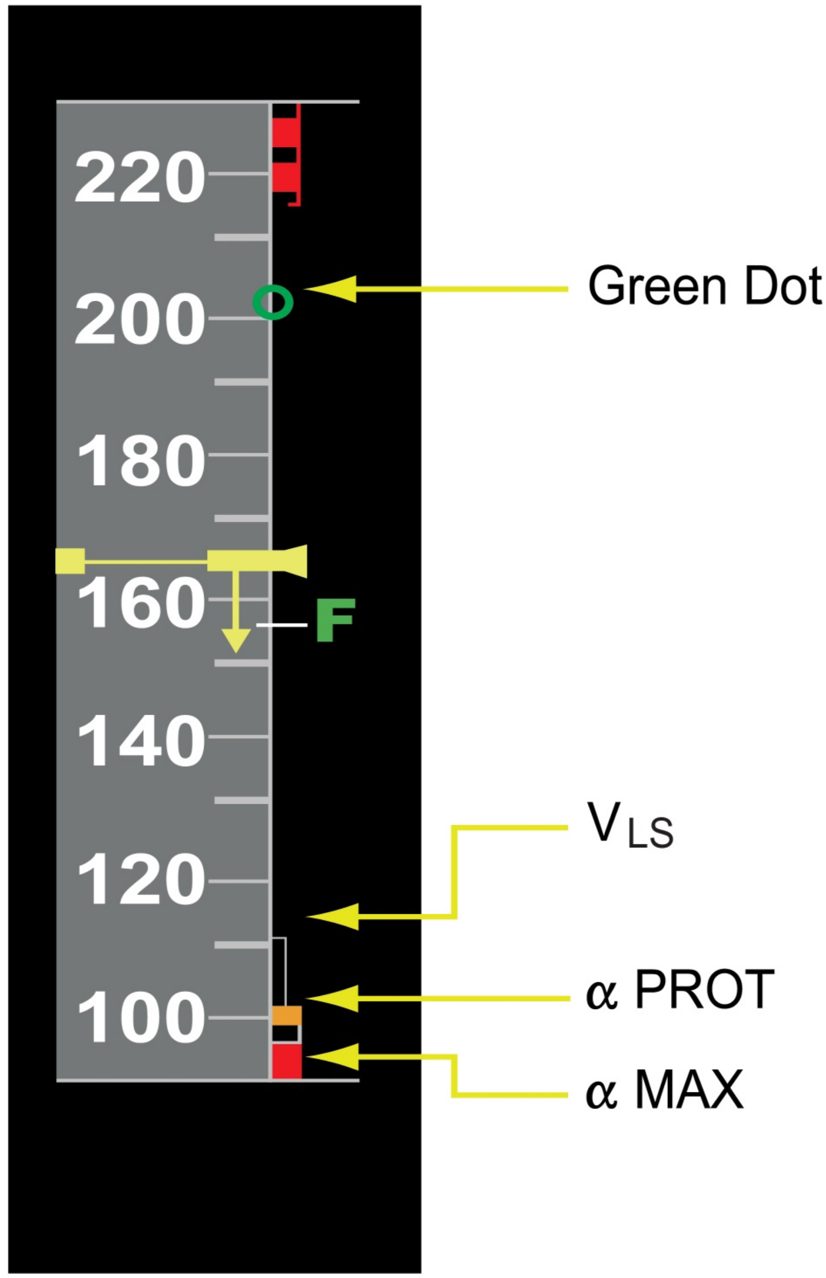

Figure 3. The A320 airspeed scale, including select characteristics and protection speeds.

[24] CONF refers to the airplane flap and slat configuration and the flaps lever position. The flaps lever selects simultaneous movement of the flaps and slats. CONF 2 refers to slat and flap positions 2: flaps 15°, slats 22°. CONF 3 refers to slat and flap positions 3: flaps 20°, slats 22°. (The slat positions do not change when the flap lever is moved from position 2 to 3.) Each wing had two flap and five slat surfaces, which were electronically controlled and hydraulically actuated.

1.6.3 Flight Envelope Protections

The A320 is a "fly-by-wire" airplane, which means that pilot control inputs on the sidesticks are processed by flight control computers that then send electrical signals to the hydraulic actuators that move the pitch and roll flight control surfaces (the ailerons, spoilers, and elevators).[25] The A320 fly-by-wire design incorporates flight envelope protections; the flight computers are designed to prevent exceedence of the safe flight envelope in the pitch-and-roll axes when in "normal law," which is the normal operating mode of the airplane's electronic flight control system. Normal law is one of three sets of control laws (the other two control laws are "alternate law" and "direct law"), which are provided according to the status of the computers, peripherals, and hydraulic generation. The airplane cannot be stalled in normal law. According to the Airbus Flight Crew Training Manual, control law is the "relationship between the…PF's input on the sidestick, and the aircraft's response," which determines the handling characteristics of the aircraft.

The A320 flight envelope protections also incorporate a high-AOA protection, which is available from takeoff to landing and is intended, in part, to allow the pilot to pull full aft on the sidestick to achieve and maintain the maximum possible performance while minimizing the risk of stall or loss of control.

Regarding the high-AOA protection, the Airbus Flight Crew Operating Manual (FCOM) stated, in part, that, under normal law, when the AOA becomes greater than a threshold value, the system switches elevator control from flight mode to protection mode, in which the AOA is proportional to sidestick deflection. The AOA will not exceed the allowable maximum even if the pilot gently pulls the sidestick full aft. If the pilot releases the sidestick, the AOA returns to the alpha-protection threshold value and stays there. Under certain conditions, additional features built into the system can attenuate pilot sidestick pitch inputs, preventing the airplane from reaching the maximum AOA.

1.6.4 Low-Speed or -Energy Warning

The A320 also incorporated an aural warning, which was available when the airplane was operating in normal law, to enhance the pilot's awareness of a low-speed or -energy condition. This warning is only available when the airplane is in CONF 2, CONF 3, or full flaps. The Airbus FCOM states the following:

> An aural low-energy "SPEED SPEED SPEED" warning, repeated every 5 seconds, warns the pilot that the aircraft's energy level is going below a threshold under which he will have to increase thrust, in order to regain a positive flight path angle through pitch control.

[25] Conventional aircraft flight control systems, such as the A320 rudder control system, use cables, wires, and/or hydraulic lines to translate pilot flight control inputs into flight control surface movements.

However, the low-energy warning is overridden when the airplane is below 100 feet radio altitude or when a GPWS alert is triggered. According to CVR and FDR data, GPWS alerts were triggered repeatedly during the descent, and no low-energy level alert was generated.

1.6.5 Electrical and Hydraulic Systems

The airplane was equipped with two integrated-drive generators (IDG), one mounted on each engine, which normally supply electrical power to the airplane systems. An IDG will only supply electrical power when the N_2 speed is about 54 percent or more. The airplane was also equipped with an APU that drives a third, or auxiliary, generator, which can replace the electrical power normally supplied by either IDG.

If both the primary and auxiliary power sources are lost, a ram air turbine (RAT) contained in a compartment in the left airplane belly fairing supplies hydraulic power to the controlled-speed motor generator, which then provides electrical power to the airplane. During normal conditions, the RAT is retracted into the fuselage and does not operate. When all of the airplane's electrical power is lost and the airplane has an airspeed greater than 100 knots (kts), the RAT will automatically deploy and begin providing electrical power. The RAT was found in the extended position when the airplane was recovered from the water. Both RAT blades were present, and no major deformation of the blades was observed.

The airplane is equipped with three main hydraulic systems, referred to as green, blue, and yellow, which together supply hydraulic power at 3,000 pounds per square inch (psi) to the airplane's main hydraulic power users, including the flight controls. The slats are powered by both the green and blue hydraulic systems, and the flaps are powered by both the green and yellow hydraulic systems. The three hydraulic systems are not hydraulically connected.

Each of the three hydraulic systems is pressurized by either an engine-driven or electric motor-driven pump. The blue system's electric pump supplies hydraulic power when either engine is operating. The green and yellow systems' engine-driven pumps are connected to the left and right engine, respectively, and these pumps supply hydraulic power when their respective engine is operating. The engine-driven hydraulic pumps are driven by the N_2 spool and are able to supply hydraulic pressure as long as the engine is rotating. Generally, the lower the N_2 speed, the lower the hydraulic flow that can be delivered by the engine-driven hydraulic pumps.

1.6.6 Engines

The airplane was equipped with two CFM International CFM56-5B4/P dual-rotor, turbofan engines. CFM is a partnership between General Electric Company (GE) in the United States and Société Nationale d'Étude et de Construction de Moteurs d'Aviation (Snecma) in

France.[26] The CFM engines were jointly certificated under a bilateral agreement between the FAA and the French Direction Générale de L'Aviation Civile (DGAC) in accordance with 14 CFR Part 33 regulations and Joint Aviation Authorities (JAA) *Joint Aviation Regulations–*Engines (JAR-E) requirements, jointly referred to as Part 33.[27] At a minimum, all of the FAA requirements had to be met for certification, and, if a JAA requirement was more stringent than an FAA requirement, then the more stringent standard had to be met for certification. The FAA issued the CFM56-5B4/P engine a domestic TC on June 20, 1996; at that time, Amendment 33-11 to 14 CFR 33.77, "Foreign Object Ingestion," was the basis for compliance.

The left engine, serial number (S/N) 779-828, was manufactured on September 12, 2000, and installed on the airplane on January 15, 2008. At the time of installation, the left engine had accumulated 16,233 hours and 11,897 cycles since new (CSN). At the time of the accident, the left engine had accumulated 19,182 hours, 13,125 CSN, and 2,949 flight hours since its last maintenance inspection.

The right engine, S/N 779-776, was manufactured on February 16, 2001, and installed on the airplane on May 28, 2006. At the time of installation, the right engine had accumulated 17,916 hours and 6,755 CSN. At the time of the accident, the right engine had accumulated 26,466 hours, 10,340 CSN, and 8,550 flight hours since its last maintenance inspection. The CFM56-5B4/P engine comprises an inlet area, which contains a gas-turbine-driven ducted fan; a 5-stage,[28] low-pressure compressor (LPC) (also referred to as the "booster"); a 9-stage, high-pressure compressor (HPC); a combustor; a single-stage, high-pressure turbine (HPT); a 4-stage, low-pressure turbine (LPT);[29] and an exit exhaust nozzle. Figure 4 shows a cutaway of a turbofan engine.

[26] The engines were jointly designed and manufactured in the United States and Europe. The CFM56 product line name is a combination of the two parent companies' commercial engine designations: GE's CF6 and Snecma's M56.

[27] The JAA is an associated body of the European Civil Aviation Conference, which represents the civil aviation regulatory authorities of participating European States that agreed to cooperate in developing and implementing common safety regulatory standards and procedures. In 2002, the European Aviation Safety Agency (EASA), a Europe-wide regulatory authority that will eventually take over all of the functions of the JAA, was created. On September 28, 2003, EASA took over responsibility for the airworthiness and environmental certification of all aeronautical products, parts, and appliances designed, manufactured, maintained, or used by persons under the regulatory oversight of European Union Member States.

[28] A stage comprises a pair of stationary vanes and rotating blade rows.

[29] For the LPT, the fan is considered stage 1; therefore, the first stage of LPT blades is considered stage 2.

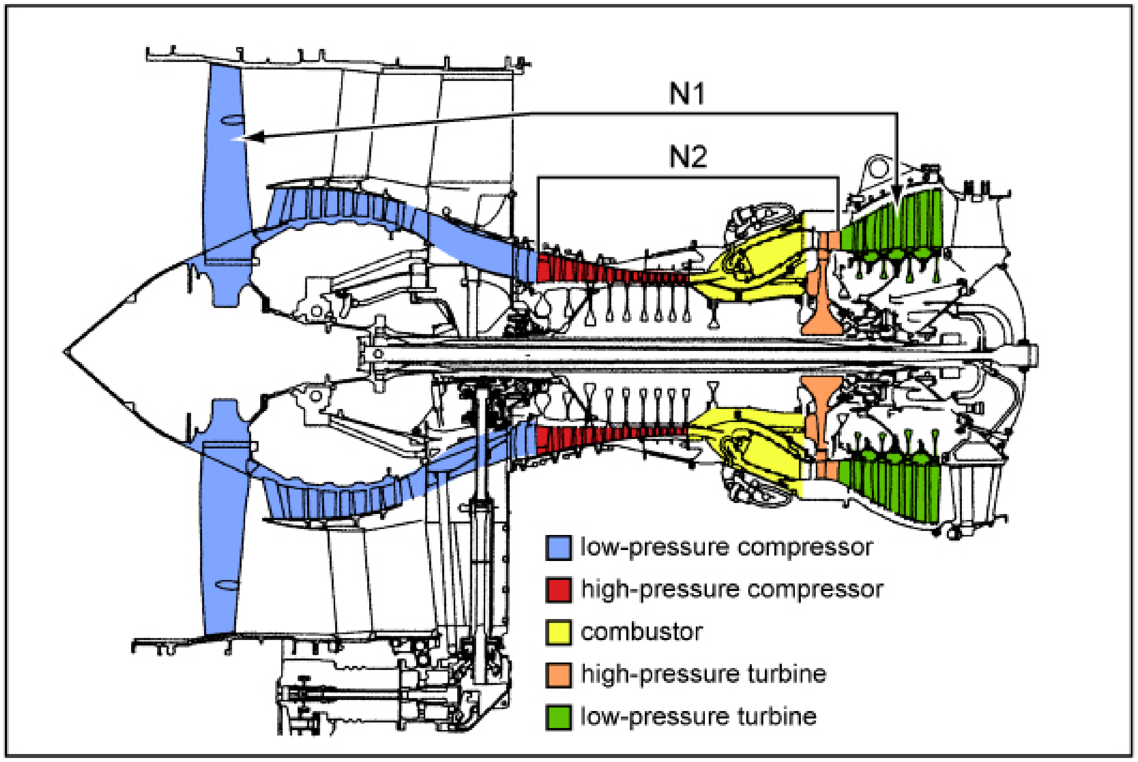

Figure 4. Cutaway of a turbofan engine showing the LPC, HPC, combustor, HPT, and LPT.

The ducted fan comprises a two-piece spinner with an aluminum alloy front cone and rear frustum. The rear frustum is bolted to the fan disk and is part of the fan blade retention system. Thirty-six titanium fan blades, which incorporate a midspan damper for support, are installed into the fan disk. A steel alloy fan inlet case, which is designed to contain a failed fan blade and any associated debris, is bolted to the fan frame structure and the fan cowl inner barrel.

Sixty-eight fan outlet guide vanes (OGV) are located between the rotor and the frame struts within the fan inlet case and are designed to direct the secondary airflow to the bypass duct. The inner surface of the fan inlet case is lined with 6 forward acoustical panels, 1 shroud, 6 midacoustical panels, and 12 aft-acoustical panels.

Air enters the engine inlet area, passes through the ducted fan, and is then channeled to two distinct flow paths. Most of the air bypasses the engine core and is directed through the bypass duct, providing about 70 percent of the engine's overall thrust. The remaining air enters the engine core, where it is compressed; mixed with fuel; combusted; expanded through the LPT, providing rotational power to the fan; and then exhausted, supplying about 30 percent of the engine's overall thrust. Figure 5 shows the two airflow paths through the turbofan engine.

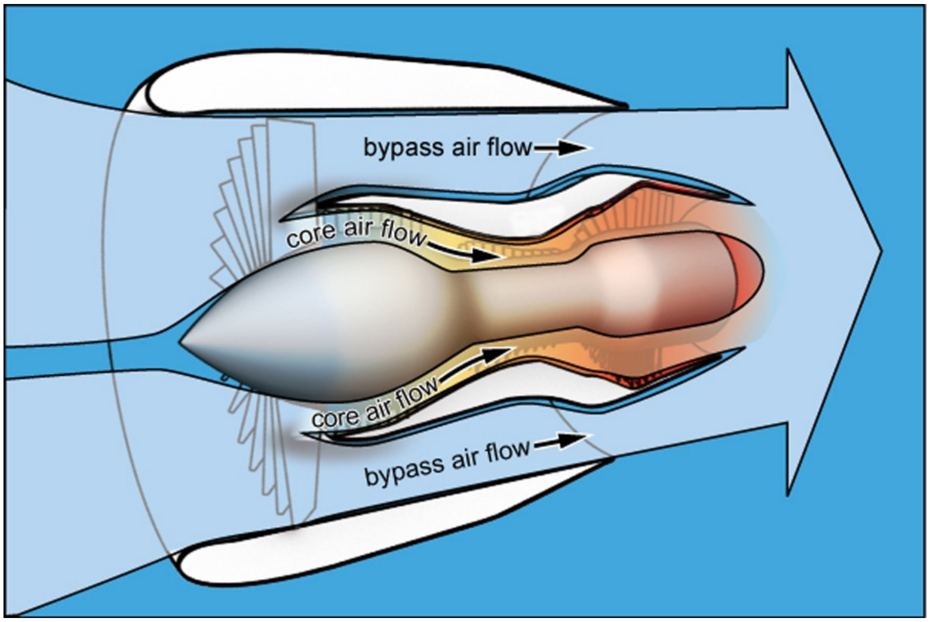

Figure 5. A diagram showing the two airflow paths through the turbofan engine.

A bird may strike any part of the engine inlet area. If a bird enters the inlet near the outer radius, it will most likely strike only the fan blades, continue along the bypass duct, and be ejected at the rear of the engine. In this case, the fan blades may exhibit some form of leading edge impact damage and may bend and fracture. Debris continuing downstream can damage the bypass duct and fan OGVs. All of this damage negatively affects thrust production; however, typically, the engine will still be able to operate at a lower thrust level.

If a bird enters the inlet near the inner radius close to the spinner, a portion of the bird may be ingested by the engine core, possibly damaging the internal components, including the inlet guide vanes (IGV), LPC and HPC vanes and blades, or the combustor. If the damage is sufficient, the engine may stall or flame out,[30] rendering it unable to produce appreciable thrust. (See section 1.12.2 for information about the damage sustained by both engines as a result of the bird strike.)

1.6.6.1 Bird-Ingestion Certification Requirements

1.6.6.1.1 Requirements at the Time of Certification

As noted, 14 CFR Part 33 regulations contain the airworthiness standards that engines are required to comply with to obtain an FAA TC. The aircraft engine certification process consists

[30] A stall is a local disruption of the normal air flow through the engine compressor, which can be caused by an internal component failure, including a broken vane or blade. A flameout is an engine failure caused by the extinction of the flame in the combustion chamber.

of many certification tests or analyses that demonstrate that the engine is compliant with its TC basis, and the TC is issued upon successful completion of all of the certification requirements.

As noted, the CFM56-5B4/P engine was certificated in 1996; at that time, the engine had to meet the bird-ingestion requirements contained in 14 CFR 33.77, "Foreign Object Ingestion," Amendment 33-11,[31] which included bird-ingestion requirements that had been added on March 26, 1984, with the issuance of Amendment 33-10. Section 33.77 stated, in part, the following:

> (a) Ingestion of a 4-pound [large-sized] bird …may not cause the engine to—
> (1) Catch fire;
> (2) Burst (release hazardous fragments through the engine case);
> (3) Generate loads greater than those specified in Sec. 33.23(a);[32] or
> (4) Lose the capability of being shut down.
>
> (b) Ingestion of 3-ounce birds or 1 1/2-pound [medium-sized] birds[33]…may not—
> (1) Cause more than a sustained 25 percent power or thrust loss;
> (2) Require the engine to be shut down within 5 minutes from time of ingestion; or
> (3) Result in a potentially hazardous[34] condition.

According to Section 33.77, the medium bird-ingestion criterion for CFM56-5B4/P-sized engines was seven, 1 1/2-pound birds volleyed[35] into critical areas of the engine (two birds were volleyed into the engine core area, and five birds were volleyed into the fan blade area at midspan, outer panel, and two intermediate locations) in rapid sequence to simulate a flock encounter. The large-bird ingestion criterion for CFM56-5B4/P-sized engines was a single, 4-pound bird volleyed into a critical area of the fan but not in the core area.

To comply with these requirements, the CFM56-5B4/P engine was subjected to a medium-bird test, which was intended to test the fan blades, structure, and core machinery for resistance to impact from, and ingestion of, multiple medium-sized birds. The engine was also subjected to a large-bird test, which was intended to test the fan blades, flammable fluid lines, and support structure for resistance to impact from, and ingestion of, a single, large bird. These tests were performed with the engine at 100-percent takeoff power.

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[31] The applicable JAA requirements were contained in JAR-E, change 7 C3-2, paragraph 20.2. Amendment 33-11 did not affect the bird certification requirements.

[32] Title 14 CFR 33.23(a), "Engine Mounting Attachments and Structure," states, "the maximum allowable limit and ultimate loads for engine mounting attachments and related engine structure must be specified."

[33] The 3-ounce bird ingestion requirement did not apply if a 1 1/2-pound bird could pass through the IGVs into the rotor blades, which was demonstrated successfully for the accident engine.

[34] At the time that Amendment 33-10 went into effect, engine hazards were defined as fire, uncontained debris, mount failure, and inability to shutdown.

[35] To volley means to shoot the birds into the engine (as defined by critical ingestion parameters that include bird speed, critical engine target location, and fan speed) in a specified time within the normal flight operations up to 1,500 feet agl, but not less than the minimum takeoff-decision speed for the airplane.

A December 15, 1992, test report stated that, during the medium-bird ingestion test, the CFM56-5B4/P engine continued to operate with no more than a 25-percent loss of thrust for 5 minutes after the bird ingestion and demonstrated no hazard to the aircraft and no change in handling characteristics after the birds were ingested. The report stated that the engine met the medium-bird test requirements, and the FAA and the DGAC jointly approved the report.

An August 25, 1992, test report stated that, during the large-bird ingestion test, the CFM56-5B4/P engine did not release hazardous fragments, the fan imbalance was negligible, and the test generated lower loads and fan blade distress than the fan blade-out test.[36] The report stated that the engine met the large-bird test requirements, and the FAA and the DGAC jointly approved the report.

In early 1993, additional tests were conducted to comply with DGAC CFM56-5B1/-5B2-5B4 Special Condition No. 1,[37] which changed the medium-bird weight requirement to 2 1/2 pounds and required the engine to operate with no more than a 25-percent loss of thrust for 20 minutes after the bird ingestion. Five tests were conducted. For the tests, a 2 1/2-pound bird was volleyed into critical locations on the fan, LPC assembly, spinner, HPC, and combustor, and the engine was run for 20 minutes to demonstrate the capability for further operation. A March 10, 1993, test report stated that the engine operated for 20 minutes with no risk of imminent hazard to the airplane, no exceedence of engine limitations, and no change in handling characteristics. The report stated that the engine passed the special-condition tests, and the FAA and the DGAC jointly approved the report.

In 1996, changes were made to the CFM56-5B4/P engine core design, requiring that the core portion of the medium-bird certification test demonstration be rerun to qualify the new hardware. For the test, two 1 1/2-pound birds were volleyed into the engine core in rapid sequence, and the engine was run for 20 minutes to demonstrate the capability for further operation.[38] The June 20, 1996, test report stated that the engine operated for 20 minutes with no risk of imminent hazard to the airplane, no exceedence of engine limitations, and no change in handling characteristics. The report stated that the engine passed the tests, and the FAA and the DGAC jointly approved the report.

1.6.6.1.2 Amendments Made After Certification

Since 1996, amendments have been made to Part 33 regulations that affect the bird-ingestion requirements for newly certificated engines. For example, on September 5, 2000, the FAA adopted new regulations under Amendment 33-20, which became effective on

[36] The fan blade-out test is an engine certification requirement contained in 14 CFR 33.94, "Blade Containment and Rotor Unbalance Tests," which is intended to demonstrate the engine's capability of containing engine damage without catching fire and without its mounting attachments failing.

[37] A special condition is a modified or additional rule that can be issued by an aviation authority. The DGAC issued Special Condition No. 1 during the certification period for the engine.

[38] GE's design changes only affected the engine core; therefore, the fan-shot portion of the test did not have to be rerun.

December 13, 2000, and created a new Section 33.76, "Bird Ingestion,"[39] to better address the overall bird-ingestion threat to turbine-powered aircraft. According to the FAA, these requirements were adopted, in part, as a response to the National Transportation Safety Board's (NTSB) Safety Recommendation A-76-64.[40]

The new regulations significantly expanded the requirements for operating after bird ingestion. In part, the large-bird weight requirement, contained in Section 33.76(b), changed from 4 pounds to 4, 6, or 8 pounds, depending on engine size. Further, the medium-bird weight requirement, contained in Section 33.76(c), changed from 1 1/2 pounds to a combination of a 1 1/2-pound bird plus a 2 1/2-pound bird, depending on engine size, with no more than 25-percent loss of thrust for 20 minutes of operation (a 15-minute increase over the previous FAA requirement). The tests were required to be run with the engine at 100-percent takeoff power or thrust.

Most recently, the FAA adopted new regulations under Amendment 33-23, which became effective on November 16, 2007, and introduced a new class of bird, the large flocking bird, for testing the fan blades, flammable fluid lines, and support structure. The large flocking bird weight requirement, contained in Section 33.76(d), was 4, 4 1/2, or 5 1/2 pounds, depending on engine size,[41] and the engines had to continue running on a decreasing sliding scale from 90-percent maximum takeoff power for 20 minutes after ingestion.[42] These changes harmonized FAA and European Aviation Safety Agency (EASA) bird-ingestion standards for aircraft turbine engines type certificated by the United States and the EASA countries. Only newly designed engines obtaining a TC must meet the latest requirements; therefore, the accident engine was not required to meet any of the new requirements that resulted from the rule changes made after its TC was issued.

[39] Section 33.77, which previously addressed foreign-object ingestion requirements, including bird strikes, was changed to address only ice ingestion.

[40] The NTSB issued Safety Recommendation A-76-64 as a result of the November 12, 1975, Overseas National Airways, Inc., accident, which was caused by the ingestion of several large birds into one of its three GE CF6 engines. The NTSB determined that the bird-ingestion certification requirements in effect at the time did not provide adequate safeguards against the ingestion potential of future large turbofan engines. Safety Recommendation A-76-64 asked the FAA to "amend 14 CFR 33.77 to increase the maximum number of birds in the various size categories required to be ingested into turbine engines with large inlets. These increased numbers and sizes should be consistent with the birds ingested during service experience of these engines." In response, the FAA issued a report titled, "A Study of Bird Ingestions Into Large High Bypass Ratio Turbine Aircraft Engines," which concluded that additional bird-ingestion service data were needed to improve the validity of the FAA's database of bird-ingestion events. On July 30, 1986, the NTSB classified Safety Recommendation A-76-64 "Closed–Acceptable Action." Although the NTSB closed the safety recommendation, as discussed in this section, the FAA continued to take actions to improve the bird-ingestion requirements of turbofan engines.

[41] The large-flocking-bird requirement only applies to engines with inlet areas greater than 3,875 square inches. Smaller transport-category airplane engines, such as the CFM56-5B4/P, which has an inlet area of 3,077 square inches, are exempt from this test.

[42] For example, the test requires that, for the first 14 minutes of operation after ingestion, the engine must produce no less than 50 percent of the maximum takeoff power, but, toward the end of the test, the engine is allowed to produce between 5 and 10 percent of the maximum takeoff power.

1.6.6.1.3 Postaccident Actions

As a result of the US Airways accident, the FAA engine and propeller directorate, jointly with EASA, initiated a reevaluation of the existing bird-ingestion certification regulations to determine whether new rulemaking was necessary. A working group, including members from the FAA, EASA, and Aerospace Industrie Association propulsion committee, was tasked to do the following:

1. Update the bird-ingestion rulemaking database (BRDB) to include industry data for all bird-ingestion events from January 1, 2000 (when the BRDB was last updated), through the end of 2008.[43] (Currently, the BRDB includes data from January 1, 1970, to December 31, 1999.)

2. Once the BRDB is updated, perform a statistical analysis of the raw data.

3. Reevaluate the FAA and EASA compliance methods to ensure that the appropriate test demonstrations are still valid.

The working group is expected to use this information to reevaluate whether current regulations still meet FAA and EASA safety objectives and additional action or rulemaking changes are necessary.

1.6.7 Airframe Ditching and Emergency Landing Certification Requirements

Certification for ditching is optional since not all airplane types will be used to conduct EOW operations. The accident airplane was certificated for ditching. (See section 2.1 for an explanation of why the NTSB considers this accident to be a ditching.) Airbus airplanes are designed and certificated according to the requirements of 14 CFR Part 25, "Airworthiness Standards: Transport-Category Airplanes." Section 25.801, "Ditching," contains the transport-category certification requirements that pertain to the behavior and response of the airplane during a ditching. Therefore, if certification with ditching provisions is requested, the airplane must meet the requirements of Section 25.801, which states, in part, the following:

> (b) Each practicable design measure, compatible with the general characteristics of the airplane, must be taken to minimize the probability that in an emergency landing on water, the behavior of the airplane would cause immediate injury to the occupants or would make it impossible for them to escape.

[43] Originally, the update of the BRDB was expected to be completed by the end of 2009; however, the last meeting on the BRDB occurred from March 16 to 18, 2010, at which time, it was determined that the data needed further refinement. Participants are continuing to update the database and tentatively plan to meet again during summer 2010.

> (c) The probable behavior of the airplane in a water landing must be investigated by model tests or by comparison with airplanes of similar configuration for which the ditching characteristics are known.
>
> (d) It must be shown that, under reasonably probable water conditions, the flotation time and trim of the airplane will allow the occupants to leave the airplane and enter in the life rafts required by [Section] 25.1415. If compliance with this provision is shown by buoyancy and trim computations, appropriate allowance must be made for probable structural damage and leakage.

In addition, at the time that the accident airplane was certificated, 14 CFR 25.561, "Emergency Landing Conditions – General," Amendment 25-23, which was issued on April 8, 1970, was in effect and stated, in part, the following:

> (a) The airplane, although it may be damaged in emergency landing conditions on land or water, must be designed as prescribed in this paragraph to protect each occupant under those conditions.
>
> (b) The structure must be designed to give each occupant every reasonable chance of escaping injury in a minor crash landing when…
>
> (3) The occupant experiences the following ultimate inertia forces relative to the surrounding structure:
>
> (i) Upward, 2.0 G.[44]
>
> (ii) Forward, 9.0 G.
>
> (iii) Sideward, 1.5 G.
>
> (iv) Downward, 4.5 G.

See sections 1.15.1.1 and 1.15.1.2 of this report for information about ditching exit and safety equipment requirements, respectively.

As noted, the FAA approved the A320 model TC on December 15, 1988. The ditching certification for the airplane was based on over 200 ditching tests conducted on scale models of A300 B2 and Dassault Mercure airplanes, taking into account their similar geometry to the A320 in accordance with Section 25.801(c),[45] and National Advisory Committee for Aeronautics

[44] One G is equivalent to the acceleration caused by the earth's gravity (32.174 feet per second^2).

[45] The water tank tests that formed the basis of the ditching substantiation effort for the A320 were conducted by the Institut de Mécanique des Fluides de Lille (IMF Lille), an engineering laboratory in Lille, France, that

(NACA), now the National Aeronautics and Space Administration (NASA), reports from the 1950s.[46] The tests were conducted to identify the approach scenario (in terms of airplane parameters, including glideslope, pitch, and airspeed) that would provide the best overall behavior during a ditching (no nose diving or loss of aircraft control, no fuselage breakup, and minimum lower fuselage deformation). The NTSB notes that the tests were conducted to determine the best way, not the only way, to set up the airplane for a ditching to achieve the certification requirements and to provide an idea of how the airplane may perform during a ditching.

The January 21, 1988, Airbus certification test report stated that the fuselage of an A320 would "undergo no destruction liable to create a water passage" if the airplane ditched with the following parameters:

- landing gear retracted,
- 11° pitch,
- -0.5° glideslope, and
- flaps in landing configuration for minimum speed.

According to Airbus, the ditching certification criteria also assumed that engine power was available, that the descent rate was 3.5 feet per second (fps), and that the airplane landed longitudinal to any water swells. These criteria are consistent with the test results published in the NACA reports.

The ditching inertial loads values defined in Section 25.561(b)(3) were compared to the A300 B2 and Mercure test model data, and the longitudinal and vertical accelerations measured in the tests were below the specified values. In addition, the models used for the ditching tests were calibrated such that the water pressure acting on the models could be derived from the deformation of the lower fuselage. Based on water pressures derived from the tests on similar aircraft, the water pressure for the A320 was calculated. The average external pressures were calculated at the recommended pitch (11°), maximum landing weight, a glideslope of -1° (twice the recommended value), and minimum speed. The corresponding average external pressure calculations indicated that the fuselage skin and stringers and the cargo floor structure (crossbeams and support struts) demonstrated sufficient strength under the applied external pressures.

specializes in fluid dynamics research. These tests are documented in J. Gobeltz and P. Gythiel, "Essais d'Amerissage Force Sur Bassin d'Une Maquette au 1/16 ème de l'Avion Mercure" (Water-Tank Tests of the Water-Landing Forces on a 1/16 Scale Model of the Mercure Aircraft), Report No. 74-5 (Lille, France: 1974). See section 1.18.4 for more information about these tests.

[46] See (a) L.J. Fisher and E.L. Hoffman, *Ditching Investigations and Effects of Design Parameters on Ditching Characteristics,* Report No. 1347 (Langley, Virginia: 1956). (b) E.E. McBride and L.J. Fisher, *Experimental Investigations of the Effects of Rear Fuselage Shape on Ditching Behavior*, NACA Technical Note 2929 (Langley Research Center, Hampton, Virginia: 1953).

Table 2 shows A320 certification values and the actual values experienced during the accident flight.

Table 2. Certification and accident flight values.

	Certification	**Accident Flight**
Mass (in pounds)	145,505	151,017
Pitch attitude (in °)	11	9.5
Airspeed (in knots)	118	125
Glideslope (in °)	-1	-3.5
Descent rate (in fps)	3.5	12.5
Average external pressure (in psi)	7.3	15.1
Maximum external pressure (in psi)	10.9	22.6

1.6.8 US Airways Maintenance Program

1.6.8.1 General

The US Airways A320-214 maintenance inspection program is contained in its time limits manual (TLM) and includes daily, overnight, weekly, and fixed-interval inspections. Further, all engine maintenance inspections, including component, servicing, periodic, and heavy inspections, are incorporated into the TLM. According to the airplane's maintenance records, the daily and overnight checks conducted the day before the flight and the last weekly check, conducted on January 10, 2009, noted no discrepancies. The airplane's last fixed-interval inspection before the accident was conducted on December 6, 2008.

1.6.8.2 Engine Maintenance Records

US Airways also maintained a Continuing Analysis and Surveillance System (CASS) to oversee its Continuous Airworthiness Management Program, as required by federal regulations.[47] A review of CASS reports from October 2008 to January 2009 revealed no systemic issues except for the occurrence of 12 compressor stalls in December 2008. Four of these stalls occurred on CFM56-5B4/P engines; however, none of these stalls occurred on the accident airplane.

[47] In accordance with 14 CFR 121.373, "Continuing Analysis and Surveillance," each certificate holder must establish and maintain a system for the continuing analysis and surveillance of the performance and effectiveness of its inspection program and the program covering other maintenance, preventative maintenance and alterations, and for the correction of any deficiency in those programs, regardless of whether those programs are carried out by the certificate holder or by another person.

The engine logbook entries for both engines from January 1, 2008, to January 15, 2009, were reviewed for discrepancies. The review of the left engine logbook entries revealed no issues or discrepancies. The review of the right engine logbook entries revealed that, on January 13, 2009, 2 days before the accident, the right engine stalled at an altitude of about 17,000 feet on a flight from LGA to CLT.[48] Maintenance personnel at CLT replaced the T25 temperature sensor probe per Airplane Maintenance Manual 73-21-20 and accomplished a borescope inspection of the stage-5 LPC blades. No faults were noted, and the airplane was returned to service. No further stall discrepancies were logged.

1.7 Meteorological Information

Weather observations at LGA and in other areas near the airport are made by automated surface observing systems (ASOS), which record continuous information on wind speed and direction, cloud cover (reported in feet agl), temperature, precipitation, and visibility (in statute miles), and transmit an official report each hour. The closest ASOS to the accident site was located about 1.6 miles east of the accident site in Central Park, New York City, New York. The 1451 Central Park surface weather observation indicated the following: winds 290° at 8 kts, visibility 10 miles, cloud ceiling 3,700 feet broken, temperature -6° C, dew point -15° C, and altimeter setting 30.24 inches of mercury (Hg). The 1551 observation indicated the following: winds 310° at 9 kts, visibility 10 miles, few clouds at 4,200 feet, temperature -7° C, dew point -16° C, and altimeter setting 30.28 inches of Hg.

The National Oceanic and Atmospheric Administration, National Ocean Service, owns and maintains buoy station BATN6–8518750 in Battery, New York. According to a BATN6-8518750 report, the water temperature of the Hudson River near the accident location about the time of the accident was 5.2° C (41.36° F), and the current was ebbing at 1.4 kts.

1.8 Aids to Navigation

No problems with any navigational aids were reported.

1.9 Communications

No technical communications problems were reported by the flight crew or any of the air traffic controllers who handled the accident flight.

[48] According to the flight crew that reported the engine stall, the QRH procedure was accomplished, and the stall did not reoccur; the flight continued uneventfully to CLT.

1.10 Airport Information

LGA is a Part 139-certificated airport operated by the Port Authority of New York and New Jersey (NY and NJ) under a lease with New York City. LGA is located in the Borough of Queens, New York City, 8 miles from midtown Manhattan and is at sea level. LGA has two runways: runway 4/22 and runway 13/31. In 2007, about 397,280 operations, including commercial, general, and military aviation operations, were conducted at LGA.

1.10.1 FAA Guidance on Airport Wildlife Hazard Management

Part 139-certificated airports are required to maintain a safe operating environment, which includes the mitigation of wildlife hazards. According to 14 CFR 139.337, "Wildlife Hazard Management," certificated airports are required to conduct a wildlife hazard assessment (WHA) when 1) an air carrier aircraft experiences multiple wildlife strikes, 2) an air carrier aircraft experiences substantial damage from a wildlife strike, 3) an air carrier aircraft experiences engine ingestion of wildlife, or 4) wildlife of a size or quantity capable of causing any of the previously mentioned events is observed to have access to any airport flight pattern or aircraft movement area.

The FAA recommends that, during the assessment process, certificated airport operators implement the standards and practices contained in Advisory Circular (AC) 150/5200-33B, "Hazardous Wildlife Attractants on or near Airports," Section 1-4, "Protection of Approach, Departure, and Circling Airspace." The AC recommends that airports consider wildlife attractants within 10,000 feet of the airport and, if the attractant could cause hazardous wildlife movement into or across the approach or departure airspace, out to 5 statute miles[49] from the airport.

The WHA is submitted to the FAA, which then determines if the airport needs to follow up and develop a Wildlife Hazard Management Plan (WHMP). If the FAA determines that a WHMP is needed, such a plan should be developed using the guidance contained in AC 150/5200-33B and the Wildlife Hazard Management at Airports Manual[50] and incorporated into the airport's airport certification manual (ACM).

[49] A statute mile is 5,280 feet.

[50] The FAA and U.S. Department of Agriculture collaborated to produce the Wildlife Hazard Management at Airports Manual (revised in July 2005), which contains information to assist airport personnel to understand and mitigate wildlife hazards to aviation; conduct wildlife hazard assessments; and develop, implement, and evaluate WHMPs. The manual also includes specific information on the nature of wildlife strikes, legal authority, government agency roles and responsibilities, and pertinent regulations.

1.10.2 LGA Wildlife Hazard Management Program

The LGA ACM includes the airport's WHMP. The LGA WHMP in effect at the time of the accident was developed by the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services, in 2002 and was subsequently approved by the FAA. The LGA WHMP emphasizes the use of techniques to exclude, disperse, or remove hazardous wildlife from the airfield. LGA also uses the following additional wildlife mitigation strategies: it helps manage the Canada goose population at Rikers Island;[51] sponsors studies to examine different varieties of grass to identify varieties aversive to waterfowl; monitors the airport for standing water and drains or removes the attractant water as quickly as is feasible; observes perching activities and modifies perching areas by adding bird deterrent devices or making them undesirable in other ways; posts signs around airport terminals, hangars, construction areas, and taxi-hold areas to remind employees and drivers that feeding wildlife is absolutely prohibited; covers waste receptacles; and monitors hangars and buildings for bird presence, and, if birds are observed, notifies tenants that they are responsible for removing and excluding the birds.

The LGA WHMP notes that certain birds, including Canada geese, pose serious strike threats to airplanes and emphasizes the removal of these species. An LGA bird supervisor is available 24 hours a day, 365 days a year, to perform wildlife control activities, maintain wildlife hazard management logs, recover and identify carcasses for wildlife-strike reporting, and gather and report other wildlife-strike information.

Airport certification inspections conducted at LGA from April 2003 through April 2008 found no discrepancies with the airport's WHMP. During the June 2009 public hearing on this accident, an FAA representative stated that the distance and altitude where the bird strike occurred were well outside the area expected to be covered by LGA's WHMP.

1.10.3 Air Traffic Control

The LGA ATCT provides ATC services from the surface to 2,000 feet, and the New York TRACON provides ATC services from 2,000 feet to 15,000 feet within 5 miles of LGA. The New York TRACON was responsible for flights descending into and climbing out of LGA; John F. Kennedy International Airport (JFK), New York, New York; and Newark Liberty International Airport (EWR), Newark, New Jersey. For at least 1 hour before the accident, ATC received no pilot reports of bird activity. Further, on the day of and before the accident, no bird warning advisories were broadcast on the automated terminal information service, which is a continuous broadcast of recorded noncontrol information in selected terminal areas. The FAA Airport Facility Directory entry for LGA included the following advisory: "Flocks of birds on and in the vicinity of the airport."

[51] Rikers Island is located in the East River and is adjacent to the runways at LGA.

ATC radar coverage for the LGA area is provided by airport surveillance radar (ASR)-9 radar located at JFK. The ASR-9 is a short-range (60 miles) radar that provides position and track information to controllers at the New York TRACON and other control towers, including the LGA ATCT, for aircraft operating within terminal airspace.

ATC services provided by LGA tower controllers during the taxi and departure from runway 4 were reported to be normal. At 1525:51, the captain initiated contact with the New York TRACON LGA departure controller. At 1527:01, when the airplane's altitude was about 2,500 feet, recorded radar data from the EWR and JFK radar sites indicated that the airplane's path intersected a string of unidentified primary targets. A subsequent review of the radar replays showed that these primary targets were not displayed to the LGA departure controller. (See section 1.10.3.3 for more information about the displayed radar targets.)

At 1527:33, the captain advised the LGA departure controller that the airplane had hit birds and lost thrust in both engines and that the flight would be returning to LGA. The departure controller then advised the LGA ATCT local controller to "stop departures, we got an emergency returning." The local controller then asked for the returning flight's call sign, and the departure controller responded, "it's (unintelligible) fifteen twenty nine he uh bird strike. He lost all engines. He lost the thrust to the engines he's returning immediately." The local controller replied, "got it." However, the accident airplane's call sign was "Cactus 1549." The sequencer controller, a noncontrol position located to the left of the departure controller, contacted the ATCT, provided controllers the correct call sign, Cactus 1549, and informed them that the flight crew would like to land on runway 31 at LGA.

At 1528:37, the ATCT cab coordinator advised the LGA departure controller that "runway 4 is also available, if he needs it," and, 16 seconds later, he contacted the LGA Port Authority to advise that the Port Authority of NY and NJ needed to be alerted that an airplane was going to be in the Hudson River. About 1540, the controller was advised by a nearby helicopter pilot that the airplane was in the water. Both LGA ATCT and New York TRACON personnel immediately notified the U.S. Coast Guard (USCG), the New York Police Department (NYPD), and various other search and rescue operations.

1.10.3.1 ATC Guidance

According to FAA Order 7110.65, "Air Traffic Control," Chapter 5, "Radar," Section 4, "Transfer of Radar Identification," when controllers make a handoff, they are to relay the aircraft position, identification (the aircraft's call sign or discrete beacon code), and the assigned altitude. When controllers receive a handoff, they are to respond by stating the aircraft identification (call sign or discrete beacon code) and then "radar contact." As noted, when the New York TRACON LGA departure controller contacted the LGA tower controller to report the returning flight, he provided the incorrect call sign and did not provide the airplane's location. However, the New York TRACON LGA departure controller was not required to provide this information to the LGA tower controller because he was just providing information to the tower controller, not making an official handoff.

During postaccident interviews, the LGA departure controller indicated that he did not provide the airplane's position because the airplane had departed LGA just 45 seconds before declaring the emergency and that he believed that the full data block was still being displayed on the tower controllers' radar displays. The tower controllers indicated that they believed that the flight was further away and that they expected another call from the departure controller to advise them when the flight was closer to LGA.

Controllers usually program the automated radar terminal system (ARTS) to display data blocks, which contain the aircraft's type, altitude, ground speed, and unique call sign, for all aircraft directly under their control and for other aircraft that may affect their operations. On the day of the accident, LGA tower controllers had chosen to display data blocks for aircraft under the control of the tower and aircraft under the control of the approach and departure sectors immediately adjacent to LGA airspace. Other aircraft in the area were shown on the tower controllers' displays as position symbols only, without their associated data blocks.

When the airplane was about 1/2 mile past the departure end of runway 31 at LGA, the New York TRACON departure controller, in keeping with standard practice, maintained responsibility for the airplane but transferred its information to the Liberty West controller who would next handle the airplane. Because the LGA tower controllers had chosen to display only data blocks for aircraft under control of the tower and sectors immediately adjacent to LGA airspace, the data block for the accident airplane disappeared from the LGA tower controllers' radar displays because the Liberty West airspace was not adjacent to the LGA airspace; therefore, they did not know the location of the airplane. As a result of this element of the accident, the NTSB issued Safety Recommendation A-09-112. (See section 1.18.2 for more information.)

1.10.3.2 Traffic Conflict

About the time that the captain stated that the airplane would be going in the Hudson River, two AS350 helicopters (N152TA and N461SA) were conducting air tour operations nearby over the river. The LGA ATCT class B airspace (CBA) controller, who was responsible for monitoring the CBA surrounding LGA,[52] stated that he immediately started looking for flight 1549 after he learned that it was returning to LGA. He stated that he did not see it on the radar display, so he began manually selecting each unidentified target on the display to bring up the flight data for the associated aircraft. While the controller was trying to find the airplane's location on his display, the airplane passed close above N461SA, which resulted in a conflict alert between the accident airplane and the helicopter at 1529:10. The conflict alert caused the ARTS to force the flight data block information for the airplane onto the tower controllers' radar displays, making them aware of the airplane's position and altitude. Nine seconds later, the CBA

[52] Typically, the LGA CBA controller, who was working all the visual flight rules helicopters in the LGA airspace, was responsible for flights in a 6-mile radius from the surface to 2,000 feet. In postaccident interviews, he stated that he set up the radar display with a range of a 12-mile radius from the surface to 4,000 feet.

controller advised N152TA of traffic. Shortly thereafter, the helicopter pilot reported that he had the airplane in sight and that he was “maintaining visual.”

1.10.3.3 Airport Surveillance Radar

Although the ASR-9 radar system is primarily intended to track aircraft by identifying an on-board transponder, it has a limited ability to provide information about other phenomena, such as birds, balloons, and precipitation, by detecting the radar energy reflected from these objects. Radar returns based on reflected energy rather than transponder signals are known as “primary” returns. Many primary returns are not of interest for ATC purposes and could potentially distract controllers or interfere with the system’s detection of phenomena of interest. Therefore, primary returns are filtered from the system except for those that appear to be relevant for ATC purposes. In particular, the radar system attempts to identify and retain targets that move consistently, remain visible from sweep to sweep, and have a ground speed of at least 30 kts. If a primary return meets these criteria, it is likely to be classified as a “correlated” target, indicating a high level of confidence that it is of interest for ATC purposes. If a primary return does not meet these criteria, it may either be discarded as clutter (for example, returns produced by nonmoving objects, such as terrain or bridges) or, if the return cannot be conclusively discarded as clutter, classified as an “uncorrelated” target and forwarded to the display system. Controllers can opt to display only correlated primary targets or to display both correlated and uncorrelated primary targets.

A review of the recorded radar for the time surrounding the bird strike, about 1515 to about 1535, indicated that 14,614 primary targets were detected, 1,716 of which were correlated and identified as having flight characteristics similar to an aircraft. However, according to the recorded keyboard entries and filter selections in effect at the LGA departure controller position at the time, the controller had chosen to display only correlated primary targets, which did not include the primary returns associated with the flock of birds. A postaccident replay of the LGA departure controller’s display showed no primary targets until the collision occurred.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with an Allied Signal/Honeywell Model SSCVR solid-state CVR. The CVR was sent to the NTSB’s laboratory for readout and evaluation. The CVR was undamaged, and the audio was played back normally. The recording consisted of four separate channels: the captain and first officer audio panels, the CAM, and the PA system. The recording provided good to excellent quality audio information.[53]

The CVR recording began at 1500:32 as the flight crew was preparing for the flight and ended at 1530:43.7. A transcript was prepared of the entire 30-minute, 12-second recording and is provided in appendix B of this report.

1.11.2 Flight Data Recorder

The airplane was equipped with a Honeywell Model 980-4700 solid-state FDR. The FDR was sent to the NTSB's laboratory for readout and evaluation. The FDR was in good condition, and the data were extracted normally. The NTSB verified 178 parameters of airplane flight information for the entire accident flight.

1.12 Wreckage and Impact Information

1.12.1 Structural Damage

The right engine was found attached to the wing, and the left engine was found separated from the wing. (Detailed engine damage is discussed in section 1.12.2.) The horizontal and vertical stabilizers and portions of the movable control surfaces remained attached to the airplane. The nose and main landing gear remained attached to the airplane and were found in the up-and-locked position. No evidence of an in-flight or postcrash fire was found.

Both the forward and aft cargo doors were open when the airplane was lifted from the river. The forward cargo door frames, rollers, latches, and drift pins were in good condition and undeformed. The forward cargo door interlock mechanism exhibited no signs of damage and functioned properly. The aft cargo door latches and rollers were in good condition, but the door frame structure was fractured at multiple locations. The aft cargo door handle was fractured into multiple pieces. A piece of carbon fiber reinforced plastic was found wedged between the door handle and the handle housing.

The cabin of the airplane was intact, and no crew or passenger seats were dislodged. The left, forward passenger door (1L) was found open, undamaged, and in the armed mode. The right, forward passenger door (1R) was found open and in the armed mode, and it could not be closed. The door was twisted (rotated clockwise when viewed externally) on its hinge, and two

[53] The NTSB rates the quality of CVR recordings according to a five-category scale: excellent, good, fair, poor, and unusable. See appendix B for a description of these ratings.

tie rods had separated. Neither telescopic girt bar[54] was damaged, and both girt bars were engaged in their respective floor fittings. The left and right aft passenger doors, 2L and 2R, respectively, were found in good condition. Door 2L was found open and in the armed position (the slide/raft deployed during the recovery operations). Door 2R was found closed and in the armed position.

The fuselage and wings sustained damage during the bird-strike event, ditching, and recovery efforts. The upper portion of the radome exhibited dents, a crushed honeycomb core, skin fractures, and punctures consistent with damage sustained during the ditching and recovery efforts. The damage described below focuses on the damage resulting from the bird-strike event and ditching.

The left side of the forward fuselage from frame (FR) 1 to FR12 had numerous gouges, scrapes, and dents between the frames, and the fuselage skin was punctured at FR4. A smooth, 6- by 12-inch dent consistent with soft-body impact damage was located between FR11 and FR12. Three punctures were observed in the fuselage skin between FR13 and FR15. Another puncture, measuring 8 by 11 inches, was observed between FR21 and FR22. A dent with no evidence of paint transfer was observed below the right cockpit window with traces of bird remains in the damaged area. (See section 1.16.2 for information about the identification of the organic remains found on the airplane structure and in the engines.) No further damage to the forward, right side of the fuselage was observed from the radome to FR35. Figure 6 shows the A320 fuselage frame locations.

Most of the water impact damage was observed on the aft fuselage, from FR49 to FR70, the aft pressure bulkhead. The observed damage increased progressively from no damage at FR47, to subcargo floor crushing from frames FR50 to FR56, large subpassenger floor deformations to FR60, partial loss/failure of the lower fuselage skin panels aft of FR60, and loss of the lower portion of the aft pressure bulkhead at FR70.

Specifically, portions of the left-side belly fairing aft of the wing were either fractured or missing. The right-side belly fairing was missing from FR37 to FR51. The lower left side of the rear fuselage was fractured between FR56 and FR64 and bent outward away from the airplane centerline. The lower right side of the rear fuselage was crushed and buckled inward from FR56 to FR70. The internal cargo structure was damaged, and the floor panels at FR57 were buckled upward.

[54] EOW-equipped A320s, like the accident airplane (see section 1.15.1.2), have telescopic girt bars attached to the slide/rafts by a fabric girt. The girt bar allows the slide/raft pack to be removed from one floor-level exit's floor fittings and moved to and deployed from another door, if necessary, in the event of a water impact and subsequent emergency evacuation.

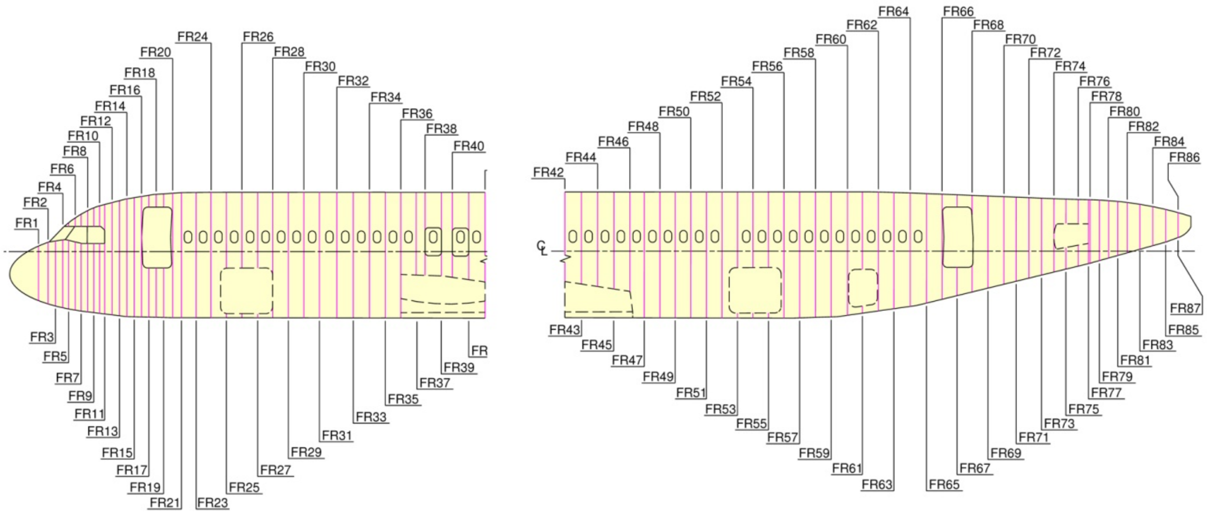

Figure 6. Diagram showing the A320 fuselage frame locations.

The crossbeams from FR66 aft were sheared in the aft direction, but the longitudinal seat tracks remained in position. The lower third of the aft pressure bulkhead was sheared away, and the lower part of the fuselage was torn in the aft direction. The tail cone, including the APU, was separated from its attachment points to the fuselage, except for the right-side lower location, and no longer retained its conical shape.

Three areas of the main cabin floor were damaged: (1) from FR55 to FR62 (located on the right side of the airplane, about row 22), (2) a punctured floor area in the aisle near the direct-view (aft, center aisle) jumpseat, and (3) from FR66 to FR70 in the aft galley.

The floor from FR55 to FR62 was fractured and buckled upward about 7 to 8 inches (primarily beneath seat 22E on the right side of the airplane), and the fasteners and fastener inserts in the panels were damaged.

The FR65 vertical beam had punctured through the cabin floor in front of the direct-view jumpseat about 11 inches forward of the seat pan and 19 inches left of the lavatory wall.[55] The passenger floor crossbeam web and lower flange in this area were bent in the aft direction. The left-side passenger floor support strut was sheared above the FR65 attachment point and was fractured below the floor crossbeam. The right-side passenger floor support strut was sheared close to the FR65 and crossbeam attachment points. The center passenger floor support strut was

[55] According to Airbus, the FR65 vertical beam is a nonstructural beam installed between the passenger and cargo floors at the aircraft center line to support the cargo liner. The beam is designed to be held in place by two quick-release, removable pins. Removing the pins and rotating the beam down allowed maintenance personnel to access the waste water tank. The beam does not carry loads during normal operation and is designed to carry longitudinal loads up to 1.5 G aft in the event of a crash.

missing at the upper attachment angles on the floor crossbeam. The cargo floor structure was completely missing in this area.

The two floor panels covering the aft galley area from FR66 to FR70 were pushed upward, the fasteners and fastener inserts in the panel were damaged, the fastener heads had pulled through the honeycomb flooring material, and the floor panels were broken. The upward deformation of the panel created a 2- to 3-inch gap around the perimeter of the panel, providing visibility directly into the subfloor cargo compartment.

1.12.2 Engine Damage

The left engine was found near the initial impact location of the airplane with the water on January 23, 2009 (8 days after the accident). Examinations revealed that the left engine had separated at the front and rear wing attachment fittings. The nacelle was fractured and deformed in several locations. No indication of engine uncontainment was found. The thrust reverser was found in the stowed position.

The left engine inlet lip was intact but exhibited crushing and had an 8- by 9-inch dent, consistent with soft-body impact, at the 4 o'clock position[56] of the lip. The outer nacelle skin aft of the inlet lip was fractured at the 3 to 9 o'clock position, and the lower portion of the skin was missing. The exhaust duct was present but crushed.

The left engine spinner was intact. Paint on the front of the spinner cone was missing at the tip in a 3-inch-long spiral pattern. The aft cone segment was intact, but a dent about 3/16-inch deep was found at the location of the platform of fan blade No 18.[57] When the spinner was removed, organic tissue was found.

All of the left engine fan blades were present and intact but were bent aft about 1 to 3 inches in a predominantly skewed fan-plane pattern. All of the blade leading edge tips were curled in the direction opposite of rotation, and the curled-edge size ranged from very small to about 1/4 inch. The trailing edge of one fan blade was torn and notched with about 3/8 inch of material folded. The trailing edges of three fan blades were notched in a circular shape with about 1/4 to 3/8 inch of material folded in the direction opposite of rotation.

The two lower forward acoustical panels at the 5 to 7 o'clock position in the left engine fan inlet case were damaged, but the corner retaining inserts were still attached to the fan case.

[56] All directional references to front and rear, right and left, top and bottom, clockwise and counterclockwise are made aft looking forward. The top is the 12 o'clock position. The direction of the rotation of the engine is clockwise.

[57] The fan blades were prenumbered during installation, and, for convenience, this numbering scheme is used to identify blades of interest. The blades are numbered in a counter-clockwise direction (aft looking forward).

The left engine fan shroud was rotationally scored 360° to varying depths. A spiral-shaped rotational score mark about 1/4-inch deep was found at the 4 to 6 o'clock position.

Sixty of the 68 OGVs located between the fan rotor and frame struts were present and intact; the other 8 OGVs were missing. The LPC IGV inner platform was deformed outward into the flowpath at the 2 to 7 o'clock position. Five stage-1 LPC IGVs were fractured, two were missing at the 1 o'clock position, and three were separated at the outer platform and bent in the direction of rotation. The trailing edges of 18 IGVs were dented in the direction of rotation. Foreign material consistent with bird feathers and tissue was found wedged between the outer platform panels and the fan case.

Detailed examinations revealed that the two separated LPC IGVs were ingested into the engine core and had caused nicks, tears, and fractures throughout the LPC and HPC stages. Foreign material consistent with bird feathers and tissue was found on the outer surface of the outer vane ring at the location of the fractured vanes. Further, five stage-1 HPC blades were found fractured, and the remaining blades were battered and bent. The stage-0 HPC variable guide vanes (VGV) were found disconnected from the VGV actuator.[58]

The left engine combustor case was intact and appeared to be undamaged. When disassembled, examination of the combustor dome revealed crushing on the forward dome section between the 3 and 6:30 clock positions consistent with soft-body impact damage.

The right engine was found still attached to the airplane. Examinations revealed that the right engine nacelle was fractured and deformed in several locations. No indication of engine uncontainment was found. The thrust reverser was found in the stowed position.

The right engine inlet lip appeared to be undamaged. The acoustical panels in the inlet duct appeared to be undamaged except for a small section between the 11 and 12 o'clock positions.

The right engine spinner was intact and undamaged. The front of the spinner cone exhibited a brown stain about 4 inches long starting about 2 inches from the tip. All of the right engine fan blades were present and intact but were bent aft about 1/2 inch. Five of the right engine fan blades exhibited a large-radius curvature[59] dent at the midspan location. A portion of a feather was found stuck between two adjacent fan blades at the midspan damper.

The two lower acoustical panels at the 5 to 7 o'clock position in the right engine fan inlet case were damaged. The right engine fan shroud was rotationally scored 360° to varying depths.

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[58] The HPC VGVs directionally guide the flowing compressed air onto the spinning rotor blades, thus controlling the compressor stall margins across all engine speed ranges.

[59] Large-radius curvature or deformation is associated with impact from soft material, such as rubber or fleshy animal tissue. Small-radius deformation is characterized as small-radius dents or sharp-edged tears and is associated with impact from hard material, such as ice or metal.

A spiral-shaped rotational score mark about 1/4-inch deep was found at the 4 to 7 o'clock position.

The right engine OGVs were present and intact. Three LPC IGVs were fractured, two were missing, and one was still attached to the vane ring by its inner end. Foreign material consistent with bird feathers and tissue was found wedged between the outer platform panels and the fan case. Detailed examinations revealed that the separated IGVs had been ingested into the engine core and had caused nicks, tears, and fractures throughout the booster and HPC stages. Foreign material consistent with bird remains was found on the outer surface of the outer vane ring at the location of the fractured vanes. The right engine stage-0 VGVs were entirely destroyed. Additionally, four stage-1 HPC blades were fractured, and the remaining blades were battered and bent.

The right engine combustor case was intact and appeared to be undamaged. When disassembled, examination of the combustor dome revealed crushing on the forward dome section consistent with soft-body impact. About 1 cup of charred remains was found in the combustor area.

Visual examinations revealed that all of the fractured surfaces on both engines were consistent with overload, and no signs of preexisting damage or fatigue-type failures were found. Ultraviolet light[60] inspections of both engine cores revealed that foreign material consistent with bird feathers and tissue was inside the engine from the spinner through the LPC to the stage-1 HPC.

1.13 Medical and Pathological Information

On the evening of January 15, 2009, the captain and first officer provided urine specimens to US Airways for drug testing about 2205 and took breathalyzer tests about 2221. Both pilots tested negative for drugs and alcohol.[61]

Forty-five passengers and all 5 crewmembers were transported to hospitals after the accident. According to medical records, two of the transported passengers and flight attendant B sustained serious injuries. One of the passengers sustained a fractured xiphoid process, which is a small ossified extension to the lower part of the sternum. The other passenger suffered hypothermia and was not released from the hospital until about 1645 on January 17, 2009. Flight attendant B sustained a V-shaped, 12-centimeter-long 5-centimeter-deep laceration to her lower left leg that required surgery to close.

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[60] Organic proteins, such as bird remains and blood, will fluoresce green when illuminated with ultraviolet light.

[61] The US Airways testing results certificates indicated that the captain and first officer tested negative for the following drugs: marijuana, cocaine, amphetamines, opiates, and phencyclidine.

Further, during postaccident interviews, two passengers who were not initially transported to a hospital after the accident reported having sustained serious injuries. The medical records they provided to the NTSB indicated that one of these passengers sustained a fractured left shoulder and that the other passenger sustained a fractured right shoulder.

1.14 Fire

No in-flight or postaccident fire occurred.

1.15 Survival Aspects

1.15.1 Ditching Requirements

As noted previously, the accident airplane was certificated for ditching; therefore, in addition to having to meet the requirements of 14 CFR Section 25.801, it had to meet the requirements of Sections 25.807(i), "Ditching Emergency Exits for Passengers;" 25.1411, "General;" and 25.1415, "Ditching Equipment."

1.15.1.1 Emergency Exits

The airplane was equipped with four floor-level Type I exits: one located on the forward, left side (door 1L); one located on the forward, right side (door 1R); one located on the aft, left side (door 2L); and one located on the aft, right side (door 2R) of the airplane.[62] Each of these exits was equipped with a door-mounted, automatically inflating Type II slide/raft that had a quick-release handle on the girt to separate the slide/raft from the airplane if an evacuation occurred in water.[63] The airplane was also equipped with four Type III overwing exits. Each overwing exit pair was equipped with an automatically inflating, off-wing Type IV exit ramp/slide.[64] The off-wing ramp/slides were contained in external compartments behind each wing and automatically deployed and inflated when the overwing exit doors were opened. The off-wing ramp/slides did not have quick-release handles.

[62] According to 14 CFR 25.807, "Emergency Exits," a Type I exit is a floor-level exit with a rectangular opening of not less than 24 inches wide by 48 inches high, with corner radii not greater than one-third the width of the exit. A Type III exit is an exit with a rectangular opening of not less than 20 inches wide by 36 inches high, with corner radii not greater than one-third the width of the exit, and with a step-up inside the airplane of not more than 20 inches. If the exit is located over the wing, the step-down outside the airplane may not exceed 27 inches.

[63] According to Technical Standard Order (TSO) TSO-C69c, "Emergency Evacuation Slides, Ramps, Ramp/Slides, and Slide/Rafts," Type II is an inflatable slide also designed to be used as a life raft (a slide/raft) in the event of a water landing

[64] According to TSO C-69c, Type IV is a combination inflatable exit ramp and wing-to-ground slide. The off-wing ramp/slides were intended to be used in the event of a ground, not a water, evacuation.

Title 14 CFR Section 25.807(i) states that all airplanes with a passenger seating configuration of 10 or more passenger seats must have no less than two exits above the waterline on each side of the airplane to allow passengers to evacuate within the flotation time (before the window sill of the exit goes underwater).

A May 17, 1988, certification report indicated that, assuming the certification parameters, the lowest points of the aft passenger exits on an A320-200 would remain above the waterline for 7 minutes 15 seconds.[65] A June 10, 1992, Airbus certification report considered two evacuation scenarios: one in which all of the exits were available and another in which two exits on the same side of the airplane were available and one of the largest slide/rafts was unusable.[66] The analyses of both scenarios found that neither evacuation time exceeded 7 minutes 15 seconds.[67]

1.15.1.2 Safety Equipment

The accident airplane was 1 of 20 A320s equipped as an EOW airplane in the US Airways fleet of 75 A320s.[68] The airplane had the following equipment on board: crewmember life vests at every jumpseat location, passenger life vests at every seat for primary passenger flotation, seat cushions for auxiliary passenger flotation, 10 infant life vests (stowed in a bag in the last overhead bin), 2 emergency locater transmitters, 4 slide/rafts (one slide/raft was located at each of the floor-level exits),[69] 4 survival kits, and 4 life lines.[70] The accident airplane had the statements, "Life Vest Under Your Seat" and "Bottom Cushion Usable For Flotation," printed on the passenger service units (next to the reading light switches) above each row of seats.

The ditching requirements contained in Section 25.1411 state, in part, that required safety equipment for use by crewmembers in an emergency must be readily accessible and stowed such that the equipment is directly accessible, is in obvious locations, and is protected from inadvertent damage.[71] Section 25.1411 further states that the stowage provisions for life rafts must accommodate enough rafts for the maximum number of occupants and allow for the rapid

[65] According to Airbus calculations, the doorsills of doors 2R and 2L would be 4.65 and 14.72 inches above the waterline, respectively.

[66] An additional 20-person life raft was also stowed in an overhead bin during the certification tests. The 20-person life raft was required because the airplane's seating capacity was 185 and the slide/raft capacity was only 176 (four 44-person occupancy slide/rafts).

[67] The times for each scenario were 2 minutes 26 seconds and 4 minutes 13 seconds, respectively, for an A320-200 with 185 occupants.

[68] Non-EOW airplanes are not required to carry passenger life vests, slide/rafts, or survival kits.

[69] Each slide/raft was rated to carry 44 passengers and had an overload capacity of 55 passengers.

[70] Life lines were required by 14 CFR 91.509(b)(5), "Survival Equipment for Overwater Operations." A life line is intended to be mounted to the airplane fuselage, anchored to a point on the wing, and used by people on the wing to prevent them from falling into the water.

[71] The NTSB notes that the Boeing 737 NG is designed such that the aft portion of the airplane sits low in the water after a ditching, which makes the aft exits unusable; therefore, the slide/rafts are stowed in overhead bins near the center of the airplane rather than near the aft passenger exits.

detachment and removal of the raft for use at other than the intended exits. In addition, the life rafts must be stowed near exits through which the rafts can be launched. Further, the regulation states that the stowage provisions for life vests must accommodate one life vest for each occupant and that each life vest must be within easy reach of each seated occupant.[72] Lastly, Section 25.1411 states that there must be provisions to store life lines and that these provisions must allow one life line to be attached to each side of the fuselage and arranged to allow the life lines to enable the occupants to stay on the wing after ditching.

Section 25.1415 states, in part, that each life raft and vest must be approved. In addition, unless excess rafts of enough capacity are provided, the overload capacity of the rafts must accommodate all airplane occupants if one raft of the largest rated capacity is unavailable for use, and each raft must have a static line designed to hold the raft near the airplane but that can be released if the airplane becomes totally submerged.

1.15.2 Preflight Briefing Requirements

The accident flight was a non-EOW flight. US Airways procedures required its flight attendants to brief passengers in accordance with 14 CFR 121.571(a)(1)(iv), "Briefing Passengers Before Takeoff," which states that, if the airplane is equipped with flotation equipment, flight attendants are required to brief passengers on all flights on the location and use of any required emergency flotation means.

AC 121-24C, "Passenger Safety Information Briefing and Briefing Card," dated July 23, 2003, states the following:

> When the aircraft is equipped with life preservers [also referred to as "life vests"], the briefing must include instructions about the location and removal of life preservers from stowage areas, including pouches, and the donning and inflation of the life preservers. If the aircraft is equipped with both flotation cushions and life preservers, flight attendants should brief passengers on both types of equipment and must brief passengers on the required flotation equipment.

US Airways' FAA-accepted In-Flight Emergency Manual followed the AC guidance and specified that, if the airplane is equipped with both flotation seat cushions and life vests, flight attendants should brief passengers on both types of equipment, including the location and use of life vests. The CVR recorded flight attendant B orally brief the location and use of the flotation seat cushions; however, it did not record her brief the location of or the donning procedures for life vests.

[72] In addition, because the airplane was used for EOW operations, it also had to meet the operational requirements of 14 CFR 121.339, "Emergency Equipment for Extended Overwater Operations," which states, in part, that an EOW-equipped airplane must be equipped with a life vest for each airplane occupant.

1.15.3 Safety Information Card Requirements

According to 14 CFR Section 121.571(b), each passenger-carrying airplane must carry, in convenient locations for use of each passenger, printed cards supplementing the oral briefing and containing diagrams and methods of operating the emergency exits and other instructions necessary for the use of emergency equipment.

The airplane had safety information cards in the passenger seatback pockets that provided instructions on the operation of the emergency exits. A section of the card also shows the passenger brace positions. The brace positions shown on the US Airways safety information card were similar to the current FAA guidance on brace positions, which is contained in AC 121-24C, Appendix 4, which states, "in aircraft with high-density seating or in cases where passengers are physically limited and are unable to place their heads in their laps, they should position their heads and arms against the seat (or bulkhead) in front of them." Figures 7 and 8 show the brace positions contained in AC 121-24C and the US safety information card, respectively.

1.15.4 US Airways Flight Attendant Training

US Airways provided flight attendants with initial and recurrent training. The initial training included guidance and procedures to follow during a ditching. A portion of a student guide titled, "Section IV – Ditching," dated January 2008,[73] instructs flight attendants to assess door exits during a ditching emergency and to look for the water level, obstructions, fire, aircraft pitch, and structural damage. The guide states that, if an exit is blocked, there is time, and no immediate life threatening situations exist, a slide can be transferred from a blocked exit. According to the guide, the exits most likely to be usable during a ditching will be the forward doors.

The initial training also required flight attendants to participate in a 2-hour "wet" raft drill, which demonstrated the proper use of flotation seat cushions and life vests, procedures needed to release a slide, inflation of a life raft (not slide/raft), and erection of a canopy. Flight attendants also performed an evacuation for a planned and unplanned water landing, during which they donned life vests, jumped into a pool, inflated one chamber of the life vest, and entered a life raft. After the practice evacuation, the flight attendants were asked questions about the location and purpose of the equipment on board the life raft.

As part of flight attendants' recurrent training, US Airways required flight attendants to participate, on a periodic, rotational basis, in exercises such as a 35-minute emergency equipment exercise; a 1-hour, non-EOW A319 "planned cabin prep" water landing exercise; and a 20-minute, A320 "dry ditch" hands-on exercise. According to the dry ditch instructor's guide, flight attendants were shown a video demonstrating slide deployment and detachment procedures, slide/raft and life raft inflation, and transfer of a slide/raft from one exit to another on

[73] Students were to review the guide as supplemental information just before or after receiving the classroom lecture on a particular topic.

Figure 7. Passenger brace position shown in AC 121-24C.

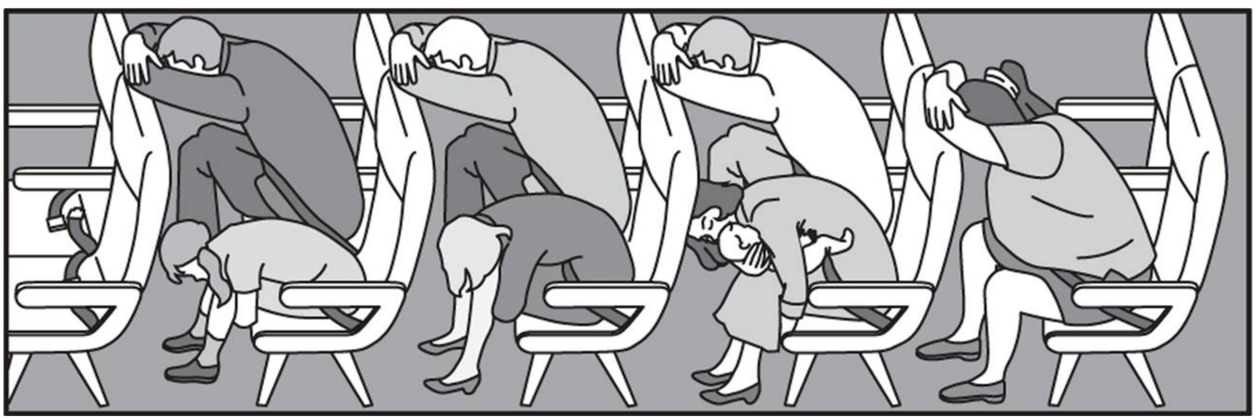

Figure 8. Passenger brace positions shown in the US Airways safety information card.

several aircraft types. The flight attendants were then shown an inflated A320 slide/raft and its different components, including the "For Ditching Only" flap, quick-release handle, raft knife, and stenciled instructions.

1.15.5 Evacuation of Passengers and Crewmembers

Within seconds after the ditching, the crewmembers and passengers initiated the evacuation of the airplane. Flight attendant C reported that door 1R opened normally and that the slide/raft inflated automatically. However, she stated that door 1R started to close during the evacuation, intruding about 12 inches into the doorway and impinging on the slide/raft.[74] She stated that she was concerned that the slide/raft would get punctured, so she assigned an "able-bodied" man to hold the door to keep it off of the slide/raft. She stated that he held the door

[74] After the accident, US Airways reviewed maintenance data for 10 percent of its Airbus aircraft. The review revealed no trends that would indicate any problems with the operation of the 1R doors or the doors' gust locks.

while occupants evacuated under his arm. Flight attendant A reported no difficulties opening door 1L or getting it to lock against the fuselage; however, she reported that the slide/raft did not inflate automatically when she opened the door. She stated that she pulled the manual inflation handle and that the slide/raft inflated.[75]

According to flight attendant B, after the impact, she went into the aft galley and assessed the conditions outside of door 2L, at which time, she realized the airplane was in the water. Door 2L was “cracked” open, but it was unclear by whom.[76] Subsequently, both flight attendant B and some of the passengers began redirecting passengers to move forward. Flight attendant B stated that she began improvising commands and told “young, able-bodied” passengers to climb over the seats to get people away from the water.

According to flight attendants A and C, some of the passengers were bottle-necked at the overwing exits; therefore, the flight attendants called them forward, and, as a result, some of the mid- and aft-located passengers exited from the forward doors. Flight attendant B also exited from door 1R, at which time, she realized that her left leg was injured. According to the flight attendants, the evacuation was relatively orderly and timely.

The captain and first officer assisted the flight attendants with the evacuation of the airplane. The captain stated in interviews that he and the first officer noted that a number of passengers had evacuated the airplane without life vests; therefore, they obtained some life vests from under the passenger seats in the cabin and passed them out to passengers outside of the airplane. He further stated that, following the evacuation, he and the first officer inspected the cabin to ensure that no more passengers or crewmembers were on board. Subsequently, the captain and first officer exited the airplane onto the 1L slide/raft.

Several videos showing the airplane’s water impact and the passengers’ subsequent evacuation and rescue were examined during the investigation. The cameras contained time-stamped recordings; however, because the times were neither accurate nor identical, time estimations were used. By using the time of initial impact as 1530:43 (as recorded on the FDR) and common events in the videos, the NTSB determined that the following occurred:

- 1530:58 – left overwing exits opened, first passenger subsequently exited
- 1531:06 – door 1L opened
- 1531:11 – door 1R opened
- 1531:16 – the 1R slide/raft fully deployed

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75 Although flight attendant A did not report having a problem pulling the manual inflation handle, the first two passengers to reach door 1L reported that she seemed to be struggling with the slide/raft. As a result, one of them chose to jump in the water. A video analysis conducted by the NTSB indicated that about 20 seconds elapsed after flight attendant A opened door 1L and the slide/raft began to inflate.

76 Flight attendant B reported that a passenger came into the aft galley and lifted the handle of door 2L, “cracking” the door open; however, several passengers reported that the door was “cracked” open before they arrived in the aft galley.

- 1531:23 – one passenger jumped into water from door 1L
- 1531:26 – 1L slide/raft began to inflate
- 1534:40 – first vessel arrived on scene
- 1554:43 – last vessel departed with last rescued passengers off left off-wing slide

See section 1.15.6 for more information about the emergency response.

1.15.5.1 Occupant Evacuation Exit Usage

The NTSB contacted 146 of the 150 passengers by telephone and/or passenger questionnaires to gather information about the accident flight and evacuation.[77] The passenger information and information gathered during postaccident interviews with the flight and cabin crewmembers were used to determine which exits were used by each occupant during the evacuation. Figure 9 shows the exits used by the occupants during the evacuation.

[77] No information could be collected from 4 of the 150 passengers despite numerous attempts to contact them.

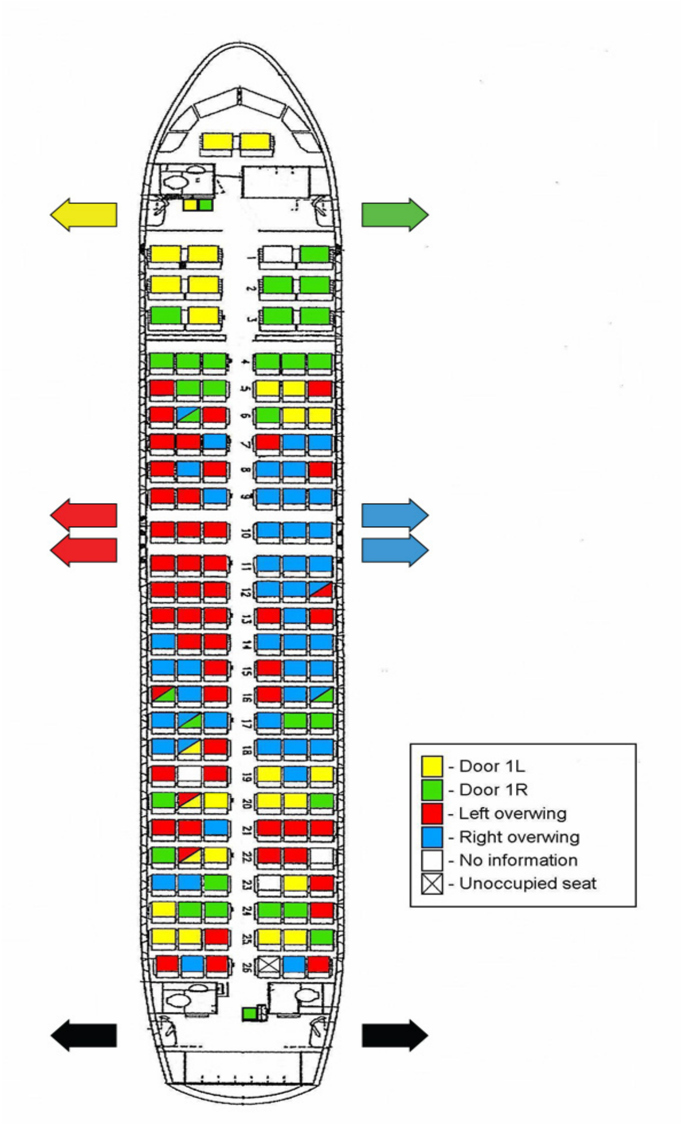

Figure 9. Occupant evacuation exit usage.

Note: Because of postevacuation passenger movement, the chart does not accurately indicate the locations where people were rescued. Additionally, several passengers exited the airplane, reentered, and exited the airplane a second time. These passengers' seat locations are designated with a '/'. The first exit used is represented by the upper color while the second exit is shown by the lower color.

A female passenger was seated in 19E, which is a middle seat on the right side of the airplane and is indicated in blue in figure 9, with her 9-month-old son on her lap. During postaccident interviews, she indicated that, when the captain stated, "brace for impact," the male passenger in 19F offered to brace her son for impact. The lap-held child's mother stated that she thought the passenger in 19F "knew what he was doing," and she gave her son to him. Neither the mother, the lap-held child, nor the passenger who held the child was injured. The mother stated that, after landing, the passenger gave her son back to her and that she evacuated onto the right wing.

1.15.5.2 Additional Information About the Flight and Evacuation

The information provided by passengers also indicated that the following occurred during the flight and evacuation:

- 25 passengers (17 percent) reported watching most of the preflight safety demonstration, and an additional 19 passengers (13 percent) reported watching some of the demonstration.
- 12 passengers (8 percent) reported reading the safety information card before or during the flight.
- 77 passengers (53 percent) retrieved seat cushions during the evacuation. Of these, 45 (31 percent) retrieved the seat cushion from their own seat, 27 (18 percent) retrieved a seat cushion from a different seat, and 5 (3 percent) found a seat cushion floating in the cabin.
- 5 passengers (3 percent) reported retrieving life vests from under their seats after impact.[78] An additional 5 passengers (3 percent) reported retrieving a life vest from under a different seat after impact.
- 21 passengers (14 percent) reported being given a life vest that came from the airplane by someone during or after they had evacuated.

1.15.6 Emergency Response

According to ATC records, LGA ATCT personnel activated the Emergency Alert Notification System using the red crash phone at 1528:53. According to the Port Authority of NY and NJ LGA Emergency Plan, when the FAA tower activates the crash alarm signaling an aircraft accident, a request for emergency equipment is immediately relayed through a conference circuit to various airport offices, including the airport police, and emergency response agencies, including the USCG, NYPD, Fire Department of New York (FDNY), and emergency medical services (EMS). The NYPD incident logs showed that, upon notification of the accident,

[78] Two additional passengers retrieved and donned their life vests before impact.

a level 3 mobilization, which required a predetermined number of personnel and equipment to respond to an accident or incident, was transmitted to the NYPD, FDNY, EMS, New York Office of Emergency Management (OEM), Federal Bureau of Investigation, and Red Cross. Personnel from the New York Waterway (NY WW), Port Authority of NY and NJ, Weehawken Police Department (WPD), and New Jersey OEM also responded to the accident. In addition, a rescue boat was dispatched from LGA.[79]

The NY OEM uses a Citywide Incident Management System (CIMS), which establishes the roles and responsibilities and designates authority for city agencies performing and supporting emergency response. CIMS implements the National Incident Management System (NIMS).[80] When the New York City public safety agencies respond to a complex, multiagency and multijurisdictional incident or accident, the CIMS management doctrine defines how the emergency response is managed. After receiving the crash alarm, the New York OEM personnel began coordinating resource requests from the FDNY, NYPD, and Red Cross.

The airplane was ditched on the Hudson River near the NY WW Port Imperial Ferry Terminal in Weehawken, New Jersey. Many NY WW ferries were operating over established routes in the local waterway, and the ferry captains either witnessed the accident or were notified about it by the director of ferry operations. Seven NY WW vessels responded to the accident and recovered occupants. According to the USCG and FDNY incident log, the first NY WW vessel arrived on scene about 1534, and the six other NY WW ferries arrived on scene by about 1540. The incident log also indicated that one FDNY fire rescue boat and two small USCG boats arrived on scene about 1539 and 1548, respectively. Table 3 summarizes the emergency response information.

[79] In accordance with 14 CFR Part 139, certificated airports are required to include in their emergency plans a water rescue plan if significant bodies of water and marsh lands are situated beneath the approach and departure paths within at least 2 miles of the runway end.

[80] In March 2004, the Department of Homeland Security developed and implemented the NIMS, which provides a systematic, proactive approach to guide departments and agencies at all levels of government, nongovernmental organizations, and the private sector to work seamlessly to prevent, protect against, respond to, recover from, and mitigate the effects of incidents, loss of life and property, and harm to the environment.

Table 3. Summary of emergency response information.

Vessel Name and Operator	Vessel Type	Drop-off Location
Thomas Jefferson, NY WW	Ferry	Pier 79 (New York)
Thomas H. Kean, NY WW	Ferry	Port Imperial (New Jersey)
Moira Smith, NY WW	Ferry	Arthur's Landing (New Jersey)
Yogi Berra, NY WW	Ferry	Port Imperial
Athena, NY WW	Ferry	Pier 79
George Washington, NY WW	Ferry	Port Imperial
Admiral Richard E. Bennis, NY WW	Ferry	Port Imperial
Marine 1 Alpha, FDNY	Fire rescue boat	Pier 79
CG33139, U.S. Coast Guard	Small boat	Chelsea Piers (New York)
CG25640, U.S. Coast Guard	Small boat	Arthur's Landing

The Port Imperial Ferry Terminal was designated as the central triage site in accordance with the Port Authority of NY and NJ LGA Emergency Plan. Initially, the proximity of the airplane to the Port Imperial Ferry Terminal made it an ideal occupant drop-off location. However, as the fuselage and ferries drifted with the river current of 1.4 kts, delivery of the occupants to a central drop-off location became more challenging. As a result, several vessels dropped off passengers at different locations, as shown in table 3, because they had occupants on board who were wet, and these locations were closer when they departed the floating airplane. Ninety-one of the 146 passengers contacted after the accident indicated that they were dropped off on the New York side of the Hudson River, and 55 of them indicated that they were dropped off on the New Jersey side of the river. The five crewmembers were dropped off on the New York side of the Hudson River.

In accordance with federal regulations, the USCG assumed incident command and maintained radio contact with the NY WW ferry captains, NJ OEM, and NYPD. The USCG incident commander shut down vessel traffic on the Hudson River about 1535.[81] The WPD established an incident command post in New Jersey at the Port Imperial Ferry Terminal, and the New York OEM established three incident command posts at Chelsea Pier, the Jacob Javits Center, and the NY WW New York terminal.

[81] The Hudson River reopened to nonemergency traffic on a limited basis about 1937.

In October 2008, NY WW participated in a planning table-top exercise with the Port Authority of NY and NJ. Further, several months before the accident, New York and New Jersey emergency response agencies participated in a mass-casualty exercise at the Port Imperial Ferry Terminal. Before the accident, NY WW had asked to participate in the mass-casualty exercises with the New York and New Jersey response agencies; however, the request was not granted. The day after the accident, the Port Authority of NY and NJ informed the NY WW that they would be included in future mass-casualty emergency response exercises between New York and New Jersey emergency response agencies. NY WW also conducted a series of monthly drills, live exercises, and actual rescues before the accident.

1.16 Tests and Research

1.16.1 Airplane Performance Study

The NTSB conducted an airplane performance study to analyze the motion of the airplane based on the touchdown location shown on a surveillance video analyzed by the Bureau d'Enquêtes et d'Analyses (BEA);[82] CVR, FDR, and EWR ASR data;[83] and meteorological information.

At 1524:57, both thrust levers were advanced, and, subsequently, both engines' N_1 and N_2 speeds began accelerating in unison to the full takeoff power of 85 percent N_1. The speeds of both engines were similarly matched and stable during the takeoff and initial climb. Immediately after the bird encounter, the left engine decelerated from 82 to 35 percent N_1, the right engine decelerated from 82 to 15 percent N_1, and the airspeed started to decrease. Subsequently, the airplane's altitude continued to increase while the airspeed decreased, until 1527:30, when the airplane reached its highest altitude of about 3,060 feet at an airspeed of about 185 kts calibrated airspeed (KCAS).[84] The altitude then started to decrease as the airspeed started to increase, reaching 210 KCAS at 1528:10 at an altitude of about 1,650 feet.

From 1529:00 to 1530:00, the airplane descended from 1,200 to 200 feet, and the airspeed stabilized between 185 and 193 KCAS. At these airspeeds, the AOA ranged between 7° and 9°. At 1529:49, as the airplane was descending through 270 feet, the flap lever was moved to the CONF 2 position. As the flaps deployed, the airplane descended to about 210 feet and then climbed briefly, reaching about 360 feet before descending again. At CONF 2, the alpha-protection threshold value increased from 8° to 14.5°, and the alpha-maximum value increased from 11° to 17.5° (the airplane's maximum allowable AOA). Before flaps 2 was selected, the green dot speed would have been about 223 kts. After flaps 2 was selected, the

[82] The video came from a surveillance camera located on the roof of Pier 88 in New York and presents a nearly complete view of the ditching of the airplane on the Hudson River.

[83] The CVR, FDR, and EWR ASR data were synchronized to the EWR ASR time as a common reference time.

[84] The PFD would display the airspeed in kts indicated airspeed.

green dot speed would not have been displayed to the pilot; instead, a maneuvering F speed would have been displayed, which would have been about 150 kts on the accident flight.

Starting at 1530:36, when the airplane was at a radio altitude of about 100 feet, the FDR recorded a progressive pull aft on the left sidestick, with a momentary relaxation from 5° to 3° at 1530:37, returning to 7° about 1 second later. At 1530:39, as the airplane descended through 50 feet, the sidestick moved aft more abruptly, reaching its aft limit (16°) at 1530:41 and remaining there until touchdown at 1530:43. As the airplane descended below 50 feet, the alpha-protection threshold value increased from 14.5° to 15.5°.

According to FDR data, the airplane touched down on the Hudson River at an airspeed of 125 KCAS with a pitch angle of 9.5° and a right roll angle of 0.4°. Calculations indicated that the airplane ditched with a descent rate of 12.5 fps, a flightpath angle of -3.4°, an AOA between 13° and 14°, and a side slip angle of 2.2°.

1.16.1.2 Airbus Simulation

Airbus performed a simulation of the last 300 feet of the accident flight, which indicated that the airplane was performing as designed and was in alpha-protection mode from 150 feet to touchdown. The Airbus simulation indicated that, from 1530:36 to 1530:43, the flight control system attenuated the effect of the pilot's airplane nose-up (ANU) sidestick inputs below 100 feet radio altitude.

1.16.2 Biological Material Sampling and Analysis

NTSB investigators collected seven samples of unknown material from the wreckage after the accident. Investigators also collected 10 samples of biological material from the right engine fan, the radome, the No. 3 flap track on the left wing, and various locations on the fuselage. Two additional samples were collected from the shroud from the No. 3 flap track on the left wing after it was removed from the airplane. In addition, a USDA representative and GE personnel collected six samples from the exterior of the left engine before its teardown at the GE facility. After the engine teardowns, 23 additional samples of biological material including feathers, blood, muscle, and bone were collected from the left engine, and 14 samples were collected from the right engine.

All of the samples were sent to the Smithsonian Institution, National Museum of Natural History, Division of Birds, Feather Identification Laboratory, in Washington, DC, for analysis and identification.[85] According to the feather laboratory analysis report, 39 of the samples were

[85] The FAA maintains a contract with the Smithsonian Institute Feather Identification Laboratory for analysis and identification of bird remains found on airports. The results of the analyses are returned to the airport, the FAA, and the USDA Wildlife Services Program for addition to the FAA National Wildlife Strike Database.

submitted for DNA testing. Eighteen of the 39 samples, 14 of which were from the engines, contained viable DNA and matched 99 percent or more to the Barcode of Life Database[86] for Canada goose (*Branta canadensis*). Fifty-three of the samples, 50 of which were from the engines, contained feathers or feather fragments consistent with Canada geese. DNA sexing was successful on 16 of the 18 samples from the engines and wings. Both male and female Canada goose remains were found in the left engine, only male remains were found in the right engine, and only female remains were found on the No. 3 flap track on the left wing.

The Smithsonian Institution also performed a stable-hydrogen isotope analysis of the feather material collected from the airplane engines and compared the results with feather samples collected from resident geese in the New York region. The results indicated that the feathers from the airplane engines were similar to samples of known migratory geese and were significantly different from year-round resident populations from the New York region.[87]

1.16.3 Operational Factors and Human Performance Simulations

From April 14 through 16, 2009, the NTSB Operations and Human Performance Group, including members from Airbus, US Airways, the U.S. Airline Pilots Association, and the BEA, conducted flight simulations at the Airbus Training Center, Toulouse, France. The simulations were conducted using an Airbus A320 full-motion, pilot-training simulator and a fixed-base engineering simulator to determine whether the accident airplane could have glided to and landed at LGA or TEB after the bird strike, considering both an immediate return to LGA and a return after a 35-second delay. The simulations were also conducted to evaluate the operational procedures for ditching the airplane within the flightpath and pitch angles assumed during the airplane's ditching certification process.

The simulators were programmed to duplicate as closely as possible the conditions of the accident flight, including winds, temperature, altimeter setting, and weight and balance. The profile flown duplicated as closely as possible the accident profile (the airplane position, thrust setting, altitude at beginning of turns, thrust reduction and cleanup altitudes, speeds, and altitude/speed combination) up to the time of the almost total loss of thrust in both engines. During the simulations, the pilots followed the US Airways Engine Dual Failure checklist after the loss of thrust occurred and relied on their training and experience to complete the test conditions. An observer documented observations and times, and data from the engineering simulator were recorded electronically for later review and analysis.

[86] The Barcode of Life Database is an international collaborative effort to generate a unique genetic barcode for every species of life on Earth.

[87] See (a) F.D. Caccamise, L.M. Reed, P.M. Castelli, S. Wainright, and T.C. Nichols, "Distinguishing Migratory and Resident Canada Geese Using Stable Isotope Analysis," *Journal of Wildlife Management*, vol. 64, no. 4 (2000), pp. 1084–1091. (b) P.P. Marra, C.J. Dove, R. Dolbeer, N.F. Dahlan, M. Heacker, J.F. Whatton, N.E. Diggs, C. France, and G.A. Henkes, "Migratory Canada Geese Cause Crash of US Airways Flight 1549," *Frontiers in Ecology and the Environment*, vol. 7, no. 6 (2009), pp. 297–301.

The pilots were fully briefed on the maneuver before they attempted to perform it in the simulator. The following three flight scenarios were flown: (1) normal landings on runway 4 at LGA, starting from an altitude of 1,000 or 1,500 feet on approach; (2) attempted landings at LGA or TEB after the bird strike, starting both from zero groundspeed on takeoff from runway 4 at LGA and from a preprogrammed point shortly before the bird strike and loss of engine thrust; and (3) ditching on the Hudson River starting from 1,500 feet above the river at an airspeed of 200 kts.

During the first flight scenario, all of the pilots were able to achieve a successful landing in both simulators. The flightpath angles at touchdown for these landings ranged from -0.8° to -1.3°. Regarding the second flight scenario, 20 runs were performed in the engineering simulator from a preprogrammed point shortly before the loss of engine thrust in which pilots attempted to return to either runway 13 or 22 at LGA or runway 19 at TEB. Five of the 20 runs were discarded because of poor data or simulator malfunctions. Of the 15 remaining runs, in 6, the pilot attempted to land on runway 22 at LGA; in 7, the pilot attempted to land on runway 13 at LGA; and in 2, the pilot attempted to land on runway 19 at TEB. In eight of the 15 runs (53 percent), the pilot successfully landed after making an immediate turn to an airport after the loss of engine thrust. Specifically, two of the six runs to land on runway 22 at LGA, five of the seven runs to land on runway 13 at LGA, and one of the two runs to land on runway 19 at TEB immediately after the loss of engine thrust were successful.[88] One run was made to return to an airport (runway 13 at LGA) after a 35-second delay,[89] and the landing was not successful.

Regarding the third flight scenario, a total of 14 runs were performed in the engineering simulator in which pilots attempted to touch down on the water within a target flightpath angle of -0.5°, consistent with the structural ditching certification criteria. Two of the 14 runs were discarded because of poor data. Of the remaining 12 runs, 4 were attempted using CONF 2, 4 were attempted using CONF 3, and 4 were attempted using CONF 3/Slats only.

In 11 of the 12 runs, the touchdown flightpath angle ranged between -1.5° and -3.6° (the touchdown flightpath angle achieved on the accident flight was -3.4°). In 1 of these 12 runs, a -0.2° touchdown flightpath angle was achieved by an Airbus test pilot who used a technique that involved approaching the water at a high speed, leveling the airplane a few feet above the water with the help of the radar altimeter, and then bleeding off airspeed in ground effect until the airplane settled into the water.

[88] The immediate turn made by the pilots during the simulations did not reflect or account for real-world considerations, such as the time delay required to recognize the bird strike and decide on a course of action.

[89] The 35-second delay accounted for real-world considerations, such as the time delay required to recognize the extent of the engine thrust loss and decide on a course of action.

1.17 Organizational and Management Information

US Airways, Inc. is headquartered in Tempe, Arizona. At the time of the accident, US Airways operated about 3,129 scheduled daily departures (including its US Airways Express flights) to 156 domestic and 44 international destinations. US Airways operated over 650 airplanes, including, Airbus 319, 320 (the accident airplane type), 321, and 330; Boeing 737, 757, and 767; and Embraer 190 airplanes. US Airways employed about 33,743 employees, including 4,289 pilots. US Airways has major hubs at CLT; Philadelphia International Airport, Philadelphia, Pennsylvania; and Phoenix Sky Harbor International Airport, Phoenix, Arizona.

1.17.1 Operational Guidance

1.17.1.1 Abnormal and Emergency Situations

The airplane was equipped with an electronic centralized aircraft monitor (ECAM) system, which presented data on the engine/warning and system display located in the cockpit. If the flight warning computer (FWC) detects an airplane system failure, the failure type and the flight crew actions to be taken are displayed on the ECAM displays in the cockpit. In certain instances, an abnormal event cannot be sensed by the airplane's systems. For events that cannot be sensed by, or presented on, the ECAM system, pilots were to use the US Airways QRH,[90] which contained abnormal and emergency procedures for such events. The QRH also contained six procedures, referred to as "ECAM Exceptions," which were to be used instead of the ECAM action. The back cover of the QRH listed the six ECAM exceptions and immediate action items and the page numbers where each checklist was located within the QRH.

The US Airways A319/320/321 Pilot Handbook (PH), Chapter 9, "Non-Normal Operations," contains non-normal procedures and methodology. The PH states, in part, that, when a non-normal situation is evident, the pilots should methodically accomplish the following steps:

1. PF - maintain aircraft control;
2. Identify the non-normal situation, PM - cancel the warning or caution, if applicable;
3. PM - determine if situation requires an Immediate Action or if it is an ECAM Exception;
4. PM - accomplish Immediate Action Items, if applicable;
5. Captain - assigns PF;
6. PM - accomplish non-normal procedure; and

[90] The US Airways QRH was developed in accordance with the Airbus QRH.

7. PM - accomplish ECAM followup procedures, if applicable.

The expanded step 3 items stated that, once the airplane flightpath and configuration are properly established and the airplane is not in a critical phase of flight (for example, takeoff or landing), the PM should determine and verbalize whether the non-normal situation is an immediate action item or an ECAM exception and refer to the immediate action and ECAM exception indexes on the back cover of the QRH. The ECAM exception index indicated that a dual-engine failure was an ECAM exception and directed the PM to the Engine Dual Failure checklist procedures contained in the QRH.

The first officer indicated that, because he had just completed training, he immediately recognized that the event was an ECAM exception; therefore, he was able to promptly locate the procedure listed on the back cover of the QRH, turn to the appropriate page, and start executing the checklist.

1.17.1.2 US Airways Engine Dual Failure Checklist

According to Airbus, the Engine Dual Failure checklist was originally developed "based on the highest probability in time of exposure that a dual engine failure would occur." Because Airbus airplanes spend much more time at higher altitudes and, therefore, a dual-engine failure had the highest probability of occurring at a high rather than a low altitude, Airbus designed the Engine Dual Failure checklist for the occurrence of a dual-engine failure above 20,000 feet. Airbus indicated that it had not considered developing a dual-engine failure checklist for use at a low altitude.

During postaccident interviews, Airbus personnel indicated that the Airbus Engine Dual Failure checklist was amended in 2005 as part of the Airbus Continuing Improvement Process.[91] Airbus stated that it changed the Engine Dual Failure checklist because of accident reports in which crewmembers stated that it was not easy to jump from one procedure to another. The main change was to include two parallel steps—one for a fuel remaining scenario and the other for a no fuel remaining scenario. In addition, the change included incorporating ditching procedures, which were originally located in the Ditching checklist, into the Engine Dual Failure checklist. The NTSB notes that the separate Ditching checklist includes steps to select the GPWS and terrain alerts to OFF to avoid nuisance warnings during final descent; however, the ditching procedures contained in the amended Engine Dual Failure checklist do not include these steps.

The Engine Dual Failure checklist included the following three parts:

- Part 1 required the flight crew to differentiate between a no fuel remaining and a fuel remaining condition and included steps to attempt an engine restart.

[91] The US Airways Engine Dual Failure checklist was last revised on February 11, 2008.

- Part 2 contained guidance for the flight crew to follow if an engine restart was successful or if an engine restart was not possible.
- Part 3 contained guidance for the flight crew to follow if a forced landing or a ditching was anticipated.

During postaccident interviews, the pilots stated that, because of the low altitude and limited time available, they were unable to initiate Parts 2 and 3 of the Engine Dual Failure checklist.

1.17.1.2.1 Part 1 of the Engine Dual Failure Checklist

In response to Part 1, the pilots followed the steps for a fuel remaining condition, which are outlined, in part, below. (See appendix C for the entire Engine Dual Failure checklist.)

a. Start engine ignition

b. Confirm thrust levers at idle

c. Maintain optimum relight airspeed of 300 kts

d. Determine a landing strategy (determine the most appropriate place for forced landing/ditching)

e. If emergency generator is not on-line, turn on emergency electrical power

f. Notify ATC

g. Turn FAC 1 OFF then ON (Resetting FAC 1 enables recovery of characteristic speeds displayed on the PFD and permits recovery of rudder trim even if no indication is available.)

If no relight after 30 seconds:

h. Confirm engine master switches 1 and 2 are OFF

Wait 30 seconds:

i. Turn engine master switches 1 and 2 ON

Note: Unassisted start attempts can be repeated until successful or until APU bleed is available.

If unsuccessful:

j. Verify that crew oxygen masks are ON (above 10,000 feet)

When below flight level (FL) 250:[92]

k. Start APU

l. Turn wing anti-ice OFF

When below FL 200:

m. Turn APU bleed ON

Note: If APU bleed is available, APU bleed assisted starts may be accomplished at green dot speed.

n. Confirm engine master switches 1 and 2 are OFF

Wait 30 seconds:

o. Turn engine master switches 1 and 2 ON one at a time

According to CVR evidence and postaccident pilot statements, the pilots accomplished steps a[93] and b of Part 1 of the Engine Dual Failure checklist. Regarding step c, the pilots stated that they determined that, because of the airplane's low altitude and airspeed, they would not be able to reach the optimum relight speed of 300 kts to attempt a windmilling restart of the engines, which is an emergency in-flight procedure in which the effect of ram airflow passing through the engine provides rotational energy to turn the engine core.

Regarding step d, the captain stated that, based on the airplane's position, altitude, airspeed, and heading away from the airport and the amount of time it took to stabilize the airplane and analyze the situation, he determined that returning to LGA was not possible. He further stated that returning to LGA would have been an "irrevocable choice" and that, if he had attempted to land there and realized that he could not, he would have had no other landing options. He stated that before he would make the decision to land on a runway, he would need to ensure that he would not land short or long, that he could line up the flightpath with the runway, that he could stay on the runway, and that he would have a sink rate that was survivable and

[92] FL 250 is an altitude of 25,000 feet msl based on an altimeter setting of 29.92 inches of Hg.

[93] The captain stated that he accomplished step a by memory before calling for the Engine Dual Failure checklist.

would not collapse the landing gear and create a postcrash fire. He stated that he could not afford to make the wrong decision and that he was confident that he could make a successful water landing. The first officer stated that they discussed returning to LGA but that the airport was too far away at the decision-making point and that the airplane was coming down fast.

Regarding attempting to land at TEB, the captain stated they were "too far away, too low, and too slow" and that the only other option that was "long enough, smooth enough, and wide enough" was the Hudson River. The first officer stated that TEB did not look viable and appeared too far away and that the only other option was straight ahead down the Hudson River.

Regarding step e, the pilots stated that they determined that electrical power was established and, therefore, that the RAT did not need to be manually deployed. Further, immediately after the loss of engine thrust, the captain started the APU.

The pilots executed steps f and g. Regarding step h, the first officer stated that, because the left engine appeared to be operating at a reduced level, he initially selected only the right engine master switch to OFF.[94] The first officer stated that he was not sure if he waited 30 seconds, as required by step h, before selecting the right engine master switch back to the ON position (step i).

The first officer stated that, at some point after attempting to relight the right engine and after determining that not much time remained before a landing would be necessary, he selected the left engine master switch to the OFF position and, after a short delay, he selected the left engine master switch to the ON position to initiate a restart of that engine. According to the pilots, they were unable to continue beyond step i of the procedure because of the short time left before a landing would be necessary.

FDR data indicated that both thrust levers were set to the idle position at 1528:01, about 50 seconds after the bird encounter. The N_1 and N_2 speeds for the left engine both decreased while the speeds for the right engine did not respond. About 30 seconds later, the right engine master switch was moved to the OFF position.[95] According to the Airbus FCOM, for an automatic start sequence, when the engine master switch is in the OFF position and the throttle is set at idle, the fuel valve will only open when the N_2 speed is more than 15 percent when in flight. When the first officer attempted to move the right engine master switch to the ON position, the N_2 speed was less than 15 percent. At 1529:27, the left engine master switch was moved to the OFF position, at which time the N_2 speed was about 83 percent. The left engine master switch was moved to the ON position about 10 seconds later, at which time the N_2 speed was about 39 percent.

94 The purpose of selecting the master switch to the OFF position was to reset the full-authority digital engine controls. The purpose of waiting 30 seconds before selecting the master switch back to the ON position was to ventilate the engine combustion chamber before attempting a restart.

95 The engine master switch position is not recorded by the FDR; however, the engine master switch position was derived indirectly by noting the position of the high-pressure fuel valve.

1.17.1.2.2 Parts 2 and 3 of the Engine Dual Failure Checklist

As noted, the pilots were not able to initiate parts 2 and 3 of the Engine Dual Failure checklist. These parts contained airspeed and configuration guidance for pilots to follow when an engine restart is considered impossible and a ditching is anticipated. The checklist stated that, when an engine restart was considered impossible, the optimum speed at which to fly was the green dot speed. It noted that, at green dot speed, the airplane can fly up to about 2.5 miles per 1,000 feet with no wind and that the average descent rate is 1,600 feet per minute. The checklist further indicates that the airplane should be configured for a ditching before 3,000 feet (flaps 3 selected and landing gear up).[96] The ditching procedure also contained the following note:

> In case of strong crosswind, ditch facing into the wind. In the absence of strong crosswind, ditch parallel to the swell. Touchdown with approximately 11 degrees of pitch and minimum vertical speed.

During postaccident interviews, the captain stated that he attempted to maintain green dot speed, the optimum airspeed to fly if an engine restart was considered impossible, before deploying the flaps. He stated that he could not recall exactly what the airplane's airspeed was after he selected flaps 2 but that he referenced the airspeed tape during this time and thought that he kept the airspeed "safely above V_{LS}."

FDR data indicated that, after the almost complete loss of engine thrust and before flaps 2 was selected, the airspeed was variable and decreasing from about 220 to 180 kts and that, after flaps 2 was selected to the time the airplane touched down, the airspeed was variable and decreasing from about 180 to 125 kts. Before flaps 2 was selected, the V_{LS} would have been about 204 kts, and the green dot speed would have been about 223 kts. After flaps 2 was selected, the V_{LS} would have been about 145 kts. The green dot speed is not displayed to the pilot when flaps are extended; instead, a maneuvering F speed is displayed, which would have been about 150 kts on the accident flight.

During postaccident interviews, the captain indicated that he decided to use flaps 2 for the ditching because there were "operational advantages to using flaps 2." He stated that using flaps 3 would not have lowered the stall speed significantly and that it would have increased the drag. He stated that he was concerned about having enough energy to successfully flare the airplane and reduce the descent rate sufficiently. He stated that, from his experience, using flaps 2 provides a slightly higher nose attitude and that he felt that, in the accident situation, flaps 2 was the optimum setting.

[96] The US Airways and Airbus QRHs also contained a separate Ditching checklist; however, these procedures applied to when a ditching was anticipated and at least one of the engines was running. The Ditching checklist referred the pilot to the Engine Dual Failure checklist for the procedures to follow if a ditching was anticipated and the engines were not running.

According to both US Airways and Airbus checklist procedures, only slats,[97] not flaps, were available after a dual-engine failure because of the loss of the green and yellow engine-driven hydraulic pumps and the resultant loss of hydraulic pressure in those systems. However, FDR data indicated that none of the three (green, blue, or yellow) hydraulic systems indicated low pressure. According to the Airbus FCOM, assuming hydraulic power existed, the selection of flaps 2 would result in slats 22° and flaps 15°.

Postaccident flap position measurements taken along the right wing[98] flap track beam corresponded with flap position 2. Examination of the flap lever in the cockpit determined that it was in position 2. Slat position measurements taken along the right and left wing slat track beams corresponded with slat configuration 2 or 3 (the slat positions do not change when the flap lever is moved from position 2 to 3).

1.17.2 Evacuation Procedures

The US Airways QRH contained an Evacuation checklist, which included the following procedures for the captain: select parking brake ON, turn engine master switches 1 and 2 to OFF, and initiate the evacuation command. The checklist included the following procedures for the first officer: notify ATC; after the engine master switches are OFF, push fire (engine and APU) pushbuttons; and discharge fire agents, if required. The procedures further stated that, after all possible assistance has been rendered, the captain and first officer should leave the airplane by any suitable exit and direct passengers away from the airplane.

The pilots stated in interviews that, after the ditching, the first officer initiated the Evacuation checklist. The captain stated that he considered completing his part of the checklist but that he realized that the items would not help the situation. He stated that he could not make an announcement over the PA system because of the loss of electrical power after the ditching,[99] so he opened the cockpit door and issued a verbal "evacuate" command. He added that, when he exited the cockpit, the cabin crew had already started evacuating passengers from the airplane.

1.17.3 Flight Crew Training

According to the US Airways Airbus fleet captain, the company has been operating under the Advanced Qualification Program (AQP) since 2002. The AQP is a voluntary program approved and overseen by the FAA that seeks to improve the safety of Part 121 operations

[97] The deployment of the RAT will continue to run the blue hydraulic system, which provides power to the slats and allows them to extend.

[98] These measurements could not be taken on the left wing because damage made the measurement points inaccessible.

[99] According to Airbus, the PA system is designed to function under these circumstances.

through customized training and evaluation. The US Airways AQP included indoctrination training, qualification training (QT), and continuing qualification training (CQT).

Newly hired pilots were required to attend a 9-day indoctrination training course to provide them with an overview of the policies, procedures, and practices at US Airways. After successfully completing the indoctrination training, trainees attended QT, which was a 23-day course including ground school and simulator training. Simulator training occurred in two phases: phase 1 included 4 days of maneuvers training, during which pilots developed proficiency of core skills and maneuvers and 1 day of maneuvers validation, and phase 2 included 3 days of additional simulator training that focused on threat and error management (TEM) and line operations proficiency. After successfully completing QT, trainees completed operating experience in line operations under the supervision of a company check pilot.

US Airways included two PowerPoint presentations on autothrust and AOA protections during ground school. In addition, autothrust, AOA protections, and flight control laws were demonstrated during a simulator session. Information on these topics was also provided to pilots in the US Airways A319/320/321 Training Manual (TM) and the A319/320/321 Controls and Indicators Manual.

According to the US Airways AQP manager, the training program was based on a 24-month cycle with a 12-month training evaluation period. Following qualification on an airplane, a crewmember was required to complete annual CQT and quarterly distance-learning modules. The CQT was a 3-day course, which included technical ground school; continuing qualification maneuvers observation, consisting of briefings and simulator scenarios; and continuing qualification line-operational evaluation, consisting of simulator sessions similar to line checks. The CQT was valid for 1 year and revised annually. The US Airways AQP manager stated that the AQP training program evaluation included a continual review of information collected from integrated data sources and an annual review by an extended review team, which met annually and included members from US Airways and the FAA. During postaccident interviews, the captain stated that company training "absolutely" helped him during the accident event because he was trained on fundamental values to "maintain aircraft control, manage the situation, and land as soon as the situation permits."

According to US Airways training department personnel, bird-strike avoidance training was not included in the ground school curriculum or simulator syllabus. A ground school instructor stated that bird strikes did come up in the lecture environment when pilots asked about "what if" scenarios. He stated that, in these cases, instructors tried to answer the questions to the best of their knowledge.

According to Airbus' vice president of Flight Operations Support and Services, bird-strike hazards were not specifically addressed in its training program but were covered in a flight operations briefing note titled, "Operational Environment: Birdstrike Threat Awareness," which was available to all Airbus operators on its website. During training at Airbus on before-takeoff standard operating procedures, exterior airplane lights usage was mentioned as a method to help minimize bird-strike hazards. Although Airbus included engine failure and damage scenarios in its flight-simulator training curriculum, the training did not specifically identify a scenario as being caused by a bird strike.

1.17.3.1 Dual-Engine Failure Training

US Airways QT training included a dual-engine failure in the A320 simulator. According to interviews with US Airways training personnel, instructors ran through the QRH Engine Dual Failure checklist with the crew and provided training on the procedures contained in that checklist before the simulator session.

During the simulator session, the dual-engine failure scenario was initiated at 25,000 feet.[100] The crew was led to attempt to relight the engines by windmilling. The scenario was designed, and the simulator programmed, so that the windmilling relight was not successful, which led the crew to start the APU and attempt an APU-assisted restart of one of the engines. The training scenario was considered completed after the training crew successfully restarted one engine using APU bleed air. During postaccident interviews, a US Airways instructor stated that the scenario was normally completed at an altitude from about 8,000 to 10,000 feet. During the training scenarios, at least one engine is always restarted; therefore, the pilots never reached the point of having to conduct a forced landing or ditching.

The NTSB conducted informal discussions with U.S. operators of A320 airplanes to gather information about flight crew training programs. All of the contacted operators indicated that their dual-engine failure training was conducted at high altitudes in accordance with Airbus recommendations and industry practices. The operators revealed that the intent of the training scenarios was to simulate a high-altitude, dual-engine failure scenario and train pilots on the available methods to restart an engine in flight, not to simulate a catastrophic engine failure for which a restart was unlikely.

None of the contacted A320 operators included in their training curricula a dual-engine failure scenario at a low altitude or with limited time available. The A320 operators indicated that the training scenarios generally presented situations for which the course of action and landing location were clear and sufficient time was available to complete any required procedures before landing. The only low-altitude scenarios presented during training were single-engine failures at, or immediately after, takeoff. The A320 operators also indicated that dual-engine failure training was generally only provided during initial, not recurrent, training.

The discussions with A320 operators also indicated that low-altitude, dual-engine failure checklists are not readily available in the industry. One operator stated that it has initiated a review of its procedures as a result of the US Airways accident to determine if a new checklist needed to be developed. Another operator stated that, although it does not have a low-altitude

[100] The US Airways dual-engine failure training was similar to Airbus training except that the dual-engine failure simulator scenario was initiated at 35,000 instead of 25,000 feet.

event checklist, in the past, its simulator training had included low-altitude and limited-time dual-engine failures to stimulate pilots' thinking on situational awareness and planning.

1.17.3.2 Ditching Training

US Airways provided ditching training during ground school. The training consisted of a PowerPoint presentation that reviewed the US Airways QRH Ditching checklist, which assumed that at least one engine was running. Ground school also included training on airplane-specific equipment; the use of slides, life vests, and life rafts; and airplane systems related to ditching. According to postaccident interviews and the US Airways Pilot Handbook TM, the function and use of the ditching pushbutton[101] was discussed during ground school, flight simulations, and preground-school scenario-based training in the CQT curriculum.

The US Airways Flight Operations Manual (FOM) TM included nonairplane-specific guidance on ditching procedures and techniques. In addition, the FOM TM addressed ditching when power was not available and stated the following:

> **Power Not Available.** If no power is available, a greater than normal approach speed should be used until the flare. This speed margin will allow the glide to be broken early and gradually, decreasing the possibility of stalling high or flying into the water.
>
> If the wings of the aircraft are level with the surface of the sea rather than the horizon, there is little probability of a wing contacting a swell crest. The actual slope of a swell is very gradual. If forced to land into a swell, touchdown should be made just after the crest. If contact is made on the face of the swell, the aircraft may be swamped or thrown violently into the air, dropping heavily into the next swell. If control surfaces remain intact, the pilot should attempt to maintain nose up attitude by rapid and positive use of the controls.

Ditching scenarios were not included in either the US Airways or Airbus simulator training curriculum.

The US Airways ditching guidance was similar to military ditching guidance[102] and ditching guidance contained in the FAA Aeronautical Information Manual (AIM), both of which state that, if no power is available, the approach speed used during a ditching should be greater than normal down to the flare to provide the pilot with a speed margin to break the glide earlier and more gradually, thus allowing the pilot time and distance to "feel for the surface." Other

[101] Pushing the ditching pushbutton closes all of the valves below the water line (such as the outflow, avionics, ram air, and pack inlet valves) to help the airplane float longer.

[102] See (a) Aircraft Emergency Procedures Over Water," USCG CG-306; USAF AFM-64-6; Army FM-20-151; USN OPNAV INST 3730.4A (1968) (b) AIM, Chapter 6, "Emergency Procedures," Section 3, "Distress and Urgency Procedures," Paragraph (e), "Ditching Procedures."

literature on this issue also suggested that, when no power is available to the airplane, using flaps may result in the airplane flying at a lower nose attitude and descending more steeply and make it more difficult for the pilot to judge the flare.[103] The NTSB notes that the benefits achieved when using flaps, such as a lower stall speed, should be weighed against the challenges associated with using flaps.

1.17.3.3 CRM and TEM Training

US Airways provided training on crew resource management (CRM) and TEM[104] during basic indoctrination training, CQT, and distance-learning modules. In addition, US Airways integrated CRM and TEM into all aspects of its training, including ground school and flight simulations.

During postaccident interviews, the captain was asked to describe the crew coordination[105] between him and the first officer during the accident event. The captain stated that he thought that the crew coordination was "amazingly good" considering how suddenly the event occurred, how severe it was, and what little time they had. The captain indicated that, because of the time constraints, they could not discuss every part of the decision process; therefore, they had to listen to and observe each other. The captain further stated that they did not have time to consult all of the written guidance or complete the appropriate checklist, so he and the first officer had to work almost intuitively in a very close-knit fashion. For example, the captain stated that when he called for the QRH, about 17 seconds after the bird strike, the first officer already had the checklist out. The captain credited the US Airways CRM training for providing him and the first officer with the skills and tools that they needed to build a team quickly and open lines of communication, share common goals, and work together. During postaccident interviews, the first officer stated that he and the captain each had specific roles, knew what each other was doing, and interacted when necessary.

[103] R.L. Newman, "A Case History and Review of the Record," SAFE Journal, vol. 18, no. 1 (1988), pp. 6–15.

[104] According to a US Airways instructor pilot, TEM training "was based on the realization that pilots made mistakes and…was designed to find ways to prevent mistakes and correct errors."

[105] Coordination involves the ability of crewmembers to incorporate and synchronize the tasks required of them in a correct and timely manner and requires optimal effort from all crewmembers to work effectively. Research indicates that, when crews share an understanding of the tasks (what they are and how to accomplish them), communications are improved and more efficient, which is critical during periods of high workload. See (a) J.A. Cannon-Bowers, S.I. Tannenbaum, E. Salas, and C.E. Volpe, "Defining Team Competencies and Establishing Team Training Requirements," in R. Guzzo and E. Salas, eds., *Team Effectiveness and Decision Making in Organizations* (San Francisco, California: Jossey-Bass, 1995), pp. 333–380. (b) R.J. Stout, J.A. Cannon-Bowers, E. Salas, and D.M. Milanovich, "Planning, Shared Mental Models, and Coordinated Performance: An Empirical Link is Established," *Human Factors*, vol. 41, no. 1 (1999), pp. 61–71.

1.17.4 FAA Oversight

At the time of the accident, the FAA Certificate Management Office (CMO) for US Airways employed one aircrew program manager (APM) and one assistant APM (who was in training) for the US Airways Airbus fleet. During postaccident interviews, the APM indicated that five aviation safety inspectors assisted him with oversight of US Airways Airbus training and operations. Oversight activity included surveillance and observation of flight crewmembers, instructors, check airmen, and aircrew program designees during training, checking, and line operations. According to interviews, each aviation safety inspector or APM conducted, on average, two or three surveillance activities weekly at US Airways.

The principal operations inspector (POI) for US Airways was stationed at the Coraopolis, Pennsylvania CMO. During interviews, the POI indicated that three assistant POIs were also assigned to the US Airways certificate. The POI stated that he did not normally conduct surveillance activities himself but that he had oversight of the APMs, with whom he interacted daily, and operational programs for each fleet at US Airways. The POI was responsible for approving amendments to training and operational procedures manuals. He stated that he required a review and recommendation by the APMs before he approved any amendments. In addition, any airplane-specific procedures were compared to the manufacturer's recommended procedures, and changes to non-normal procedures were coordinated with the CMO before approval.

1.18 Additional Information

1.18.1 Wildlife-Strike Hazard Information

1.18.1.1 General

Wildlife strikes to aircraft, about 98 percent of which involve birds, cost the civil aviation industry in the United States about $625 million per year.[106] At least 229 people have died and 194 aircraft have been destroyed as a result of wildlife strikes in civil and military operations from 1988 to April 2009.[107] Since 1960, 26 large-transport aircraft have been destroyed because

[106] See *Wildlife Strikes to Civil Aircraft in the United States 1990-2007*, FAA and USDA, APHIS, Wildlife Services Serial Report No. 14 (Washington, DC: Federal Aviation Administration and U.S. Department of Agriculture, 2008).

[107] See (a) W.J. Richardson and T. West, "Serious Birdstrike Accidents to Military Aircraft: Updated List and Summary," *Proceedings of the 25th International Bird Strike Committee Meeting, April 17–21, 2000, Amsterdam, The Netherlands* (Amsterdam, The Netherlands: 2005), pp. 67–98. (b) J. Thorpe, "Fatalities and Destroyed Aircraft Due to Bird Strikes, 1912-2002," *Proceedings of the 26th International Bird Strike Committee Meeting, May 5 –9, 2003, Warsaw, Poland,* vol. 1 (Warsaw, Poland: 2003), pp. 85–113.

of bird strikes worldwide, and 93 percent of these strikes occurred during takeoff or landing at an altitude of about 500 feet agl or less when the airplane was still near an airport.[108]

The number of wildlife strikes annually reported in the United States increased significantly from 1990 to 2007.[109] According to a USDA report, various reasons account for the increase in wildlife-strike reports.[110] For example, airports have large areas of grass and pavement, which are attractive habitats to birds for feeding and resting. In addition, modern turbofan-powered aircraft have quieter engines and, therefore, are less obvious to birds than older and noisier turbine-powered and piston-powered aircraft. Additionally, commercial aircraft operations in the United States have increased by about 2 percent per year since 1980. Further, research has shown that various government-sponsored programs initiated over the past 40 years, such as pesticide regulation, wildlife refuge system expansion, wetlands restoration, and land-use changes, have resulted in increases in populations of many wildlife species in North America.[111]

Of the estimated 650 bird species that nest in North America, 36 have average body masses of more than 4 pounds. Of the 31 of these species for which population trend data are available, 24 species (77 percent) showed population increases, 2 showed population decreases, and 5 showed stable populations over the past 20 to 40 years. Further, 13 of the 14 species that had body masses of more than 8 pounds, such as the Canada goose, showed population increases.

1.18.1.2 Canada Goose Information

Canada goose populations in North America can be divided into two groups based on migratory behavior. One group consists of migratory geese that engage in annual seasonal migration and spend the winter and summer months in different locations. The other group consists of nonmigratory geese, or resident geese, that have established year-round residency in a particular location. As shown in the graph in figure 10, the Canada goose population has increased nationally from 1.2 million in 1970 to 5.5 million in 2008.[112] The resident goose population has increased the most, from 0.2 million in 1970 to 3.9 million in 2008; in contrast, the migrant goose population has been relatively stable since 1990, with a population of about 1.6 million. In summary, resident geese comprised 19 percent of the total Canada goose population in 1970, 39 percent in 1990, and 71 percent in 2008.

[108] See R.A. Dolbeer, "Height Distribution of Birds Recorded by Collisions with Aircraft," *Journal of Wildlife Management,* vol. 70, no. 5 (2006), pp. 1345–1350.

[109] Currently, wildlife-strike reporting to the FAA is voluntary, and the data, which are maintained in the FAA National Wildlife Strike Database, only reflect about 20 percent of overall strikes. See section 1.18.1.3 for information about wildlife-strike reporting and safety recommendations that have been issued to address this issue.

[110] See FAA and USDA, APHIS, Wildlife Services Serial Report No. 14.

[111] See R.A. Dolbeer and P. Eschenfelder, "Amplified Birdstrike Risks Related to Population Increases of Large Birds in North America," *Proceedings of the 26th International Bird Strike Committee Meeting May 5 –9, 2003, Warsaw, Poland*, vol. I (Warsaw, Poland: 2003), pp. 49–67.

[112] The population trends are national, but the same ratio of resident geese to migratory geese applies throughout the country, particularly the New York City area, which is in the east coast migration corridor.

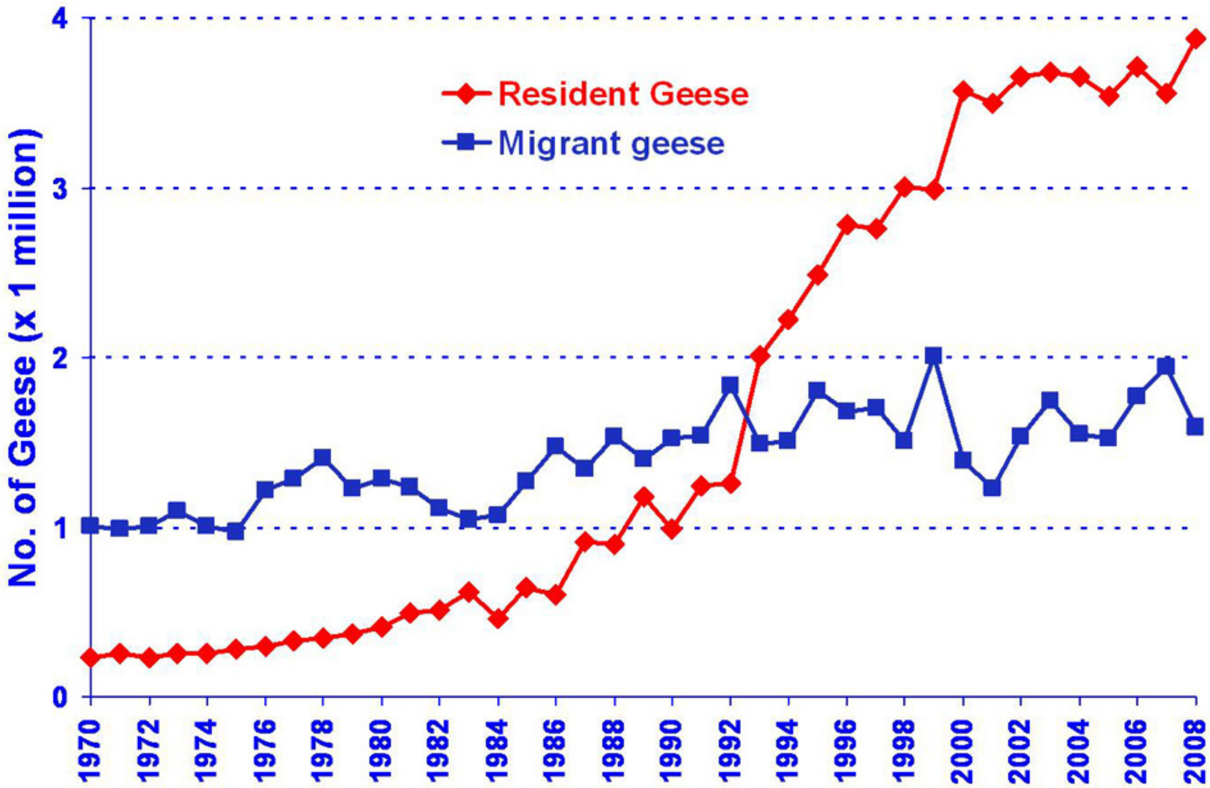

Figure 10. Graph depicting the Canada goose population from 1970 to 2008.

The average weight of a male Canada goose is from 8.41 to 9.23 pounds, and the average weight of a female Canada goose is from 7.31 to 7.75 pounds.[113] According to a USDA report, Canada geese are particularly hazardous to aviation because of their large size, flocking behavior, attraction to grazing sites at airports, and the year-round presence of their resident populations.[114]

1.18.1.3 Wildlife-Strike Reporting

AC 150/5200-32A, "Reporting Wildlife Aircraft Strikes," encourages pilots, airport operators, aircraft maintenance personnel, or anyone else who has knowledge of a wildlife strike to voluntarily report it to the FAA using FAA Form 5200-7, "Bird/Other Wildlife Strike Report." The AC provides electronic access to the form and methods for submitting it, as well as

[113] See J.B. Dunning, ed., *CRC Handbook of Avian Body Masses*, 2nd edition (Boca Raton, Florida: CRC Press, 2007).

[114] See R.A. Dolbeer and J.L. Seubert, *Canada Goose Populations and Strikes With Civil Aircraft, 1990-2008: Challenging Trends for Aviation Industry* (Sandusky, Ohio: U.S. Department of Agriculture, 2009).

information on accessing the FAA National Wildlife Strike Database[115] and the procedure for submitting animal remains to the Smithsonian Institution for species identification. The collected data are used to identify the wildlife species most commonly involved in strikes, the seasonal patterns of strikes for various species, and the extent and types of aircraft damage resulting from strikes. Reporting, data collection, and other issues related to bird strikes were discussed extensively at the public hearing held for this accident from June 9 through 11, 2009.

The FAA has collected voluntary wildlife-strike reports and maintained the National Wildlife Strike Database since 1990. The database is managed by the USDA Wildlife Services, in cooperation with the FAA. Wildlife-strike reports are sent to Wildlife Services, and the reports are then quality assured and entered into the FAA National Wildlife Strike Database. The database is available to the public and can be used to identify seasonal patterns, species involved in strikes, and the extent and type of damage resulting from strikes.

From 1990 to 2008, the FAA National Wildlife Strike Database received 89,734 wildlife-strike reports. The database wildlife-strike information for LGA from 2004 to 2008 showed that 411 wildlife strikes occurred during all phases of flight.[116] Further, the total number of reported bird strikes to airplanes increased from 1,738 in 1990 to more than 7,400 in 2007, and about 92 percent of the strikes occurred below 3,000 feet agl. Further, the data indicate that, from 1990 through 2008, 3,239 turbine-powered civil aircraft sustained damage to a single engine as a result of a bird strike and that, during the same period, 108 similar aircraft sustained damage to two engines.

In 2005, the USDA compared wildlife-strike data from three airports and three airlines with the FAA's data for various years from 1991 to 2004, and research determined that only about 21 percent of the known strike data were captured in the FAA National Wildlife Strike Database.[117] The NTSB has issued two recommendations regarding this issue since 1999.[118]

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115 The FAA National Wildlife Strike Database, which contains links to numerous sources of wildlife hazard information and the online strike-reporting form, can be found online at <http://wildlife-mitigation.tc.faa.gov>. The website is managed by Embry-Riddle Aeronautical University under an FAA contract for improving the wildlife mitigation website to ensure that it is up-to-date, user-friendly, and has the technical support necessary to maintain the wildlife-strike reporting functions and database.

116 See FAA and USDA, APHIS, Wildlife Services Serial Report No. 14.

117 The USDA obtained 14 independent sets of wildlife-strike data from three airlines and three airports for various years between 1991 and 2004. By comparing the data from the airports and airlines with the data entered into the FAA National Wildlife Strike Database, it was determined that 21 percent of known strikes were actually captured in the database. R.A. Dolbeer and S.E. Wright, "Percentage of Wildlife Strikes Reported and Species Identified Under a Voluntary System," *Proceedings of Bird Strike Committee USA/Canada Meeting 2005 Bird Strike Committee-USA/Canada 7th Annual Meeting, August 28—September 1, 2005, Vancouver, British Columbia, Canada* (Lincoln, Nebraska: University of Nebraska, 2005).

118 On November 19, 1999, the NTSB issued Safety Recommendation A-99-91, which asked the FAA to "require all airplane operators to report bird strikes to the FAA." Because the FAA took no action on Safety Recommendation A-99-91, the NTSB classified it "Closed—Unacceptable Action" on May 11, 2000. On September 29, 2009, the NTSB issued Safety Recommendation A-09-75 as a result of the March 4, 2008, crash of a Cessna 500 following an in-flight collision with large birds in Oklahoma City, Oklahoma. Safety Recommendation A-09-75 asked the FAA to "require all 14 CFR Part 139 airports and 14 CFR Part 121, Part 135, and Part 91 Subpart K aircraft operators to report all wildlife strikes, including, if possible, species identification, to the FAA National

In an effort to educate the aviation community on the importance of reporting wildlife strikes, the FAA contracted with Embry-Riddle Aeronautical University (ERAU) to conduct an outreach and education program beginning in fiscal year 2009. ERAU has identified five segments of the aviation community that will be targeted, including airport management and operating personnel, commercial air carriers, the business jet community, private or general aviation, and ATC groups. ERAU plans to exhibit at nine major seminars or conferences each year to distribute literature emphasizing the importance of wildlife-strike reporting and to demonstrate the FAA National Wildlife Strike Database's extraction capabilities.

1.18.1.4 Wildlife-Strike Hazards in the New York City Metropolitan Area

Six Part 139 airports serve the New York City metropolitan area: Stewart International Airport, Newburgh, New York; Westchester County Airport, White Plains, New York; EWR; TEB; JFK; and LGA, the last three of which are located within a 10-mile radius of Manhattan. Numerous wildlife attractants exist near these airports, including landfills; waste transfer stations; city parks; golf courses; ponds; roosting areas, such as trees and shrubs; estuaries; tidal areas that expose food sources (for example, shellfish); deep water areas that provide prey for diving birds; roadway medians for nesting Canada geese; water retention basins; open dumpsters; recreational fields; grasslands; and beaches.

According to the FAA National Wildlife Strike Database, from January 1990 to August 2008, 4,253 bird strikes occurred in the New York City area, including reports from JFK, LGA, EWR, and TEB. According to the database, 5 percent of these reported strikes included altitude information indicating that the strikes occurred between 2,200 and 4,200 feet. In general, the lowest number of wildlife strikes in North America occur during the winter months (December, January, and February), while the highest number occur during the fall migration months (August, September, and October).[119] These trends are consistent with wildlife strike data for the New York City area.

Wildlife Strike Database." *Crash of Cessna 500, N113SH, Following an In-Flight Collision with Large Birds, Oklahoma City, Oklahoma, March 4, 2008,* Aircraft Accident Report NTSB/AAR-09/05 (Washington, DC: National Transportation Safety Board, 2009). In response, the FAA conducted a research study that determined that the total number of reported strikes had increased significantly from 20 percent (during the period from 1990 to 1994) to 39 percent (during the period from 2004 to 2008) but that, although the level of reporting was higher, the number of damaging strikes had not increased. The FAA stated that, based on these findings, it was not necessary to impose mandatory wildlife-strike reporting but that it had initiated measures to increase wildlife-strike reporting by expanding and improving procedures to transfer data from FAA and industry databases to the National Wildlife Strike Database and implementing an education/outreach program with a number of aviation organizations. For more information, see (a) *Trends in Wildlife Strike Reporting, Part 1 - Voluntary System 1990 - 2008*, DOT/FAA/AR-09/65 (Washington, DC: Federal Aviation Administration, 2009). (b) *Wildlife Strike Reporting, Part 2 - Sources of Data in Voluntary System,* DOT/FAA/AR-09/63 (Washington, DC: Federal Aviation Administration, 2009).

[119] See FAA and USDA, APHIS, Wildlife Services Serial Report No. 14.

1.18.1.5 Wildlife Hazard Mitigation Research Programs

Ongoing wildlife research is conducted by the FAA Technical Center, Atlantic City, New Jersey; the USDA National Wildlife Research Facility, Sandusky, Ohio; and the Center of Excellence in Airport Technology at the University of Illinois at Urbana-Champaign, Urbana, Illinois. According to the FAA, the research falls into the categories of habitat modification and harassment techniques. Habitat modification research includes grass-height studies to determine which grass heights detract birds from feeding and grass-type studies to determine which grass types are not preferred by birds. Habitat modification research has also examined the use of artificial turf, earthworm control, rodent control, and landfill control techniques to control wildlife populations.

Research in harassment techniques includes studying the effectiveness of using air cannons, lasers, dogs, and effigies of owls and other birds to harass and scare birds. Based on this research, air cannons, effigies, falconry, dogs, rodent and earthworm control, planting unappealing vegetation, artificial turf, landfill eradication or modification, and water runoff detention pond modification have been implemented at many airports with good results. Similarly, the USDA reported that the use of lasers has been shown to be effective in repelling birds from hangars and other areas on the airfield and that there is anecdotal evidence, but no conclusive evidence, that using weather radar on airplanes disperses birds from the airplane's flightpath. Research into the capabilities and feasibility of avian radar is also ongoing and will be discussed in section 1.18.3.1.

1.18.2 Previously Issued Safety Recommendation Resulting From This Accident

Safety Recommendation A-09-112

As a result of the US Airways accident, on October 7, 2009, the NTSB issued Safety Recommendation A-09-112 to the FAA to address the potential safety consequences of an air traffic controller not knowing the location of an airplane experiencing an emergency. Safety Recommendation A-09-112 asked the FAA to do the following:

> Modify [FAA] radar data processing systems so that air traffic controllers can instruct the systems to process the discrete transponder code of an aircraft experiencing an emergency as if it were an emergency transponder code.

On December 11, 2009, the FAA stated that the Standard Terminal Automation Replacement System currently has the capability to display emergency symbology of an aircraft in distress that will notify every controller within the facility of the situation. The FAA stated that the controller can make a keyboard entry that will add a visual indication to the data block, which is displayed at every radar position, including ATC radar displays. The FAA added that the Common Automated Radar Terminal System does not currently have this functionality but that a National Change Proposal has been submitted and approved and that the implementation of this capability is scheduled for spring 2010.

On April 2, 2010, the NTSB stated that it was pleased that the FAA had increased the functionality of its Standard Terminal Automation Replacement System so that controllers are notified of aircraft in distress and that similar improvements have been approved for the Common Automated Radar Terminal System. The NTSB indicated that, although the FAA's actions were responsive, this recommendation also applied to the radar data processing systems used by Air Route Traffic Control Center and Microprocessor En Route Automated Radar Tracking System facilities because situations similar to this accident can occur in any radar facility. Therefore, pending its review of the FAA's actions to address the radar data processing systems used by these facilities, the NTSB classified Safety Recommendation A-09-112 "Open—Acceptable Response."

1.18.3 Previous Related Safety Recommendations

1.18.3.1 Bird-Strike Hazard Mitigation

The NTSB has had long-standing concerns about bird- and other wildlife-strike hazards and has issued several safety recommendations as a result of its investigations of accidents related to these issues. For example, following two serious bird-strike events involving Part 121 air carrier airplanes,[120] on November 19, 1999, the NTSB issued several safety recommendations to the FAA and other federal agencies related to wildlife hazard management and bird strikes; two of these recommendations are discussed below.

Safety Recommendation A-99-86

In its November 19, 1999, letter, the NTSB issued Safety Recommendation A-99-86, which asked the FAA to do the following:

> Evaluate the potential for using Avian Hazard Advisory System [AHAS] technology for bird strike risk reduction in civil aviation and if found feasible, implement such a system in high-risk areas, such as major hub airports and along migratory bird routes, nationwide.

On February 14, 2000, the FAA stated that it agreed with the intent of the recommendation, had allocated research funds to study the use of AHAS technology for monitoring bird movements nationally, and had determined that AHAS is well suited for

[120] On February 22, 1999, a Boeing 757 operated under Part 121 by Delta Air Lines, Inc., as a scheduled passenger flight, sustained substantial damage after penetrating a flock of birds during takeoff from Covington, Kentucky. The flight crew entered the airport traffic pattern for an immediate return for landing and landed the airplane without further incident. On March 4, 1999, a Douglas DC-9-15F, operated under Part 121 by USA Jet Airlines, Inc., as a domestic air cargo flight, sustained a severe engine-power loss after encountering a flock of large birds while on final approach for landing in Kansas City, Missouri. The pilot regained enough power in one engine to continue the approach and land the airplane. The reports for these accidents, NTSB case numbers NYC99LA064 and CHI99FA012, respectively, can be found online at <http://www.ntsb.gov/ntsb/query.asp>.

monitoring bird movements regionally but, because of limitations inherent in the system, that it was not suitable for monitoring bird movements on or within 5 miles of an airport; therefore, a different type of radar must be used for these purposes. The FAA stated that it would conduct a detailed review of all of the components that make up AHAS and that, based on the results, it would determine how AHAS could be modified for use in commercial aviation. The FAA added that it would also review other technologies and radar systems that could be used locally.

On May 11, 2000, the NTSB responded that it appreciated that the FAA's evaluation addressed the potential use of prediction radar in areas where AHAS is not effective. Because the FAA's evaluation determined that AHAS was not effective in high-risk areas and continued to research other forms of radar for those areas, the NTSB classified Safety Recommendation A-99-86 "Closed—Acceptable Action."

Since the closing of Safety Recommendation A-99-86, the FAA has continued to research the use of radar systems for monitoring birds at airports. For example, in 2000, the FAA and the U.S. Navy Space and Naval Warfare Systems Center sponsored a research project to determine if low-cost, small mobile radars can reliably detect birds at or near (within about 3 to 5 miles of) airports and be used to develop an airport bird-strike advisory system that is compatible with existing airport operational systems. Based on the results of the research project, the FAA plans to develop radar system performance standards and prepare guidance for airports on how to acquire, deploy, operate, and maintain the units.

As part of the radar evaluation project, mobile avian radar has been installed at Seattle-Tacoma International Airport, Seattle, Washington; Naval Air Station Whidbey Island, near Oak Harbor, Washington; Chicago O'Hare International Airport, Chicago, Illinois; and JFK. An additional avian radar evaluation system is scheduled to be installed at Dallas/Fort Worth International Airport, Dallas/Fort Worth, Texas, in 2010. According to the FAA,[121] preliminary results from the experimental avian radar systems have not yet indicated if the systems would be capable of providing alerts that would be operationally suitable for making specific decisions on landing or takeoff, and its research is continuing to address these operational issues. However, the FAA indicated that radar data have been shown to be useful in tracking and quantifying wildlife movements on and around airports and that this information could be used to enhance existing wildlife control programs.

Safety Recommendation A-99-88

In its November 19, 1999, letter, the NTSB also issued Safety Recommendation A-99-88, which asked the FAA, in consultation with the USDA, to do the following:

[121] See Federal Aviation Administration, "Wildlife Hazard Mitigation Requirements and Programs," fact sheet, January 16, 2009 <http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=10376> (accessed March 1, 2010).

> Require that [WHAs] be conducted at all 14 [CFR] Part 139 airports where such assessments have not already been conducted.

On February 22, 2000, the FAA stated that it was not necessary to initiate additional regulations to require all Part 139 airports to conduct WHAs. The FAA indicated that to require all Part 139 airports to conduct WHAs without the occurrence of one of the triggering events required by 14 CFR 139.337(a) would place an undue burden on many airports that do not have a history of wildlife strikes. The FAA stated that the actions it was taking in response to other safety recommendations related to bird strikes would address the safety issue and that it planned no further action.

On May 11, 2000, the NTSB stated that, although it understood the potential fiscal burden on airports, it strongly felt that the effort was necessary to ensure that all airports become aware of potential hazards of wildlife strikes, regardless of their location. The NTSB classified Safety Recommendation A-99-88 "Closed—Unacceptable Action" because the FAA had not taken the recommended action.

1.18.3.2 Survivability Issues

The NTSB has published safety studies on air carrier overwater emergency equipment and procedures and emergency evacuation of commercial airplanes and, based on these studies, has issued many safety recommendations related to survival factors. Safety recommendations pertinent to this accident are discussed in this section.

Safety Recommendations A-85-35 through -37

On July 2, 1985, the NTSB issued several safety recommendations as a result of NTSB Safety Study 85/02, "Air Carrier Overwater Emergency Equipment and Procedures."[122] Safety Recommendations A-85-35, -36, and -37 asked the FAA to do the following:

> Amend 14 CFR 121 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of [Technical Standard Order] TSO-C13 ["Life Preservers"] within a reasonable time after the adoption of the current revision of the TSO; ensure that 14 CFR 25 is consistent with the amendments to Part 121. (A-85-35)[123]

[122] See *Air Carrier Overwater Emergency Equipment and Procedures*, Safety Study NTSB/SS-85/02 (Washington, DC: National Transportation Safety Board, 1985).

[123] A TSO is a minimum performance standard issued by the FAA for specified materials, parts, processes, and appliances used on civil aircraft.

> Amend 14 CFR 125 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of TSO-C13 within a reasonable time after the adoption of the current revision of the TSO; amend Part 125 to require approved flotation-type seat cushions (TSO-C72) on all such aircraft; ensure that 14 CFR 25 is consistent with the amendments of Part 125. (A-85-36)

> Amend 14 CFR 135 to require that all passenger-carrying air carrier aircraft operating under this Part be equipped with approved life preservers meeting the requirements of the most current revision of TSO-C13 within a reasonable time after the adoption of the current revision of the TSO; amend Part 135 to require approved floatation-type seat cushions (TSO-C72) on all such aircraft; ensure that 14 CFR [*Special Federal Aviation Regulations*] SFAR No. 23 is consistent with the amendments to Part 135. (A-85-37)

On December 30, 1987, Public Law 100-223, "Airport and Airway Safety and Capacity Enhancement Act of 1987," was enacted. The public law required the Secretary of Transportation to initiate rulemaking to consider requiring "adequate, uniform life preservers, life rafts, and flotation devices for passengers, including small children and infants, on flights of an air carrier which the Secretary determines will be partly over water." On June 30, 1988, the FAA published Notice of Proposed Rulemaking (NPRM) 88-11, which proposed new requirements that "would ensure that each occupant is provided a life preserver which provides the basic benefits of high buoyancy and water stability…regardless of whether the airplane is involved in overwater operation." The FAA received 118 comments on the proposal, more than half of which were supportive. In 1997, the FAA informed the NTSB that it anticipated that a final rule would be published in the *Federal Register* by the end of that year; however, no final rule was issued.

On July 10, 2000, the FAA indicated that, because of the number of comments received in response to NPRM 88-11 and the amount of time since the NPRM was originally issued, it had written a supplemental NPRM (SNPRM) for comment, which it anticipated would be published in the *Federal Register* by October 2000. Because that date passed and no communication was received, on March 29, 2002, the NTSB classified Safety Recommendations A-85-35 through -37 "Closed—Unacceptable Action." On July 24, 2003, more than 15 years after it was originally published, the FAA finally withdrew the original NPRM 88-11 and stated, "we find the costs of proceeding with this rulemaking as proposed exceed the benefits to the public and that existing water survival equipment requirements are satisfactory."

Safety Recommendation A-85-39

Safety Recommendation A-85-39 asked the FAA to do the following:

> Amend the relevant sections of 14 CFR 121, 125, and 135 to require that all pre-departure briefings include a full demonstration of correct life preserver donning procedures.

On December 10, 1985, the FAA stated that passengers should be given information appropriate only to a particular flight and that a flight not being conducted on an EOW operation should not include a full demonstration on the donning and inflation of life vests.

On February 18, 1986, the NTSB responded that, as noted in Safety Study SS-85/02, at least 179 fully certificated airports in the United States are located within 5 miles of a significant body of water; therefore, many passengers are at risk even though they may not be on an EOW flight. The NTSB also noted that, because most air carrier accidents occur during the approach or landing phases of flight, it is appropriate for passengers to be provided with a full demonstration of correct life preserver donning procedures if a flight originates or terminates near a significant body of water.

On February 18, 1987, the FAA stated that, although many flights take off or land over bodies of water, in most cases those flights are not being operated in EOW operations and, therefore, are not required to be equipped with life preservers. The FAA noted that, if an aircraft not on an EOW flight crashed into the water, there would be little or no warning for passengers, leaving little time to don life preservers. The FAA stated that rulemaking on this subject would not be warranted.

On June 1, 1987, the NTSB stated that it was disappointed that the FAA did not plan to take action in response to Safety Recommendation A-85-39 and classified it "Closed—Unacceptable Action."

Safety Recommendations A-85-41 through -44

Safety Recommendation A-85-41 asked the FAA to do the following:

> Amend TSO-C69a to require quick-release girts and handholds on emergency evacuation slides; amend 14 CFR 121 and 125 to specify a reasonable time from the adoption of the revision of the TSO by which all transport passenger air carrier aircraft being operated under these Parts must be equipped with slides conforming to the revised TSO.

On December 23, 1988, the FAA stated that, on August 17, 1988, it issued TSO-C69b, "Emergency Evacuation Slides, Ramps, and Slide/Raft Combinations," which had been revised to require quick-release girts and handholds on emergency evacuation slides. The FAA also stated that this recommendation was addressed in NPRM 88-11. As noted, on July 9, 1997, the FAA further stated that it anticipated issuance of its final rule governing overwater emergency equipment and procedures by December 1997. The FAA indicated that the final rule would address Safety Recommendations A-85-35 and -37 directly and Safety Recommendations A-85-36 and -41 indirectly.

On June 6, 2000, the NTSB requested an update on the status of this recommendation. As noted previously, on July 10, 2000, the FAA indicated that it had written an SNPRM for comment, which it anticipated would be published in the *Federal Register* by October 2000. On August 17, 2000, the NTSB stated that it was disappointed and concerned that, in the 12 years since the FAA initially issued the NPRM and in the 15 years since Safety Recommendation A-85-41 was issued, action had not been completed. The NTSB indicated that it understood the need for the SNPRM, given the time that had passed since the NPRM was issued, but that the FAA should act promptly. On March 29, 2002, the NTSB stated that it was aware that an SNPRM had not been issued and that no efforts were underway to issue one. Given the FAA's lack of action and the amount of time that had passed since this recommendation was issued, the NTSB classified Safety Recommendation A-85-41 "Closed—Unacceptable Action."

Safety Recommendations A-85-42 and -43 asked the FAA to do the following:

> Amend TSO-C13d to require that the timed donning tests include the time to extract the life preserver from an unopened package. (A-85-42)
>
> Amend TSO-C13d to establish specific donning test performance requirements and compliance criteria, based on accepted statistical sampling practices that, at a minimum, set a lower limit on the number of persons to be used in each group test; upper and lower limits on the number of group tests that may be performed; the minimum percentage of persons in each group who must pass the test in order to count the group test a success; the minimum number of group tests that must be successful; and the composition of each group, including a requirement that only naïve subjects be used. (A-85-43)

On August 21, 1986, the FAA stated that Safety Recommendations A-85-42, -43, -45, and -46[124] were addressed in the revision of TSO-C13e, "Life Preservers." On October 27, 1986, the NTSB stated that the TSO modifications complied with the intent of these recommendations and classified Safety Recommendations A-85-42 and -43 "Closed—Acceptable Action."

Safety Recommendation A-85-44 asked the FAA to do the following:

> Amend TSO-C13d to require that the timed donning tests be performed without the use of a briefing card or a donning demonstration.

On December 10, 1985, the FAA stated that it recognized the importance of simple, quick-donning life preservers for typical untrained airline passengers. The FAA stated, however, that it was not reasonable or realistic to exclude from the donning test the preflight demonstration or passenger briefing cards.

[124] The NTSB also issued Safety Recommendations A-85-45 and -46 as a result of Safety Study SS-85/02. Safety Recommendation A-85-45 asked the FAA to "amend TSO-C13d so that it does not preclude the use of single inflation chamber life preserver designs that otherwise meet the requirements of the TSO." Safety Recommendation A-85-46 asked the FAA to "amend TSO-C13d to require an automatically activated survivor locator light." On October 27, 1986, the NTSB classified Safety Recommendations A-85-45 and -46 "Closed—Acceptable Action."

On February 18, 1986, the NTSB stated that donning tests should be performed without the benefit of a donning demonstration or briefing cards. The NTSB indicated that this requirement would truly test how easily and quickly the life preservers can be donned and would simulate more closely the actual conditions faced by passengers during a water impact accident. The NTSB requested that the FAA reconsider the need to provide the most appropriately severe situation to test subjects to determine more realistic donning times for passengers functioning in real emergency conditions.

On August 21, 1986, the FAA stated that, although it had carefully considered the NTSB's position, it still planned to take no action in response to Safety Recommendation A-85-44. Therefore, on October 27, 1986, the NTSB classified Safety Recommendation A-85-44 "Closed—Unacceptable Action."

Safety Recommendation A-00-86

On July 14, 2000, the NTSB issued Safety Recommendation A-00-86 as a result of NTSB Safety Study 00/01, "Emergency Evacuation of Commercial Airplanes."[125] Safety Recommendation A-00-86 asked the FAA to do the following:

> Conduct research and explore creative and effective methods that use state-of-the-art technology to convey safety information to passengers. The presented information should include a demonstration of all emergency evacuation procedures, such as how to open the emergency exits and exit the aircraft, including how to use the slides.

On November 14, 2000, the FAA stated that passenger inattention to preflight safety briefings should be addressed by air carriers in their crewmember training programs, flight attendant procedures, and methods of communicating passenger safety information. The FAA stated that the current state-of-the-art technology is effective and was already being used in the aviation industry. The FAA indicated that many airlines use safety briefing videos and that, as airlines acquired newer generation aircraft that were equipped for video presentations, the number of passengers who received video safety briefings would increase. The FAA further stated that, although it did not agree that additional research was needed, it would continue to encourage air carriers to use innovative ways to present safety information to passengers.

On July 25, 2001, the NTSB stated that its evacuation study found that current practices did not adequately convey safety information to passengers. The NTSB stated that it was unaware of any research or studies that had compared or evaluated how effective the current technologies are when used in preflight safety briefings. The NTSB indicated that it would like to know, for instance, whether passenger attention and knowledge retention of a video safety briefing have been objectively compared with a safety briefing by a live flight attendant. The

[125] See *Emergency Evacuation of Commercial Airplanes*, Safety Study NTSB/SS-00/01 (Washington, DC: National Transportation Safety Board, 2000).

NTSB asked the FAA to reconsider its position on identifying creative and effective methods of conveying safety information to passengers.

On December 11, 2003, the FAA indicated that previous FAA studies in human factors and extensive experience of air carriers in actual operations have shown that graphics were more effective than text, especially for passengers who were not fluent in written or spoken English, and that moving graphics might enhance the effectiveness of static graphic images. The FAA further indicated that many airlines were using overhead and seatback monitors for this purpose, and, as aircraft were upgraded or new aircraft were put into service, the ability to use moving graphics in proximity to passengers to convey safety briefing information would increase.

On May 5, 2004, the NTSB stated that the technological advances in on-board graphics displays had provided more options for improved preflight safety briefings. The NTSB indicated, however, that it was concerned that the FAA had taken no direct action to research creative and effective methods to use this new technology to address the problem of passenger inattention to briefings. The NTSB stated that it was disappointed that the FAA did not intend to further address the passenger inattention issue despite the new technology available and classified Safety Recommendation A-00-86 "Closed—Unacceptable Action."

1.18.4 Water Swell Testing

In 1974, Institut de Méchanique des Fluides de Lille conducted water-tank tests to determine the effect of water swells on water-landing forces using a 1/16-scale model of the Mercure aircraft.[126] Tests were conducted on smooth water and on four different combinations of sea swell size and approach geometry. When landing on rough water against the swells, the airplane fuselage was breached and became submerged by the end of the test runs. When landing on rough water parallel to the swells, the fuselage was breached in 7 out of 10 tests. The report concluded that, on smooth water, the water impact pitch angles tested from 11° to 15° resulted in a water landing without significant destruction at a mass of 50,000 kilograms (110,231 pounds) and with load factors less than 3 Gs. However, on rough water, only pitch angles of 13° and 15° were found to be acceptable, with a flightpath angle of -1° or less, low speed, and flaps and slats in the landing configuration. The report indicated that the lower pitch angles (pitch angles between 11° and 13°) should not be used when landing on water with swells because the engines and the fuselage would break under these conditions. The report concluded that, on rough water, landing against the swells should be avoided because this test condition always resulted in a breach of the fuselage. Rather, the swells should be contacted longitudinally and on a peak, preferably at 15° of pitch. Sideslip and roll angles should be minimized, and landing gear should be retracted for a water landing.

[126] The information presented in this section comes from selected sections of the IMF Lille test report that were translated by an NTSB investigator.

1.18.5 NASA Research on the Challenges of Abnormal and Emergency Situations

In June 2005, NASA published a report that discussed the challenges of emergency and abnormal situations in aviation.[127] The report states, "some situations may be so dire and time-critical or may unfold so quickly" that pilots must focus all of their efforts on the basics of aviation—flying and landing the airplane—with little time to consult emergency checklists. The report indicated that, although pilots are trained for emergency and abnormal situations, it is not possible to train for all possible contingencies. Further, although training under AQP provides operators with greater flexibility than guidance provided under Part 121 regulations, operators are faced with time and financial constraints limiting the "range and depth" of the emergencies trained to those that are most common and for which the checklist procedures work as expected. The report also pointed out that, although simulators have a limited ability to replicate real-world emergency and abnormal situations and demands, training for these situations does benefit pilots. The NASA report noted that a review of voluntary reports filed on the Aviation Safety Reporting System (ASRS) indicated that over 86 percent of "textbook emergencies" (those emergencies for which a good checklist exists) were handled well by flight crews and that only about 7 percent of nontextbook emergencies were handled well by flight crews.

The NASA report also addressed the design of emergency and abnormal situations checklists and procedures. The report noted that, although checklists and procedures cannot possibly be developed for all possible contingencies, checklists should be developed for emergency and abnormal situations "for all phases of flight in which they might be needed." Further, the report stated that, when designing checklists and procedures for emergency and abnormal situations, attention should be paid to the wording, organization, and structure to ensure that the checklists and procedures are easy to use, clear, and complete. The report also indicates that, because attention narrows during emergency and abnormal situations due to increased workload and stress, checklists and procedures should minimize the memory load on flight crews and that some airlines and manufacturers have reduced the number of items that have to be memorized by the flight crew (memory items). In addition, because flight crews have limited opportunities to practice abnormal situations, performing the appropriate procedures requires greater effort and concentration. Finally, flight crewmembers' attention can become narrowed, causing them to become cognitively rigid, which can reduce their ability to analyze and resolve the situation.

1.18.6 Cold-Water Immersion Information

The risks to people who are exposed to cold water are fairly well documented and understood. For example, a 2002 U.S. Army publication[128] stated the following:

[127] See B.K. Burian, I. Barshi, and K. Dismukes, *The Challenge of Aviation Emergency and Abnormal Situations*, NASA Technical Memorandum 2005-213462 (Moffett Field, California: National Aeronautics and Space Administration, 2005).

[128] See L.E. Wittmers, M.D., PhD. and M.V. Savage, *Medical Aspects of Harsh Environment,* vol. 1 (Falls Church, Virginia: Office of the Surgeon General, Department of the Army, 2002), pp. 531–552. The report

> the initial response to immersion (stage 1) has a respiratory and cardiovascular component. Respirations may become uncontrolled, with reflex gasping and hyperventilation. This panic response will decrease the breath-holding time and may lead to aspiration with subsequent drowning.

A February 2008 North Atlantic Treaty Organization Research and Technology Organization publication stated that the initial cold shock response "kills within 3-5 minutes" and that "death from cold shock is not uncommon."[129] In addition, a 2003 Transport Canada publication indicated, "it has now become clear that over half of immersion-related deaths occur during the first two stages of immersion, i.e. cold shock and swimming failure."[130] The report stated that, generally, cold-shock deaths occurred between 3 and 5 minutes, and swimming-failure deaths occurred between 5 and 30 minutes.[131] The report indicated that, during the first 10 to 15 minutes of immersion, "the cold water renders the limbs useless, and particularly the hands. It can become impossible to carry out any self-rescue procedure." The report concluded, "wherever possible, entry into water below 15°C [59° F] should be avoided. Direct entry into a life raft should be the objective."

described the four stages of cold-water immersion as follows: Stage 1: Initial immersion (0 to 3 minutes), Stage 2: Short-term immersion (3 to 15 minutes), Stage 3: Long-term immersion (greater than or equal to 30 minutes), and Stage 4: Postimmersion (core [rectal] temperature may fall, but after the incident).

[129] See M.J. Tipton and C.J. Brooks, "The Dangers of Sudden Immersion in Cold Water," *Survival at Sea for Mariners, Aviators and Search and Rescue Personnel,* RTO-AG-HFM-152 (Brussels, Belgium: North Atlantic Treaty Organization Research and Technology Organization, 2008), pp 3-1–3-10.

[130] See *Survival in Cold Waters: Staying Alive*, Transport Canada Report TP13822E (Ottawa, Ontario, Canada: Transport Canada, 2003).

[131] These deaths are often listed by medical examiners as hypothermia-related; however, hypothermic (core temperature drop) effects do not usually begin until after 30 minutes and are heavily dependent on an individual's unique characteristics (for example, age, height, weight, body fat percentage, and clothing).

2. Analysis

2.1 General

The flight and cabin crewmembers were properly certificated and qualified under federal regulations. No evidence indicated any preexisting medical or physical condition that might have adversely affected the flight crew's performance during the accident flight.

The accident airplane was equipped, dispatched, and maintained in accordance with federal regulations.

The LGA departure controller chose to display only correlated targets on his radar display. If he had chosen to display both the correlated and uncorrelated targets, he would not have been able to effectively control traffic because a large amount of extraneous information would have been shown on the display. Additionally, he would not have been able to determine whether the additional targets were birds, boats, precipitation, or any other item the radar detected. Therefore, the NTSB concludes that the LGA departure controller's decision to display only correlated primary radar targets on his radar display was appropriate.

Examinations of the recovered components revealed no evidence of any preexisting engine, system, or structural failures. The airplane met the structural ditching certification regulations in effect at the time of its certification, and the engine met the bird-ingestion certification regulations in effect at the time of its certification, as well as an anticipated additional regulation that it was not required to meet at that time.

The investigation determined that the airplane's descent rate at the time it impacted the water was 12.5 fps, more than three times the descent rate of 3.5 fps assumed during ditching certification, resulting in external pressures on the aft fuselage, primarily from FR55 to FR70, which significantly exceeded the values established to demonstrate compliance with the certification criteria. These external pressures were sufficient to cause the large-scale collapse and failure of the aft fuselage frames, cargo floor, and passenger floor struts and to initiate cracking of the lower fuselage skin, allowing water to enter the airplane. Further, the water ingress and continued forward motion of the airplane through the water resulted in postimpact pressures and suction forces that caused additional damage, including the failure of the lower fuselage skin panel and aft pressure bulkhead. Therefore, the NTSB concludes that the airframe damage was caused by the high-energy impact at the aft fuselage and the ensuing forward motion of the airplane through the water.

The term, "ditching," is not defined in federal regulations. The NTSB addressed this issue previously in its Safety Study 85/02, "Air Carrier Overwater Emergency Equipment and Procedures," which stated the following:

> [ditching] usually means a planned water event in which the flight crew, with the aircraft under control, knowingly attempts to land in water. In contrast to an inadvertent water impact, in which there is no time for passenger or crew preparation, ditching allows some time for donning life preservers, etc.

The NTSB considers this accident to be a ditching because the pilots clearly intended to ditch on the Hudson River. The accident event falls between a planned and unplanned event in that, although the pilots did not have time to complete each step of the applicable checklist, they did have sufficient time to consult the QRH, begin checklist execution, transmit radio calls, determine a landing strategy, configure the airplane for the ditching, and alert the flight attendants and passengers to "brace for impact."

Although the airplane impacted the water at a descent rate that exceeded the Airbus ditching parameter of 3.5 fps, postaccident ditching simulation results indicated that, during an actual ditching without engine power, the average pilot will not likely ditch the airplane within all of the Airbus ditching parameters because it is exceptionally difficult for pilots to meet such precise criteria with no power. Further, the water swell tests conducted on Mercure airplanes indicated that, even with engine power, water swells and/or high winds also make it difficult for pilots to safely ditch an airplane, and these factors were not taken into account during certification. (See section 2.6 for a more detailed discussion of this issue.)

Although both engines experienced an almost total loss of thrust after the bird encounter, the flight crew was able to ditch the airplane on the Hudson River, resulting in very few serious injuries and no fatalities. Further, all of the airplane occupants evacuated the airplane and were subsequently rescued. Consequently, this accident has been portrayed as a "successful" ditching. However, the investigation revealed that the success of this ditching mostly resulted from a series of fortuitous circumstances, including that the ditching occurred in good visibility conditions on calm water and was executed by a very experienced flight crew; that the airplane was EOW equipped even though it was not required to be so equipped for this particular flight; and that the airplane was ditched near vessels immediately available to rescue the passengers and crewmembers. The investigation revealed several areas where safety improvements are needed.

The analysis discusses the flight crew performance and safety issues related to the following: in-flight engine diagnostics, engine bird-ingestion certification testing, emergency and abnormal checklist design, dual-engine failure and ditching training, training on the effects of flight envelope limitations on airplane response to pilot inputs, validation of operational procedures and requirements for airplane ditching certification; and wildlife hazard mitigation. Also analyzed are survival-related issues, including passenger brace positions; slide/raft stowage; passenger immersion protection; life line usage; life vest stowage, retrieval, and donning; preflight safety briefings, and passenger education.

2.2 Engine Analysis

2.2.1 General

FDR data indicated that, during ground operation and takeoff, the N1 and N2 speeds of both engines accelerated in unison during the throttle advancement to full takeoff power and that these speeds were similarly matched and stable during takeoff and initial climb until about 1 minute 37 seconds into the flight. Although the right engine had recently experienced an engine compressor stall, US Airways had corrected the problem in accordance with maintenance manual practices, and no FDR evidence indicated that a compressor stall occurred before the bird encounter.

2.2.2 Identification of Ingested Birds

The Smithsonian Institution analyzed the feather and tissue samples from both engines and determined that the left engine contained both male and female Canada geese remains, indicating that the engine ingested at least two geese. (The average weight of a male Canada goose is from 8.4 to 9.2 pounds, and the average weight of a female goose is from 7.3 to 7.8 pounds.) The Smithsonian Institution report stated that only male Canada goose remains were found in the right engine, suggesting that it might have only ingested one bird; however, a comparison of the physical features and quantity of the damage in the two engines, which will be discussed in the following sections, indicated that the right engine ingested at least two Canada geese.[132]

2.2.3 Engine Damage

The engines were certificated to withstand the ingestion of birds of a specified weight in accordance with the certification standards and still produce sufficient power to sustain flight. (The certification requirements are discussed in section 2.2.5.) However, during this event, each engine ingested at least two Canada geese weighing about 8 pounds each, which significantly exceeded the certification standards, and neither engine was able to produce sufficient power to sustain flight after ingesting these birds. This section will discuss the progression of the damage to the engine parts, starting with the engine spinners and moving to the cores, to explain at which point in the bird-ingestion sequence the damage occurred that prevented the production of sufficient power to sustain flight.

[132] Currently, the Smithsonian Institution is unable to discriminate between multiple birds within the same species, sex, and maturity level. A more detailed DNA analysis completed in February 2010 was unable to verify whether more than one male goose was ingested into the right engine.

2.2.3.1 Engine Spinner, Fan Blade, and Fan Inlet Case Damage

If a bird enters the engine inlet near the inner radius (near the spinner), a portion of it may be ingested by the engine core because of the radius' proximity to the core. Both engine spinners on the accident airplane exhibited soft-body impact damage, indicating that both engines ingested a bird very near the inner radius of the engine inlet and that some of that bird mass entered the engine core. Although all of the left and right engine fan blades were present and intact, three of the left engine fan blades and five of the right engine fan blades exhibited damage indicating that both engines ingested a second bird near the fan midspan, but, because it was ingested near the edge of the fan blades, none of that bird mass entered the core.

When a turbofan engine ingests birds and no fan blades are fractured, the damage to the fan blades is generally localized because the bird will affect only those fan blades that actually impact or slice it as it passes through the fan plane. The number of fan blades affected by the impact is determined by the bird size, the relative bird velocity with respect to the airplane, the rotational fan speed, and the bird-impact angle. As the fan blades impact and slice the bird, the impact forces against the fan blades can be high enough to permanently deform and twist them as they bend and vibrate in response to the impact. Although the fan blades of both engines showed evidence of bird ingestion and subsequent mechanical damage, as noted, no significant fan blade damage or fractures were found.

Gouging was found on both engines' forward acoustical panels in the fan inlet case. Turbofan engine fan blades are designed to accelerate only compressible materials, such as air. When rotating fan blades contact a denser, noncompressible material, such as water, they will "bite" into the water, which will cause the blades to bend forward and cause gouging. Therefore, the fan rotors of both engines were rotating upon water impact.

2.2.3.2 Engine Core Damage

Because the fan spins rapidly, the fan blades protect the engine core by centrifugally slinging foreign objects outward into the bypass duct; therefore, most foreign objects that enter the engine inlet strike the fan blades and exit through the bypass duct, causing only fan blade damage. The spinner shape is also designed to deflect foreign objects outward to the bypass duct. However, only foreign objects of a limited size and consistency can be centrifuged or deflected from the engine's core.

Disassembly and examination of the engines revealed that two LPC IGVs in each engine had fractured because of the bird ingestion and were subsequently ingested into the engine cores, where they initiated secondary damage to the LPC and HPC. Immediately thereafter, the engine cores were incapable of supplying power to the fans; therefore, the fans could no longer rotate and produce sufficient thrust to sustain flight.

In addition, damage to the left engine HPC VGVs resulted in the blockage of most of the airflow through the compressor. The insufficient airflow into the combustor to cool the engine and through the LPT to drive the fan resulted in the loss of left engine power. Although the airflow was not blocked in the right engine as it was in the left engine, the destruction of all of the HPC VGVs and the fracture of several compressor blades caused the loss of directional control of the airflow into the compressor, causing it to stall continuously, with no recovery possible, and, eventually, to lose power.

In summary, the NTSB concludes that both engines were operating normally until they each ingested at least two large birds (weighing about 8 pounds each), one of which was ingested into each engine core, causing mechanical damage that prevented the engines from being able to provide sufficient thrust to sustain flight.

2.2.4 In-Flight Engine Problem Diagnostics

FDR data indicated that, although the engine power and fuel flow decreased immediately after the bird ingestion, both engines' LPC spools continued to rotate, and no loss of combustion occurred. According to FDR and CVR data, after the bird ingestion, the first officer followed the Engine Dual Failure checklist and spent about 30 to 40 seconds trying to relight the engines; however, since engine combustion was not lost, these attempts were ineffective in that they would not fix the problem, and the N_2 speeds could not increase during the remainder of the flight. The flight crew was unaware that the extent and type of the engine damage precluded any pilot action from returning them to operational status. If the flight crewmembers had known this, they could have proceeded to other critical tasks, such as completing only the Engine Dual Failure checklist items applicable to the situation. (See section 2.3.1 for information about the Engine Dual Failure checklist and the flight crew's accomplishment of it.)

The NTSB notes that it is unreasonable to expect pilots to properly diagnose complex engine problems and take appropriate corrective actions while they are encountering an emergency condition under critical time constraints. Many modern engines are equipped with engine sensors and full-authority digital engine controls (FADEC) that can be programmed to advise pilots about the status of an engine so that they can respond better to engine failures.

However, currently, no commercially available engines have diagnostic capabilities to identify the type of engine damage (sensors and FADECs can only identify that a problem exists) and recommend mitigating or corrective actions to pilots; yet, work has been performed to develop this technology for both military and civilian applications. For example, in 1998, the Department of the Navy, in conjunction with industry and the FAA, initiated the Survivable Engine Control Algorithm Development project, which was tasked, in part, to develop technology that would inform flight crews about an engine's condition following foreign-object or bird ingestion that resulted in engine gas path damage. The intent was to use existing engine sensors to define the type of engine damage and then apply appropriate mitigation through changing control schedules within the FADEC. Although a successful demonstration of this technology was conducted on the U.S. Navy's GE F414 turbofan engine, the project was terminated because of a lack of funding. In 2007, similar work was conducted on the GE T700 turboshaft engine; however, this project was also terminated before it was completed because of funding shortfalls.

Commercial applications for this type of technology were investigated in 2002 by NASA's Aviation Safety and Security Program, which initiated the CEDAR (Commercial Engine Damage Assessment and Reconfiguration) project using a GE CF6-80C2 engine to develop damage detection algorithms. Again, initial efforts were terminated because of a lack of funding and shifted priorities.

The NTSB concludes that, if the accident engines' electronic control system had been capable of informing the flight crewmembers about the continuing operational status of the engines, they would have been aware that thrust could not be restored and would not have spent valuable time trying to relight the engines, which were too damaged for any pilot action to make operational. Therefore, the NTSB recommends that the FAA work with the military, manufacturers, and NASA to complete the development of a technology capable of informing pilots about the continuing operational status of an engine. The NTSB further recommends that, once the development of the engine technology has been completed, as asked for in Safety Recommendation A-10-62, the FAA require the implementation of the technology on transport-category airplane engines equipped with FADECs.

2.2.5 CFM 56-5B4/P Bird-Ingestion Certification Tests

Each accident engine ingested one 8-pound bird into its core, preventing the engines from providing sufficient thrust to sustain flight, indicating that an engine of this size cannot withstand the ingestion of such a large bird into the core and continue to operate. Further, informal discussions with industry and the FAA revealed that it would not be practical to build an engine that could withstand ingesting a bird of this size into the core because of performance and weight penalties that such a design would entail. These discussions also revealed that ingesting one 2 1/2-pound bird into the engine core, which is the current engine core ingestion test requirement, is already considered a stringent test of the engine core.

The NTSB concludes that the size and number of the birds ingested by the accident engines well exceeded the current bird-ingestion certification standards.

The accident event highlighted other considerations that could be addressed during the tests related to small, medium, and large flocking birds. These considerations are discussed below.

The test requirements contained in 14 CFR 33.76(c) for the ingestion of small and medium flocking birds require that, for an engine of this size, one 2 1/2-pound bird be volleyed into the core and four 1 1/2-pound birds be volleyed at other locations on the fan disk. Each accident engine ingested one 8-pound Canada goose through to its core, much more than the weight used in the current certification tests; therefore, the accident engines sustained a significantly greater impact force than that for which they were certificated. FDR data indicated that the fan speed of both engines just before the bird ingestion was only about 80 percent, which is consistent for the airplane and atmospheric conditions at that point in the flight and is well below the bird-ingestion test fan-speed requirement of 100 percent.

Current Section 33.76(c) small- and medium-flocking-bird certification tests require that 100-percent fan speed be used; this condition involves the highest kinetic energy of the bird relative to the fan blade, which is likely the most critical condition for damage to the fan blade itself. However, an additional consideration for the severity of a core ingestion event is the volume or bird mass. Therefore, the lowest operational fan speed should be used during the tests related to small, and medium, flocking birds so that a larger portion of the bird mass passes through the fan blades. Additionally, a slower fan speed would cause less centrifuging of the bird mass as it passes through the fan, which would allow a larger portion of the bird mass to pass through to the IGVs and other core components, causing higher impact forces on them. Reducing the fan speed during the certification tests to that expected during takeoff conditions would allow more bird mass to enter the engine core.

The NTSB concludes that the current small and medium flocking bird tests required by 14 CFR 33.76(c) would provide a more stringent test of the turbofan engine core resistance to bird ingestion if the lowest expected fan speed for the minimum climb rate were used instead of 100-percent fan speed because it would allow a larger portion of the bird mass to enter the engine core. Therefore, the NTSB recommends that the FAA modify the 14 CFR 33.76(c) small and medium flocking bird certification test standard to require that the test be conducted using the lowest expected fan speed, instead of 100-percent fan speed, for the minimum climb rate. Further, the NTSB recommends that EASA modify the small and medium flocking bird certification test standard in JAR-E to require that the test be conducted using the lowest expected fan speed, instead of 100-percent fan speed, for the minimum climb rate.

Current Section 33.76(d) large flocking bird certification tests require the ingestion of one large flocking bird. However, during this test, the bird is not directed into the core; therefore, only the fan blades, flammable fluid lines, and support structure are tested. Further, the test is limited to engines with inlet areas greater than 3,875 square inches; smaller transport-category airplane engines, such as the CFM56-5B4/P, with an inlet area of 3,077 square inches, are exempt from this test. The evidence from this accident shows that large flocking birds can be ingested into smaller transport-category airplane engines and pose a threat to the engine core as well as the fan blades; however, the large flocking bird tests are not required as part of the certification process for this size engine.

The NTSB concludes that additional considerations need to be addressed related to the current 14 CFR 33.76(d) large flocking bird certification test standards because they do not require large flocking bird tests on smaller transport-category airplane engines, such as the accident engine, or a test of the engine core; the circumstances of the accident demonstrate that large birds can be ingested into the core of small engines and cause significant damage. The NTSB notes that the FAA engine and propeller directorate, jointly with EASA, initiated a reevaluation of the existing engine bird-ingestion certification regulations by tasking a working group to update the BRDB to include events through the end of 2008. Once the BRDB update is completed, the group is expected to perform a statistical analysis of the raw data and evaluate whether the current regulations still meet FAA and EASA safety objectives and whether additional actions or rule changes are necessary. Therefore, the NTSB recommends that, during the BRDB working group's reevaluation of the current engine bird-ingestion certification regulations, the FAA specifically reevaluate the 14 CFR 33.76(d) large flocking bird certification test standards to determine whether they should 1) apply to engines with an inlet area of less than 3,875 square inches and 2) include a requirement for engine core ingestion. If the BRDB working group's reevaluation determines that such requirements are needed, incorporate them into 14 CFR 33.76(d) and require that newly certificated engines be designed and tested to these requirements. Further, the NTSB recommends that, during the BRDB working group's reevaluation of the current engine bird-ingestion certification regulations, the EASA specifically reevaluate the JAR-E large flocking bird certification test standards to determine whether they should 1) apply to engines with an inlet area of less than 3,875 square inches and 2) include a requirement for engine core ingestion. If the BRDB working group's reevaluation determines that such requirements are needed, incorporate them into JAR-E and require that newly certificated engines be designed and tested to these requirements.

2.2.6 Bird-Ingestion Protection Devices for Engines

Engine design changes and protective screens have been used or considered in some engine and aircraft designs. For example, certain small turbofan engines, such as the GE CF-34 and some later model Honeywell TFE-731s, incorporate a hidden- or partially hidden-core inlet. The hidden-core inlet design hides the IGVs behind the fan hub rather than placing them directly into the airflow path; thus, all foreign objects pass over the IGVs into the bypass duct and cannot be ingested into the core. However, the hidden-core inlet design results in significant design compromises that increase as the size of the engine increases. The design requires that the engine be longer and heavier because the core inlet duct must be longer to direct the airflow into the core without separation from the duct walls and because the structure, bearings, and shafts must be lengthened. Additionally, the associated engine attachment structure and the airplane structure itself must be strengthened to account for the weight increase, resulting in an increase in fuel consumption. Another compromise the design creates is a nonoptimum relight envelope, which requires that the aircraft be put into a steep dive, an undesirable behavior in a passenger aircraft, to build up sufficient static pressure in the inlet to maintain engine core rotation for a successful emergency relight.

In addition, protective screens are currently used on some modern turbopropeller airplanes and on some turboshaft helicopter engines; however, the type of protective device used on these engines cannot be incorporated into turbofan engines because of the engine construction layout. No manufacturers have developed an inlet screen to protect turbofan engines, such as the accident engine, from bird ingestion. Several technical issues related to performance, weight, and reliability must be considered to determine whether protective screens can be used effectively and safely on turbofan engines, and these issues are summarized as follows:

Impact on engine performance. Screens can block, impede, or distort the airflow just in front of the engine, negatively impacting engine performance and exhaust emissions. Screens can cause erratic engine behavior in crosswind or gusty conditions, increasing the likelihood of a stall.

Impact on in-flight restart envelope. Screens can require a higher airplane restart airspeed to reach the desired engine windmilling rotor speeds, which reduces the restart envelope of the airplane.

Impact of vibration stresses. Screens can disturb the upstream airflow into the engine and induce airflow oscillation, resulting in high airfoil vibrations within the engine and causing premature fatigue and fracture of the fan blades or other airfoils in the engine.

Impact of icing behavior. Screens can accrete ice very easily when they pass through a moist, cool atmosphere. Unless the screens are electrically heated to prevent ice formation, a high risk of screen ice blockage exists. The heat required to deice a screen in extreme icing conditions would require additional generator capacity and large, heavy electrical hardware to deal with the extra power requirements.

Impact of screen and additional structural weight. During informal discussions with engineers from Honeywell and Boeing, it was estimated that the addition of a screen, support structure, electrical harness, and generator would add at least 1,000 pounds per engine installation. Further, the size of the pylon and wing structure would also need to be increased to accommodate the additional weight of the engine, resulting in even more weight being added to the airframe to structurally accommodate an inlet screen.

Screen failure. The reliability of any component can never be 100 percent; therefore, the risk of a screen failure and its subsequent ingestion in the engine inlet must be considered in any design. If a screen were ingested into the engine, it could cause more damage than bird ingestion, leading to a catastrophic engine failure. Damage to the flight control surfaces on the wing or rudder/stabilizer is also a possible hazard.

The NTSB concludes that, although engine design changes and protective screens have been used or considered in some engine and aircraft designs as a means to protect against bird ingestion, neither option has been found to be viable on turbofan engines like the accident engine.

2.3 Flight Crew Performance

2.3.1 Decision to Use Engine Dual Failure Checklist

At 1527:23, about 12 seconds after the bird strike, the captain took control of the airplane. Five seconds later, the captain called for the QRH Engine Dual Failure checklist, and the first officer complied. Even though the engines did not experience a total loss of thrust, the Engine Dual Failure checklist was the most applicable checklist contained in the US Airways QRH, which was developed in accordance with the Airbus QRH, to address the accident event because it was the only checklist that contained guidance to follow if an engine restart was not possible and if a forced landing or ditching was anticipated (starting from 3,000 feet). However, according to postaccident interviews and CVR data, the flight crew did not complete the Engine Dual Failure checklist, which had 3 parts and was 3 pages long. Although the flight crewmembers were able to complete most of part 1 of the checklist, they were not able to start parts 2 and 3 of the checklist because of the airplane's low altitude and the limited time available.

The Engine Dual Failure checklist was designed assuming that a dual-engine failure occurred at a high altitude (above 20,000 feet). According to Airbus, the checklist was so designed because most Airbus operations were at high altitude, and, therefore, a dual-engine failure would most likely occur at altitudes above 20,000 feet. Airbus had not considered developing a checklist for use at a low altitude, when limited time is available before ground or water impact. Discussions with A320 operators and a manufacturer also indicated that low-altitude, dual-engine failure checklists are not readily available in the industry.

In 2005, Airbus amended the Engine Dual Failure checklist by including two parallel steps, one for a fuel remaining scenario that included steps to attempt to relight an engine and one for a no fuel remaining scenario that did not include steps to attempt to relight an engine, and by incorporating the ditching procedures, which had previously been located in a separate checklist. Although the amendment allowed pilots to use one checklist, instead of several, for a dual-engine failure, it resulted in a lengthy checklist.

As noted, the Engine Dual Failure checklist did not fully apply to a low-altitude, dual-engine failure and was unduly long for such an event given the limited time available. In fact, the first officer spent about 30 to 40 seconds attempting to relight the engines (as indicated in part 1 of the checklist) because he did not know the extent of the engine damage. Further, the flight crew never reached the ditching portion of the checklist, which most directly applied to the accident situation. A checklist for a dual-engine failure or other abnormal event occurring at a low altitude would increase the chances of a successful ditching and omit many of the steps that took up the flight crew's limited time.

The NTSB concludes that, although the Engine Dual Failure checklist did not fully apply to the accident event, it was the most applicable checklist contained in the QRH to address the event and that the flight crew's decision to use this checklist was in accordance with US Airways procedures. The NTSB further concludes that, if a checklist that addressed a dual-engine failure occurring at a low altitude had been available to the flight crewmembers, they would have been more likely to have completed that checklist. This accident demonstrates that abnormal events, including a dual-engine failure, can occur at a low altitude and, therefore, that a checklist is clearly needed to address such situations. Therefore, the NTSB recommends that the FAA require manufacturers of turbine-powered aircraft to develop a checklist and procedure for a dual-engine failure occurring at a low altitude. Further, the NTSB recommends that EASA require manufacturers of turbine-powered aircraft to develop a checklist and procedure for a dual-engine failure occurring at a low altitude. In addition, the NTSB recommends that, once the development of the checklist and procedure for a dual-engine failure occurring at a low altitude has been completed, as asked for in Safety Recommendation A-10-66, require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators of turbine-powered aircraft to implement the checklist and procedure.

Although the flight crew was only able to complete about one-third of the Engine Dual Failure checklist, immediately after the bird strike, the captain did accomplish one critical item that the flight crew did not reach in the checklist: starting the APU. Starting the APU early in the accident sequence proved to be critical because it improved the outcome of the ditching by ensuring that electrical power was available to the airplane. Further, if the captain had not started the APU, the airplane would not have remained in normal law mode. This critical step would not have been completed if the flight crew had simply followed the order of the items in the checklist.

The NTSB concludes that, despite being unable to complete the Engine Dual Failure checklist, the captain started the APU, which improved the outcome of the ditching by ensuring that a primary source of electrical power was available to the airplane and that the airplane remained in normal law and maintained the flight envelope protections, one of which protects against a stall.

2.3.2 Decision to Ditch on the Hudson River

At the time of the bird strike, the airplane was about 4.5 miles north-northwest of the approach end of runway 22 at LGA and about 9.5 miles east-northeast of the approach end of runway 24 at TEB. During postaccident interviews, both pilots indicated that they thought the Hudson River was the best and safest landing option given the airplane's airspeed, altitude, and position.

About 1 minute after the bird strike, it was evident to the flight crew that landing at an airport may not be an option, and, at 1528:11, the captain reported to ATC that he did not think they would be able to land at LGA and that they might end up in the Hudson. At 1529:25, the captain told ATC that they would also be unable to land at TEB. Three seconds later, he stated to ATC that the airplane was going to be in the Hudson. During postaccident interviews, the captain stated that, "due to the surrounding area," returning to LGA would have been problematic and that it would not have been a realistic choice. He further stated that, once a turn to LGA was made, "it would have been an irrevocable choice, eliminating all other options," and that TEB "was too far away." The NTSB notes that a direct return to LGA would have required crossing Manhattan, a highly populated area, and putting people on the ground at risk.

Simulation flights were run to determine whether the accident flight could have landed successfully at LGA or TEB following the bird strike. The simulations demonstrated that, to accomplish a successful flight to either airport, the airplane would have to have been turned toward the airport immediately after the bird strike. The immediate turn did not reflect or account for real-world considerations, such as the time delay required to recognize the extent of the engine thrust loss and decide on a course of action. The one simulator flight that took into account real-world considerations (a return to LGA runway 13 was attempted after a 35-second delay) was not successful. Therefore, the NTSB concludes that the captain's decision to ditch on the Hudson River rather than attempting to land at an airport provided the highest probability that the accident would be survivable.

2.3.3 Descent and Ditching Airspeed

As noted, the flight crew was not able to initiate part 2 of the Engine Dual Failure checklist, which contained airspeed guidance for pilots to follow if an engine restart is considered impossible and a ditching is anticipated. The checklist states that, when an engine restart is considered impossible, the optimum airspeed at which to fly is the green dot speed.

Despite not reaching this portion of the Engine Dual Failure checklist, the captain stated during postaccident interviews that he thought that he had obtained green dot speed immediately after the bird strike, maintained that speed until the airplane was configured for landing, and, after deploying the flaps, maintained a speed "safely above V_{LS}," which is the lowest selectable airspeed providing an appropriate margin to the stall speed. However, FDR data indicated that the airplane was below green dot speed and at V_{LS} or slightly less for most of the descent, and about 15 to 19 knots below V_{LS} during the last 200 feet.

The NTSB concludes that the captain's difficulty maintaining his intended airspeed during the final approach resulted in high AOAs, which contributed to the difficulties in flaring the airplane, the high descent rate at touchdown, and the fuselage damage. (See additional discussion in section 2.7.1.)

During emergency situations, such as the accident event, pilots experience high levels of stress resulting from high workload, time pressure, and noise. Stress can distract pilots from cockpit duties and result in pilot errors or performance degradation.[133] For example, stress can lead to a phenomenon known as "tunnel vision," or the narrowing of attention in which simple things can be overlooked (for example, airspeed and descent rate) and an individual focuses on a

[133] See, for example, (a) K. Dismukes, G. Young, and R. Sumwalt, "Cockpit Interruptions and Distractions," *ASRS Directline*, vol. 10 (1998), pp. 4-9. (b) B.K. Burian, I. Barshi, and K. Dismukes.

narrow piece of information perceived to be most threatening or salient (for example, surrounding terrain and a suitable landing location).[134] During the emergency, the flight crew was faced with a series of GPWS and TCAS aural alerts and many ATC communications, which can also present distractions during an emergency. Further, during postaccident interviews, the captain stated that, during the emergency situation, time was very compressed and that, because he was intensely focused on maintaining a successful flightpath, his attention was narrowed.

To alleviate a pilot being overloaded by aural warnings, Airbus designed alert prioritizations to determine when cues are made available to pilots. However, in this accident, the low-speed warning was inhibited by the GPWS warnings, so that the flight crew was not made aware of the low-speed state. (See section 2.6.1.) Although a visual low-speed indication was available on the airspeed tape, the NTSB acknowledges that the flight crewmembers were overloaded with other visual cues (for example, engine parameters and outside visual references, such as buildings and bridges), which might have affected their ability to continuously monitor the airspeed tape. When the airspeed is high enough, such as the airspeed recommended in the QRH, the AOA never reaches the flight envelope protection activation threshold.

The NTSB concludes the captain's difficulty maintaining his intended airspeed during the final approach resulted, in part, from high workload, stress, and task saturation.

2.3.4 Decision to Use Flaps 2 for Ditching

The Airbus and US Airways engine dual failure checklists indicated that only blue hydraulic power would be available and, therefore, that only slats would extend when configuring for landing. Although the dual-engine failure certification assessed this worst-case scenario, the possibility of having green and yellow hydraulic systems available was also considered. FDR data indicated that, during the accident event, all three (green, blue, and yellow) hydraulic systems were available and that the flight crew was able to extend flaps and slats. In the accident scenario, the NTSB notes that the selection of flaps 3 would have allowed the airplane to fly at a lower airspeed.

At 1529:45, when the airplane was at an altitude of about 270 feet, the captain instructed the first officer to set the flaps. The first officer then stated that they were at flaps 2 and asked the captain if he "want[ed] more?" The captain replied, "no, let's stay at 2." About 1 minute later, the airplane was ditched on the Hudson River.

During postaccident interviews, the captain stated that he used flaps 2 because there were "operational advantages to using flaps 2." He stated that using flaps 3 would not have lowered the stall speed significantly and would have increased the drag. He stated that he was concerned about having enough energy to successfully flare the airplane and reduce the descent rate

[134] See C.D. Wickens, *Engineering Psychology and Human Performance,* 2nd ed. (New York, New York: Harper Collins, 1984).

sufficiently. He stated that, from his experience, using flaps 2 provides a slightly higher nose attitude and that he felt that, in the accident situation, flaps 2 was the optimum setting.

The NTSB concludes that the captain's decision to use flaps 2 for the ditching, based on his experience and perception of the situation, was reasonable and consistent with the limited civilian industry and military guidance that was available regarding forced landings of large aircraft without power.

2.3.5 CRM and TEM During the Accident Sequence

Both pilots indicated that CRM was integral to the success of the accident flight. The first officer stated that they each had specific roles, knew what each other was doing, and interacted when necessary. The captain indicated that, because of the time constraints, they could not discuss every part of the decision process; therefore, they had to listen to and observe each other. The captain further stated that they did not have time to consult all of the written guidance or complete the appropriate checklist, so he and the first officer had to work almost intuitively in a very close-knit fashion. For example, the captain stated that when he called for the QRH, about 17 seconds after the bird strike, the first officer already had the checklist out. The captain stated that the US Airways CRM and TEM training, which was integrated into all aspects of US Airways training, including ground school and flight training, gave pilots the skills and tools needed to build a team quickly, open lines of communication, share common goals, and work together.

CVR data indicate that the communication and coordination between the captain and first officer were excellent and professional after the bird strike. Further, the flight crew managed the workload by making only pertinent callouts to ATC and the cabin crew as time permitted. In addition, CVR data showed that each pilot adhered to his role and responsibilities during the accident sequence. The first officer progressed through the checklist while the captain was flying the airplane, communicating with ATC, and determining a suitable landing point. In addition, the captain used the first officer as a resource by requesting his input during the accident sequence.

The NTSB concludes that the professionalism of the flight crewmembers and their excellent CRM during the accident sequence contributed to their ability to maintain control of the airplane, configure it to the extent possible under the circumstances, and fly an approach that increased the survivability of the impact.

2.4 Abnormal and Emergency Events Checklist Design

NASA researchers have studied the difficulties inherent to designing checklists and procedures for emergency and abnormal situations. A 2005 NASA report noted that, although checklists and procedures cannot be developed for all possible contingencies, checklists should be developed for emergency and abnormal situations "for all phases of flight in which they might be needed."[135] Further, the report stated that emergency and abnormal checklists and procedures must include the necessary information and steps to respond appropriately and that, when designing checklists and procedures for emergency and abnormal situations, attention should be paid to the wording, organization, and structure of the checklists and procedures to ensure that they are easy to use, clear, and complete. The report also indicated that, because attention narrows during emergency and abnormal situations due to increased workload and stress, checklists and procedures should minimize the memory load on flight crews and that some airlines and manufacturers have reduced the number of memory items.

Accidents and incidents have shown that pilots can become so fixated on an emergency or abnormal situation that routine items (for example, configuring for landing) are overlooked.[136] For this reason, emergency and abnormal checklists often include reminders to pilots of items that may be forgotten. Additionally, pilots can lose their place in a checklist if they are required to alternate between various checklists or are distracted by other cockpit duties; however, as shown with the Engine Dual Failure checklist, combining checklists can result in lengthy procedures. Therefore, checklists should not be overly cumbersome but should still contain all of the critical items that must be accomplished and should not require pilots to rely heavily on memory items. Shorter checklists increase the likelihood that pilots can complete all pertinent items related to the emergency or abnormal situation without distracting them from other cockpit duties. Unfortunately, many checklists are designed such that pilots become "stuck" in the checklist and, therefore, complete procedures that may not be appropriate or practical for a given emergency (such as trying to restart engines). According to a NASA representative's public hearing testimony, to minimize the risk of becoming stuck in an inapplicable portion of a checklist, checklists can be designed to give pilots "opt out" points or "gates," which are conditional if-then statements. (For example, "if the aircraft is below 3,000 feet, then go to step 27.") Incorporating such points into checklists will encourage pilots to reevaluate the situation and determine whether they are using the appropriate checklist or portion of a checklist and whether the task focus should be shifted.

The NTSB notes that this is not the first accident in which checklist design was recognized as a safety issue. For example, after the September 2, 1998, Swissair flight 111 accident in which a seemingly innocuous smoke event evolved, after several minutes, into a sudden and severe in-flight fire, the Transportation Safety Board of Canada determined that the checklist that the flight crew attempted to use would have taken about 20 to 30 minutes to complete.[137] However, only 20 minutes elapsed from the time that the on-board fire was detected until the crash occurred. In late 2004, the Flight Safety Foundation began an international initiative, which included the participation of manufacturers, airlines, pilots, and government

[135] B.K. Burian, I. Barshi, and K. Dismukes.

[136] For examples of such accidents and incidents, see (a) *Wheels-Up Landing, Continental Flight 1943, Douglas DC-9-32, N10556, Houston, Texas, February 19, 1996,* Aircraft Accident Report NTSB/AAR-97/01 (Washington, DC: National Transportation Safety Board, 1997). (b) The reports for NTSB case numbers CHI94FA039 and DCA06MA009 are available online at <http://www.ntsb.gov/ntsb/query.asp>.

[137] See *In-Flight Fire Leading to Collision with Water, SwissAir Transport Limited, McDonnell Douglas MD-11, HB-IWF, Peggy's Cove, Nova Scotia, 5 nm SW, 2 September 1998,* Aviation Investigation Report A98H0003 (Quebec, Canada: Transportation Safety Board of Canada, 2003).

representatives, to improve checklist procedures for airline pilots confronting smoke, fire, or fumes when no alerts are annunciated in the cockpit. As a result of the initiative, the Flight Safety Foundation published a report containing a streamlined Smoke, Fire, and Fumes checklist template to standardize and optimize flight crew responses to such events and that included considerations for an immediate landing.[138] The NTSB believes that a similar initiative to improve other emergency and abnormal checklists is warranted.

The NTSB concludes that comprehensive guidelines on the best means to design and develop emergency and abnormal checklists would promote operational standardization and increase the likelihood of a successful outcome to such events. Therefore**,** the NTSB recommends that the FAA develop and validate comprehensive guidelines for emergency and abnormal checklist design and development. The guidelines should consider the order of critical items in the checklist (for example, starting the APU), the use of opt outs or gates to minimize the risk of flight crewmembers becoming stuck in an inappropriate checklist or portion of a checklist, the length of the checklist, the level of detail in the checklist, the time needed to complete the checklist, and the mental workload of the flight crew. The NTSB notes that, on March 16, 2010, the FAA published Information for Operators 10002SUP, "Industries Best Practices Reference List," which included resources for checklist design and use. The NTSB reviewed these resources and does not believe that they adequately address the issues described in this recommendation.

2.5 Pilot Training

2.5.1 Dual-Engine Failure Training

US Airways' dual-engine failure training, which was provided during initial training in a full-flight simulator session, was consistent with the training provided by Airbus. The dual-engine failure scenario was presented at 25,000 feet, included two engine restart attempts, and was considered complete after the restart of one engine, typically at an altitude from about 8,000 to 10,000 feet. During the training scenarios, at least one engine was always restarted; therefore, the pilots never reached the point of having to conduct a forced landing or ditching. No dual-engine failure training scenarios were presented at or near traffic pattern altitudes, and no scenarios were used to train pilots to conduct a possible ditching or forced landing. The scenarios were focused on restarting an engine in flight. Dual-engine failure scenarios were not presented during recurrent training.

During informal discussions, A320 operators indicated that their dual-engine failure training was conducted at high altitudes in accordance with Airbus recommendations and industry practices. The operators revealed that the training scenarios were intended to simulate a

[138] See "Flight Crew Procedures Streamlined for Smoke/Fire/Fumes," *Flight Safety Digest* (Alexandria, Virginia: Flight Safety Foundation, 2005), pp. 31–35.

high-altitude engine failure and train pilots on the available methods to restart an engine in flight, not to simulate a catastrophic engine failure for which a restart was unlikely. None of the contacted A320 operators included a dual-engine failure scenario at a low altitude in their training curricula. The A320 operators indicated that the training scenarios generally presented situations for which the course of action and landing location were clear and sufficient time was available to complete any required procedures before landing. The only low-altitude scenarios presented during training were single-engine failures at, or immediately after, takeoff. The A320 operators also indicated that dual-engine failure training was generally only provided during initial, not recurrent, training. The NTSB is concerned that pilots are not taught how to handle low-altitude abnormal events or to use critical thinking, task shedding, decision-making, and proper workload management to achieve a successful outcome when such events occur.

The NTSB concludes that training pilots how to respond to a dual-engine failure occurring at a low altitude would challenge them to use critical thinking and exercise skills in task shedding, decision-making, and proper workload management to achieve a successful outcome. The NTSB recommends that the FAA require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators to include a dual-engine failure scenario occurring at a low altitude in initial and recurrent ground and simulator training designed to improve pilots' critical-thinking, task-shedding, decision-making, and workload-management skills.

2.5.2 Ditching Training

US Airways provided ditching training during initial ground school. During the training, the QRH Ditching checklist, which assumes at least one engine is running, was reviewed. US Airways ditching training is similar to industry guidance on ditching, which focuses primarily on a high-altitude ditching for which sufficient time and altitude exists for the flight crew to prepare the airplane and its occupants. Further, during ditching training, power is available from at least one engine. The training also addressed atmospheric conditions, sea states, and recommended direction of landing, based on the direction of wind and water swells.

However, the training did not highlight the visual illusions that can be associated with landing on water, as noted by the accident captain during postaccident interviews when he stated that landing on water was more difficult than landing on a runway due to "a much more uniform visual field, less contrast, and fewer landmarks." Specifically, when ditching or making a forced landing on water, a pilot is susceptible to the height perception illusion (the pilot perceives a greater height above the terrain than actually exists because of a lack of contrast or visual references).[139]

[139] This information was obtained from <http://www.chinook-helicopter.com/standards/Illusions/Visual_Illusions.html> (accessed February 17, 2010) and from *Seaplane, Skiplane, and Float/Ski Equipped Helicopter Operations Handbook* FAA-H-8083-23, issued August 2004.

Further, US Airways and Airbus manuals contain very little guidance to pilots on flying techniques to use during a ditching to achieve recommended airplane attitude and airspeed at touchdown, with and without engine power. In fact, only the US Airways FOM TM included guidance for a ditching without engine power, and the guidance was not airplane specific. The NTSB notes that this guidance should also include the importance of maintaining a proper bank angle in addition to a proper attitude, airspeed, and descent rate. The NTSB is concerned that critical information about ditching techniques is not provided in industry guidance. Although the NTSB acknowledges that pilots are responsible for reading and familiarizing themselves with company manuals, it is unrealistic to expect them to recall the relevance of such critical information during an emergency without regular periodic reinforcement.

The NTSB concludes that the flight crewmembers would have been better prepared to ditch the airplane if they had received training and guidance about the visual illusions that can occur when landing on water and on approach and about touchdown techniques to use during a ditching, with and without engine power. The NTSB recommends that the FAA require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators to provide training and guidance to pilots that inform them about the visual illusions that can occur when landing on water and that include approach and touchdown techniques to use during a ditching, with and without engine power. The NTSB further recommends that the FAA work with the aviation industry to determine whether recommended practices and procedures need to be developed for pilots regarding forced landings without power both on water and land.

2.6 Operational Difficulties Not Factored Into Certification Tests

An FAA representative testified during the public hearing that operational procedures were evaluated during the A320 ditching certification process. These procedures, which were contained in the ditching portion of the Engine Dual Failure checklist, included touching down the airplane "with approximately 11° pitch and minimum aircraft vertical speed." However, with respect to validating checklist procedures, an FAA test pilot stated at the public hearing, "it's not necessarily an evaluation of the flying qualities of an airplane but an evaluation of the system characteristics in accomplishing each step to ensure that the system responds as it's expected to respond." Although airplane systems are evaluated to determine if they respond as expected, the operational procedures themselves and the ability of pilots to achieve the parameters are not. Because operational procedures and the ability of pilots to achieve the Airbus ditching parameters have not been tested, the assumption of a mostly intact fuselage when evaluating the "probable structural damage and leakage" resulting from a ditching, as required by Section 25.801(d), rests on an assertion that this condition can be reliably attained rather than on a demonstration or analysis to that effect.

Postaccident flight simulations indicated that attaining the Airbus ditching parameters without engine power is possible but highly unlikely without training. Further, attaining the parameters may not prevent a significant fuselage breach for a number of plausible conditions. The factors that increase the likelihood that, during an actual ditching, the touchdown criteria will not be met and that a significant fuselage breach will occur include the following:

- The analyses of the fuselage strength upon which the assumption of fuselage integrity is based may not consider ditching at heavy airplane weights, such as those pertaining to takeoff and climb.
- Different touchdown flight condition targets exist for ditching on flat water and on water with swells, but only the pitch angle target applicable to flat-water conditions is mentioned in guidance material available to pilots.
- Certain combinations of winds and sea swells require contradictory procedures, making a solution impossible in these cases.
- Deliberately or inadvertently slowing the airplane into the alpha-protection mode may result in an attenuation of pilot nose-up stick inputs, making it more difficult to flare the airplane, even if AOA margin to alpha maximum exists.
- Attaining the touchdown flight condition targets is an exceptionally difficult flight maneuver, and pilots cannot be expected to conduct the maneuver proficiently when the airplane has no engine power.
- Attaining the touchdown flight conditions at night or when other poor-visibility conditions exist would likely be very hard to accomplish given that, in a flight simulator in daylight conditions, the touchdown flight condition targets were only achieved once out of 12 attempts, even by pilots who were aware of the importance of maintaining sufficient airspeed, were fully expecting the dual-engine failure to occur, and knew that their failure to accomplish the maneuver would not be life-threatening.

Therefore, the NTSB concludes that the review and validation of the Airbus operational procedures conducted during the ditching certification process for the A320 airplane did not evaluate whether pilots could attain all of the Airbus ditching parameters nor was Airbus required to conduct such an evaluation. The NTSB further concludes that, during an actual ditching, it is possible but unlikely that pilots will be able to attain all of the Airbus ditching parameters because it is exceptionally difficult for pilots to meet such precise criteria when no engine power is available, and this difficulty contributed to the fuselage damage. (Section 2.10.3.1 discusses the relationship between the assumption that the fuselage will most likely significantly breach during a ditching and the need for the availability of survival equipment after such an event.) Therefore, the NTSB recommends that the FAA and EASA require applicants for aircraft certification to demonstrate that their ditching parameters can be attained without engine power by pilots without the use of exceptional skill or strength.

2.7 High-AOA-Related Issues

2.7.1 High-AOA and Low-Airspeed Awareness

Typically, pilots are made aware that an airplane has reached alpha-protection speed and that, therefore, the high-AOA protection has become active, by viewing a black and amber strip along the airspeed scale. Under normal circumstances, the black and amber strip is sufficient to alert pilots visually that they have entered alpha-protection mode. However, in emergency situations, when visual resources are overloaded, pilots may inadvertently overlook the airspeed tape. As noted, the airplane was flown at V_{LS} or slightly less for most of the descent. Maintaining a sufficiently higher airspeed makes it possible to maintain sufficient energy to significantly reduce the descent rate during the flare. The Airbus simulation indicated that the airplane performed as designed and was in the alpha-protection mode from 150 feet to touchdown. As discussed previously, the captain’s attention was narrowed, which would have made it difficult for him to maintain awareness of the airplane’s low-speed condition during the descent.

Although the A320 airplane does not provide tactile cues that a low-speed or -energy condition exists, it does have an aural speed warning, which repeats every 5 seconds and is available when the airplane is configured with full flaps, flaps 2, or flaps 3. However, the system is designed such that the warning is inhibited when the airplane is below 100 feet radio altitude or when a GPWS alert is triggered. The A320 was designed with an alert prioritization hierarchy that considered inputs from various airplane systems, including the GPWS, FWC, TCAS, and radar and the GPWS-triggered alerts had priority over a low-speed warning. CVR and FDR data indicated that 15 GPWS alerts were triggered during the descent from 300 feet to touchdown and that no low-speed aural alert was triggered during this time. Considering the alert prioritization hierarchy, low-speed warnings were likely inhibited by the GPWS alerts.

The US Airways and Airbus Ditching checklists included steps to select the GPWS and the terrain alerts to OFF to avoid nuisance warnings during final descent. The NTSB notes that, although the Engine Dual Failure checklist had been amended to incorporate the procedures for preparing and configuring the airplane for ditching, the ditching portion of the checklist did not include the step to select the GPWS system and terrain alerts to OFF. The NTSB acknowledges that the flight crew did not have sufficient time to accomplish the ditching portion of the Engine Dual Failure checklist. Regardless, the NTSB believes that the ditching procedures should be consistent in all applicable checklists.

The NTSB concludes that the guidance in the ditching portion of the Engine Dual Failure checklist is not consistent with the separate Ditching checklist, which includes a step to inhibit the GPWS and terrain alerts. Therefore, the NTSB recommends that the FAA require Airbus operators to amend the ditching portion of the Engine Dual Failure checklist and any other applicable checklists to include a step to select the GPWS and terrain alerts to OFF during the final descent.

2.7.2 High-AOA Envelope Limitations

The airplane’s airspeed in the last 150 feet of the descent was low enough to activate the alpha-protection mode of the airplane’s fly-by-wire envelope protection features. The captain progressively pulled aft on the sidestick as the airplane descended below 100 feet, and he pulled the sidestick to its aft stop in the last 50 feet, indicating that he was attempting to raise the airplane nose to flare and soften the touchdown on the water. The A320 alpha-protection mode incorporates features that can attenuate pilot sidestick pitch inputs. Because of these features, the airplane could not reach the maximum AOA attainable in pitch normal law for the airplane weight and configuration; however, the airplane did provide maximum performance for the weight and configuration at that time.

The Airbus simulation indicated that the captain's aft sidestick inputs in the last 50 feet of the flight were attenuated, limiting the ANU response of the airplane even though about 3.5° of margin existed between the airplane's AOA at touchdown (between 13° and 14°) and the maximum AOA for this airplane weight and configuration (17.5°). Airbus' training curricula does not contain information on the effects of alpha-protection mode features that might affect the airplane's response to pilot sidestick pitch inputs. The flight envelope protections allowed the captain to pull full aft on the sidestick without the risk of stalling the airplane.

The NTSB concludes that training pilots that sidestick inputs may be attenuated when the airplane is in the alpha-protection mode would provide them with a better understanding of how entering the alpha-protection mode may affect the pitch response of the airplane. The NTSB recommends that the FAA require Airbus operators to expand the AOA-protection envelope limitations ground-school training to inform pilots about alpha-protection mode features while in normal law that can affect the pitch response of the airplane.

2.8 Bird- and Other Wildlife-Strike Issues

2.8.1 Accident Bird-Strike Event

According to data from the FAA National Wildlife Strike Database, the accident was not a typical bird-strike event. Since 1960, 26 large-transport aircraft have been destroyed because of bird strikes worldwide, and 93 percent of these strikes occurred during takeoff or landing at an altitude of about 500 feet agl or less when the airplane was still near an airport. In contrast, the accident airplane struck birds at an altitude of about 2,800 feet agl about 4.3 miles from LGA, occurring at a higher altitude and further away from an airport than where most strikes occur.

According to the wildlife-strike data, the fewest bird strikes in the United States are reported in the winter months, including January, and, in the New York City area, January is 1 of 3 months with the historically lowest number of strikes involving Canada geese. Strike data for all wildlife species indicate that the second fewest bird strikes are reported in January. Therefore, the accident event occurred in a month not typically associated with high bird-strike probability.

The wildlife-strike data also indicate that, from 1990 to 2008, 3,239 turbine-powered civil aircraft sustained damage to a single engine as a result of a bird strike but that, during the same time period, 108 similar aircraft sustained damage to two engines. Therefore, the probability of incurring damage to one engine as a result of a bird strike is about 30 times greater than incurring damage to two engines.

Lastly, as of 2008, the U.S. population of migratory Canada geese was estimated to be about 1 million, and the U.S. population of resident Canada geese was estimated to be about 4 million. Therefore, the likelihood of an airplane striking a resident goose is substantially higher than striking a migratory goose. However, the Canada geese struck by the accident airplane were determined to be migratory geese by the Smithsonian Institute.

The NTSB concludes that this accident was not a typical bird-strike event; therefore, this accident demonstrates that a bird strike does not need to be typical to be hazardous.

2.8.2 Wildlife Hazard Mitigation at Part 139-Certificated Airports

The FAA has provided guidance material to airports for use in constructing, implementing, and evaluating WHMPs. In particular, the FAA recommends that airport operators follow the standards and practices contained in AC 150/5200-33B, which recommends that all airports consider wildlife attractants within 10,000 feet of the airport and, if the attractant could cause hazardous wildlife movement into or across the approach or departure airspace, out to 5 statute miles from the airport. The AC is intended to encourage airports to monitor and limit land-use activities near the airport that are attractive to wildlife. However, except for the habitat considerations referred to in the AC, an airport cannot monitor or control wildlife that enters the airspace around the airport at all altitudes. Although the accident bird strike occurred within a 5-mile radius of LGA, it occurred at an altitude of almost 3,000 feet.

During the investigation, LGA's WHMP was examined and determined to be in accordance with the requirements of 14 CFR 139.337. The NTSB notes that LGA routinely disperses, removes, or destroys birds found on or near the airfield and annually removes birds and eggs from Rikers Island, which is near the airport. Although these activities help manage wildlife near the airport, they are unlikely to affect wildlife entering the airspace above it.

Therefore, the NTSB concludes that the accident bird strike occurred at a distance and altitude beyond the range of LGA's wildlife hazard responsibilities and, therefore, would not have been mitigated by LGA's wildlife management practices.

The FAA does not require all Part 139-certificated airports to conduct WHAs or maintain WHMPs. In fact, according to an FAA representative's public hearing testimony, only about half of certificated airports in the United States have conducted a WHA. According to 14 CFR 139.337, a serious wildlife strike is required to initiate the process of wildlife-strike mitigation. The NTSB believes that Part 139-certificated airports should take action to mitigate wildlife hazards before a dangerous event occurs. Further, a WHA is needed for an airport to adequately estimate wildlife numbers and sizes and their relative hazards.

On November 19, 1999, the NTSB issued Safety Recommendation A-99-88, which asked the FAA, in consultation with the USDA, to require that WHAs be conducted at all Part 139 airports where such assessments have not already been conducted. On February 22, 2000, the

FAA stated that it was not necessary to initiate additional regulations to require all Part 139 airports to conduct WHAs and that doing so would place an undue burden on many airports that do not have a history of wildlife strikes. The FAA stated that the actions it was taking in response to other bird strike-related safety recommendations would address the safety issue and that it planned no further action. On May 11, 2000, the NTSB classified Safety Recommendation A-99-88 “Closed—Unacceptable Action.”

Although the bird strike occurred beyond the range of LGA’s wildlife hazard responsibilities, the NTSB still strongly feels that all airports, regardless of their location, should become aware of the potential hazards of wildlife strikes because wildlife strikes are most likely to occur near airports. Further, the NTSB notes that, if an airport truly has minimal wildlife presence and attractants, then a WHA for that airport would be commensurately less burdensome and costly. Further, the cost of the assessment would be incurred anyway if a triggering event occurred.

The NTSB concludes that a proactive approach to wildlife mitigation at 14 CFR Part 139-certificated airports would provide a greater safety benefit than the current strategy of waiting for a serious event to occur before conducting a WHA. Therefore, the NTSB recommends that the FAA require all 14 CFR Part 139-certificated airports to conduct WHAs to proactively assess the likelihood of wildlife strikes, and, if the WHA indicates the need for a WHMP, require the airport to implement a WHMP into its ACM. The NTSB notes that the FAA initiated rulemaking in late summer 2009 to make WHAs mandatory at all Part 139 airports whether or not a “triggering event” has occurred and hopes that an NPRM will be issued by the end of 2010 as indicated by the FAA.

2.8.3 FAA Avian Radar Research

No warnings regarding bird hazards were made to the flight crew before the flight departed LGA about 1525. During postaccident interviews, the captain stated that, in his personal experience, “the [bird hazard] warnings that we typically get are routine and general and not specific in nature and therefore have limited usefulness.” Therefore, even if the pilots had received a bird-hazard warning before departure, it would not have prevented the flight from departing as scheduled because of the general nature of the warnings.

On November 19, 1999, the NTSB issued Safety Recommendation A-99-86, which asked the FAA to evaluate the potential for using AHAS technology for bird-strike risk reduction in civil aviation and, if found feasible, implement such a system in high-risk areas, such as major hub airports and along migratory bird routes, nationwide.

In response, the FAA stated that it had determined that AHAS was well suited for monitoring bird movements regionally but that it was not suitable for monitoring bird movements on or within 5 miles of an airport. The FAA stated that it would conduct a detailed review of all of the components that comprise AHAS and, based on the results, determine how AHAS could be modified for use in commercial aviation. The FAA added that it would also review other technologies and radar systems that could be used locally. On May 11, 2000, the NTSB classified Safety Recommendation A-99-86 "Closed—Acceptable Action."

Since the closing of Safety Recommendation A-99-86, the FAA has continued to research the use of radar systems for monitoring bird activity in airport environments, including approach and departure airspace and the general airport area. The FAA indicated during the public hearing that, although research into avian radar systems was ongoing, the technology had not yet progressed to the point of being used in a "see and avoid" mode, similar to how ATC radar is used to separate airplanes. The FAA further indicated that the short-term advantage of avian radar will be to detect wildlife and remove it from the airport area with greater efficiency. Several experimental mobile avian radar installations currently use the systems for this purpose.

2.8.4 Likelihood of a Similar Bird Strike

Currently, airports are mainly responsible for the mitigation of wildlife hazards. For instance, an airport's WHMP includes habitat management strategies designed to minimize or eliminate wildlife attractants. Most of these activities are confined to an airport because of the proximity of wildlife hazards to airplanes, but airports also attempt to eliminate wildlife attractants beyond the airport perimeter. Unfortunately, as noted, practical limits exist to the ability of an airport to control hazardous wildlife in the surrounding airspace.

As noted, avian radar at airports could detect and monitor wildlife at considerable distances and various altitudes around an airport. The logical extension of this technology would be the ability to issue warnings or provide navigational instructions to pilots to prevent dangerous encounters with wildlife. However, current technology in avian radar has not progressed sufficiently to permit its use as a real-time avoidance tool, although that capability is one of the future goals of the research program.

Although radar returns from the ATC primary radar system indicated the presence of birds before the bird strike, this information was not available to the pilots for valid reasons. First, air traffic controllers do not routinely view uncorrelated primary radar information; therefore, such returns, which would include birds, are filtered out and are not displayed on the radar screen. Even if a controller chooses to view such returns, they would not contain altitude information; therefore, it would be impossible to identify a conflict between an aircraft and birds even if the targets were converging. Further, the primary mandate of air traffic controllers is to separate aircraft; therefore, reporting unidentified transient returns during a busy period is not a priority.

The NTSB concludes that, although currently no technological, regulatory, or operational changes related to wildlife mitigation, including the use of avian radar, could be made that would lessen the probability of a similar bird-strike event from occurring, considerable research is being conducted in this area. The NTSB is encouraged by the FAA's continued research in avian radar and urges it to continue to support such endeavors and keep the NTSB apprised of its efforts, including its development of radar system performance standards and the procurement and use of these systems at airports.

2.8.5 USDA Research and Other Activities

At the public hearing, a USDA Wildlife Services representative outlined the agency's current wildlife research projects, including a project to determine if pulsating lights on airplanes would make them more conspicuous to birds. Preliminary results from the project indicate that pulsating lights affect the behavior of some birds but not others. The USDA intends to continue this research using an airplane outfitted with pulsating lights. In addition, the USDA reported that the use of lasers has been shown to be effective in repelling birds from hangars and other areas on the airfield and that there is anecdotal evidence, but no conclusive evidence, that using weather radar on airplanes disperses birds from the airplane's flightpath. Another area of USDA research involves planting grasses and other vegetation unattractive to wildlife to deter them from airfields and surrounding areas. Additional research relates, in part, to modifying trash transfer stations, implementing fencing, eradicating earthworms, and designing water retention facilities to deter wildlife.

In addition to its research endeavors, the USDA assists the FAA in wildlife mitigation efforts by providing technical experts to assess and control wildlife on and around airports. USDA wildlife biologists routinely conduct WHAs around airports, as was done for LGA, to identify types and numbers of wildlife in the vicinity and then help airports to develop and implement WHMPs. In 2008, USDA wildlife biologists assisted 764 airports in wildlife mitigation activities and trained 2,200 airport personnel to FAA standards, as required under Part 139. The NTSB believes that the USDA's research activities in wildlife mitigation and guidance and its assistance to airports on these issues contribute significantly to the safety of the airport environment and strongly encourages the USDA to continue these efforts.

Preliminary reports of the effectiveness of using various bird hazard mitigation strategies, including pulsating lights, lasers, and weather radar, suggest that these techniques have potential as bird repellents and may be helpful in keeping birds away from an airplane's flightpath. However, according to witnesses at the public hearing, the effectiveness of these methods is not well understood, and further research in these areas is needed. The NTSB believes that it is important to pursue all potentially useful approaches to bird hazard mitigation and is particularly interested in those that use aircraft systems to repel birds away from airplanes.

The NTSB concludes that research on the use of aircraft systems such as pulsating lights, lasers, and weather radar may lead to effective methods of deterring birds from entering aircraft flightpaths and, therefore, reduce the likelihood of a bird strike. Therefore, the NTSB recommends that the USDA develop and implement, in conjunction with the FAA, innovative technologies that can be installed on aircraft that would reduce the likelihood of a bird strike. Further, the NTSB recommends that the FAA work with the USDA to develop and implement innovative technologies that can be installed on aircraft that would reduce the likelihood of a bird strike.

2.9 Emergency Response

Many NY WW ferries were operating over established routes in the local waterway when the accident occurred, and ferry captains either witnessed the accident or were notified about it by the director of ferry operations. Although the ferry captains were not trained to respond to a commercial airplane accident and were not affiliated with the New Jersey or New York OEM framework of emergency response agencies, they were the first to arrive on scene and rescue the occupants from the airplane wings, slide/rafts, and cold water. According to the USCG and FDNY incident log, one ferry arrived on scene within about 3 minutes of the accident, and the other six ferries arrived on scene within 10 minutes. Further, one FDNY fire rescue boat arrived on scene within 8 minutes, and two USCG boats were on scene within 17 minutes. According to video footage obtained by the NTSB, all of the occupants were rescued within about 20 minutes of the ditching.

The NTSB concludes that the emergency response was timely and efficient because of the proximity of the emergency responders to the accident site, their immediate response to the accident, and their training before the accident.

Regardless, the postcrash environment, which included a 41° F water temperature and a 2° F wind chill factor and a lack of sufficient slide/rafts (resulting from water entering the aft fuselage) posed an immediate threat to the occupants' lives. Although the airplane continued to float for some time, many of the passengers who evacuated onto the wings were exposed to water up to their waists within 2 minutes. The passengers who jumped or fell into the water (and the passengers on the wings who would have had to eventually enter the water if the emergency response had not been so timely) were at the most risk. Medical literature indicates that cold-water immersion causes cold shock, which can kill a person within 3 to 5 minutes, and swimming failure, which can kill a person within 5 to 30 minutes. Therefore, if the rescue vessels had not been near the accident site, it is likely that some of the airplane occupants would have drowned due to cold shock or swimming failure.

2.10 Survival Factors Issues

2.10.1 Accident-Related Injuries

2.10.1.1 FR65 Vertical Beam

Flight attendant B sustained a deep, V-shaped laceration to her left shin during the accident. Although she could not remember being injured and only noticed the injury after she had evacuated the airplane, the investigation determined that the FR65 vertical beam had penetrated the floor directly beneath the aft, direct-view jumpseat on which flight attendant B had been seated. The shape of the beam matched the description and location of flight attendant

B’s injury. It is likely that she did not immediately notice the injury because of the shock of the impact and immediate submersion of her legs in near-freezing water.

According to Airbus, the FR65 vertical beam is a nonstructural beam installed between the passenger and cargo floors at the aircraft centerline that is held in place by two quick-release, removable pins at its uppermost attachment point with the subfloor structure. Removing the pins and rotating the beam down allows maintenance personnel to access the waste water tank. Physical evidence indicated that, during the impact, the beam was pushed upward and rotated, allowing the removable pins to slide from the upper bracket and the beam to puncture the cabin floor above.

In April 2009, an A321 was involved in a tail strike and incurred similar damage to the FR65 vertical beam; however, the beam did not puncture the floor. Airbus’ analysis of this incident and the accident event indicated that the damage to the accident airplane was more severe because of the continuous pressure applied to the fuselage skin by the water, which led to more skin and vertical beam movement.

The NTSB concludes that flight attendant B was injured by the FR65 vertical beam after it punctured the cabin floor during impact and that, because of the beam’s location directly beneath the flight attendant’s aft, direct-view jumpseat, any individual seated in this location during a ditching or gear-up landing is at risk for serious injury due to the compression and/or collapse of the airplane structure. The NTSB notes that the A318, A319, A320, and A321 series airplanes have similar structures. Therefore, the NTSB recommends that the FAA and EASA require Airbus to redesign the FR65 vertical beam on A318, A319, A320, and A321 series airplanes to lessen the likelihood that it will intrude into the cabin during a ditching or gear-up landing and Airbus operators to incorporate these changes on their airplanes.

2.10.1.2 Brace Positions

Of the four passengers who sustained serious injuries, three received their injuries during impact. The two female passengers who sustained very similar shoulder fractures both described assuming similar brace positions, putting their arms on the seat in front of them and leaning over. They also stated that they felt that their injuries were caused during the impact when their arms were driven back into their shoulders as they were thrown forward into the seats in front of them. The brace positions they described were similar to the one depicted on the US Airways safety information card, which is shown in figure 8.

The brace positions shown on the US Airways safety information card were in accordance with current FAA guidance on brace positions contained in Appendix 4 of AC 121-24C, which states, “in aircraft with high-density seating or in cases where passengers are physically limited and are unable to place their heads in their laps, they should position their heads and arms against the seat (or bulkhead) in front of them.” (See figure 7.)

A 1988 Civil Aerospace Medical Institute (CAMI) paper explained that "the primary goal for the brace for impact position is to reduce the effect of secondary impact of the body with the interior of the aircraft."[140] The paper indicated that the idea is to preposition the body in the direction that it will likely be driven during impact. The paper further stated the following:

> If resting against a seat back with a 'break-over feature,' it may be possible to get slightly better support if the seat can be folded over until it stops or until it rests gently on the occupant in front. But if this is not done, good support will still be provided by the seat back as it folds forward of its own inertia during the crash, and is followed by the arms and head. The head and arms will slide down the seat back as it folds, but shouldn't be seriously injured.

The passenger seats on the accident airplane were 16-G compatible seats[141] that had a nonbreakover seatback design, meaning that the breakover hinge feature was "locked out" and that the seatbacks were designed to be essentially rigid and to not easily or quickly collapse forward as passengers struck them from behind. All newly manufactured 16-G compatible seats have a nonbreakover seatback design, which minimizes head movement and body acceleration before striking the seatback from behind, resulting in less serious head injuries. The NTSB notes that the guidance in AC 121-24C did not take into consideration the effects of striking seats that do not have the breakover feature because research on this issue has not been conducted.

The NTSB concludes that the FAA's current recommended brace positions do not take into account newly designed seats that do not have a breakover feature and that, in this accident, the FAA-recommended brace position might have contributed to the shoulder fractures of two passengers. Therefore, the NTSB recommends that the FAA conduct research to determine the most beneficial passenger brace position in airplanes with nonbreakover seats installed. If the research deems it necessary, issue new guidance material on passenger brace positions.

2.10.2 Evacuation

Flight attendant A reported no difficulties opening door 1L or getting it to lock against the fuselage; however, she reported that, although no water entered the door, the slide/raft did not inflate automatically. She stated that she pulled the manual inflation handle and that the slide/raft inflated normally. Although she did not report a delay in the inflation after pulling the manual

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[140] See R.F. Chandler, "Brace for Impact Positions," *Proceedings of the Fifth Annual International Cabin Safety Symposium, February 1988* Los Angeles, California (Los Angeles, California: University of Southern California, Federal Aviation Administration, and Southern California Safety Institute, 1988), pp. 279–290.

[141] A 16-G seat is tested in a manner that simulates the loads that could be expected in an impact-survivable accident. Two separate dynamic tests are conducted to simulate two different accident scenarios: one in which the forces are predominantly in the vertical downward direction and one in which the forces are predominantly in the longitudinal forward direction. The highest load factor is in the forward direction at 16 G, which is why these seats are commonly referred to as 16-G seats. Amendment 121-315, effective October 27, 2005, required that transport-category airplanes in Part 121 operations, certificated after January 1, 1958, and manufactured on or after October 27, 2009, must comply with the 16-G dynamic standard.

inflation handle, postaccident video analysis indicated that about 20 seconds elapsed after she opened door 1L until the slide/raft began to inflate. Further, both of the first two passengers to reach door 1L reported that the flight attendant seemed to be struggling with the slide/raft. The delay prompted one passenger to jump into the water before the slide/raft was inflated. Examination of the slide/raft at door 1L did not reveal any evidence as to why the slide/raft did not inflate automatically.

Flight attendant C reported no difficulties opening door 1R; however, she stated that, sometime after the 1R slide/raft finished automatically inflating, she noticed that the door had closed somewhat and was impinging on the slide/raft. Although the slide/raft was preventing the door from closing any further, she had a passenger help keep the door as far open as possible so that it would not puncture the slide/raft. Postaccident recovery of the airplane severely twisted door 1R. A visual examination of the 1R door gust lock mechanism was inconclusive as to the cause of the anomaly.

Passengers and flight attendants reported that the evacuation was relatively orderly and timely. A review of passenger exit usage indicated that, in general, passengers from the forward and mid parts of the cabin evacuated through the exit closest to their seats. (See figure 9.) However, aft-seated passengers indicated that water immediately entered the aft area of the airplane after impact and that the water rose to the level of their seat pans within seconds; therefore, they were not able to exit from their closest exits because these exits were no longer usable. Most of the aft passengers initially attempted to go to the rear exits, but flight attendant B and several passengers began shouting for everyone to go forward because the rear exits were not usable. The passengers turned around and attempted to go forward up the aisle, but, because a line had formed for the overwing exits, they initially could not move forward.

The water in the back of the airplane rose quickly, which, in addition to improvised commands from flight attendant B to "go over the seats," resulted in numerous passengers climbing forward over the seatbacks to reach a usable exit.[142] However, some aft passengers remained in the aisle queue to the overwing exits. Many of these passengers noted that, when they arrived at the exits, the wings were crowded and people were exiting slowly. They also reported that the aisle forward of the overwing exits was completely clear and that the flight attendants were calling for passengers to come forward to the slide/rafts. Many of the aft passengers complied with these instructions; therefore, the 1L and 1R slide/rafts mostly contained passengers from the very forward and very aft parts of the cabin.

The NTSB concludes that the flight attendants initiated the evacuation promptly and, that, although they all encountered difficulties at their exits, they still managed an effective and timely evacuation.

[142] Not all of the aft passengers reported hearing the flight attendant's improvised commands.

2.10.3 EOW and Ditching-Related Equipment

2.10.3.1 Slide/Rafts

2.10.3.1.1 Availability After a Ditching

The accident airplane was equipped for EOW operations; however, the flight route from LGA to CLT was not an EOW route. Therefore, the flight could have been operated with a non-EOW-equipped airplane. The amount and type of safety equipment carried by EOW-equipped airplanes differs greatly from that carried by non-EOW-equipped airplanes. Most significantly, EOW-equipped airplanes must carry passenger life vests and sufficient slide/rafts and/or life rafts to contain all of the airplane's occupants even if one slide/raft or life raft of the largest capacity is unavailable. In contrast, non-EOW-equipped airplanes may operate with just evacuation slides and flotation seat cushions. (After the ditching, two slide/rafts on the accident airplane were unavailable because of water entry in the aft cabin.)

The accident airplane was equipped with 4 slide/rafts, 2 at the front of the airplane and 2 at the back of the airplane, each of which was rated for 44 passengers with an overload capacity of 55 passengers. Because the two aft slide/rafts were unusable after water entered the airplane, only two rafts, with a combined capacity to carry 110 people, were available. However, given that this was a non-EOW flight, it was fortunate that the airplane was EOW equipped and, therefore, had any slide/rafts available at all for passenger use.

According to information gathered from 146 of the passengers and the flight and cabin crewmembers, about 64 occupants were rescued from the forward slide/rafts, and about 87 occupants were rescued from the wings and off-wing ramp/slides, which were neither detachable nor considered part of the airplane's EOW emergency equipment. Both passenger statements and photographic evidence, as shown in figure 2, indicated that the wings were very near to, if not at, standing capacity. Therefore, the wings did not have room for the additional 64 occupants who were rescued from the slide/rafts. If the airplane had not been EOW equipped, the rafts that held those occupants would not have been available. Further, at the public hearing, a US Airways representative stated that, if the accident airplane had not been equipped with slide/rafts, the flight attendants would have detached the single-lane slides at the forward doors and instructed passengers to jump into the water and hold onto them, exposing many passengers to cold water for sufficient time to likely cause serious injuries and/or fatalities.

The NTSB concludes that, although the airplane was not required by FAA regulations to be equipped for EOW operations to conduct the accident flight, the fact that the airplane was so equipped, including the availability of the forward slide/rafts, contributed to the lack of fatalities and the low number of serious cold-water immersion-related injuries because about 64 occupants used the forward slide/rafts after the ditching.

As noted, water immediately entered the aft area of the airplane after impact and rose quickly because the impact damage to the aft fuselage structure and galley floor allowed a large volume of water to enter the airplane. There were conflicting statements regarding door 2L and how it got "cracked" open, which allowed some additional water to enter the airplane. However, due to the large volume of water that had already entered the aft area of the airplane, it is immaterial how door 2L was cracked open.

As discussed previously, because of the operational difficulty of ditching within the Airbus ditching parameters and the additional difficulties that water swells and/or high winds may cause, it is very likely that, in general, after ditching an A320 airplane without engine power, the "probable structural damage and leakage" will include significant aft fuselage breaching and subsequent water entry into the aft area of the airplane. Therefore, it should be assumed that, after a ditching, water entry will prevent the aft exits and slide/rafts from being available for use during an evacuation. The NTSB understands that, during the ditching certification process, the FAA examines the manufacturer's assumptions regarding the airplane's expected integrity and buoyancy calculations. However, based on this accident, the NTSB questions the FAA's acceptance of the assumption that a ditching in which the fuselage is not significantly breached is a reasonable expectation across a range of realistic environmental conditions and pilot skills and experience.

Based on this evidence, the NTSB concludes that the determination of cabin safety equipment locations on the A320 airplane did not consider that the probable structural damage and leakage sustained during a ditching would include significant aft fuselage breaching and subsequent water entry into the aft area of the airplane, which prevents the aft slide/rafts from being available for use during an evacuation. Although this investigation only determined that an A320 airplane will most likely significantly breach after a ditching, the NTSB is concerned that the A320 may not be the only airplane that could sustain such damage after a ditching and that might have slide/rafts stowed in locations that, in the event of a ditching, would render them unusable. Therefore, the NTSB recommends that the FAA and EASA require, on all new and in-service transport-category airplanes, that cabin safety equipment be stowed in locations that ensure that life rafts and/or slide/rafts remain accessible and that sufficient capacity is available for all occupants after a ditching. The following sections will describe required EOW equipment.

2.10.3.1.2 Immersion Protection

As noted in NTSB Safety Study 85/02, "at least 179 fully certified airports in the U.S. are located within 5 miles of a body of water of at least one-quarter square mile surface area." Similarly, a 1996 FAA report found that 75.8 percent (194 of 256) of large airports worldwide had at least one overwater approach.[143] The report concluded that "approximately two-thirds of all worldwide accidents occur during those flight phases within close proximity of the airport" and that "the majority of water related mishaps occur within close proximity of the airport during these flight phases." In 1988, the FAA also stated the following in NPRM 88-11, which proposed improved water survival equipment:

[143] See *Transport Water Impact and Ditching Performance*, DOT/FAA/AR-95/54 (Washington, DC: Federal Aviation Administration, 1996).

> The likelihood of at least some part of passenger-carrying flights conducted under either Part 121 or Part 135 within the United States occurring over water is quite high and is sufficient to warrant applicability of the proposals to all passenger-carrying aircraft operated under those parts.

According to information gathered from 146 of the passengers and the flight and cabin crewmembers, about 87 occupants were rescued from the wings and off-wing ramp/slides, which were neither detachable nor considered part of the airplane's EOW emergency equipment. Although passengers would not have been instructed by the flight attendants to use the overwing exits during a planned ditching in an EOW-equipped airplane, as evidenced, many passengers did use these exits during the evacuation. Therefore, one possible means of providing additional passenger protection from water immersion could be to equip Type IV exit ramp/slides with quick-release girts so that they could be detached from the airplane if it is sinking. In fact, NTSB Safety Study 85/02 stated the following regarding immersion protection:

> Since water impact accidents occur primarily during the takeoff or landing phases of flight, not during the 'extended overwater' phase, and are not limited to aircraft equipped with slide/raft combinations, it is important that the evacuation slides on narrow-body (and, where still used, on wide-body) aircraft be modified to offer a means to avoid immersion.

At the time, CAMI was testing improvements to narrow-body evacuation slides, primarily to increase the capacity of the slides when used as a raft, and quick-release girts. The NTSB asked the FAA to monitor the progress of the developments and issue standards for the modifications as they were proven. The NTSB stated that, until such time, evacuation slides should at least be required to include handholds and quick-release girts. As a result, the NTSB issued Safety Recommendation A-85-41, which asked the FAA to do the following:

> Amend TSO-C69a to require quick-release girts and handholds on emergency evacuation slides; amend 14 CFR 121 and 125 to specify a reasonable time from the adoption of the revision of the TSO by which all transport passenger air carrier aircraft being operated under these Parts must be equipped with slides conforming to the revised TSO.

The FAA revised TSO-C69a in response to Safety Recommendation A-85-41 and included requirements for quick-release girts and handholds on slides and slide/rafts (but not on ramp/slides). However, the FAA did not amend 14 CFR Parts 121 and 125 as recommended. Therefore, on March 29, 2002, the NTSB classified Safety Recommendation A-85-41 "Closed—Unacceptable Action."

The off-wing Type IV ramp/slides were not designed to be used during a water evacuation or required to have quick-release girts or handholds; however, they automatically deployed as designed when the overwing exits were opened after the ditching. Some passengers immediately recognized their usefulness and boarded the ramp/slides to get out of the water. Eventually, about 8 passengers succeeded in boarding the left off-wing slide and about

21 passengers, including the lap-held child, succeeded in boarding the right off-wing ramp/slide. Although passengers attempted to disconnect the off-wing ramp/slides from the airplane, they were unable to do so because the ramp/slides did not have quick-release girts like slides and slide/rafts. The NTSB recognizes that A320 off-wing slides are not currently part of the EOW equipment on the airplane and are not designed to be used by passengers in this manner. However, this accident clearly demonstrates that passengers can and will successfully use the off-wing ramp/slides as a means of flotation in an emergency if they are available. However, the lack of quick-release girts prevented passengers from being able to disconnect the slides, and, if the airplane had sunk more quickly, the passengers would have had to abandon them and enter the water. Therefore, adding quick-release girts on all evacuation slides could be one method to prevent passenger immersion after an accident involving water.

The NTSB concludes that, given the circumstances of this accident and the large number of airports located near water and of flights flown over water, passenger immersion protection needs to be considered for non-EOW operations, as well as EOW operations. Therefore, the NTSB recommends that the FAA and EASA require quick-release girts and handholds on all evacuation slides and ramp/slide combinations.

2.10.3.2 Life Lines

All of US Airways' A320 EOW-equipped airplanes were required to be equipped with four life lines in accordance with 14 CFR 91.509(b)(5), "Survival Equipment for Overwater Operations." Life lines located at the overwing exits were intended to be used after a ditching by people on the wings to prevent them from falling into the water. However, it is unclear under what circumstances the life lines could be used effectively. For example, flight attendants were trained to direct passengers to exit into slide/rafts via the four floor-level exits during a planned ditching on an EOW-equipped airplane. Flight attendants were also trained to only use the overwing exits as secondary exits if a primary exit was unavailable (and it was safe to do so). Even then, given the flight attendants' locations in the cabin (at the forward- and aft-most areas of the airplane), it would be extremely difficult to physically reach the overwing exits because of the evacuating passengers. Additionally, as occurred in this accident, overwing exits are typically opened by passengers.

No information is contained on the US Airways passenger safety information card about the use or location of the life lines. Further, no information is provided to passengers about life lines during the preflight safety demonstration or individual exit row briefings. The NTSB is concerned that passengers most likely will not see or understand the placards above the overwing exit signs depicting deployed life lines and, therefore, that they will be unaware of the existence of life lines. Further, given that flight attendants will be unable to reach them during an unexpected emergency, the NTSB fails to see how life lines will be effectively used. The NTSB notes that, after exiting the airplane through the overwing exits, at least nine passengers unintentionally fell into the water from the wings.

Therefore, the NTSB concludes that, if the life lines had been retrieved, they could have been used to assist passengers on both wings, possibly preventing passengers from falling into the water. The NTSB recommends that the FAA require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators to provide information about life lines, if the airplane is equipped with them, to passengers to ensure that the life lines can be quickly and effectively retrieved and used.

2.10.3.3 Life Vests and Flotation Seat Cushions

2.10.3.3.1 Equipage

Because the accident airplane was equipped for EOW operations, it carried life vests for both passengers and crewmembers. However, given that the accident flight route was not an EOW operation, the airplane could very well have been equipped with only slides and flotation seat cushions as the primary means for passenger flotation. In that case, flight attendants would have detached the forward slides and instructed passengers to jump into the water with their flotation seat cushions and hold onto the slide.

If no slide/rafts had been available at the forward door exits, many of the passengers egressing from these exits would have had no choice but to jump into the water with no flotation device. (About 47 percent of the passengers did not exit with a flotation seat cushion.) Even if they had retrieved their flotation seat cushions, many passengers would have experienced extreme difficulty holding onto a seat cushion for more than a few minutes because of the effects of cold-water immersion. Self-righting life vests designed in accordance with TSO-C13f, such as those on the accident airplane, are designed to keep an individual's head above water even after he or she is unable to swim or effectively move his or her arms and legs.

In Safety Study 85/02, the NTSB issued Safety Recommendations A-85-35 through -37, which recommended that all Part 121, 125, and 135 passenger-carrying air carrier aircraft be equipped with approved life vests meeting the latest TSO and to ensure Part 25 requirements were consistent with the amendments made to Parts 121, 125, and 135. In response to these recommendations, on June 30, 1988, the FAA published NPRM 88-11, which proposed new requirements that "would ensure that each occupant is provided a life preserver which provides the basic benefits of high buoyancy and water stability…regardless of whether the airplane is involved in overwater operation."

In 1997, the FAA informed the NTSB that a final rule was expected to be published in the *Federal Register* by the end of that year; however, no final rule was issued. Subsequently, the FAA stated that "due to the amount of comments received and the amount of time since the NPRM was originally issued," it had decided to publish an SNPRM by October 2000. When that date passed and no communication was received, on March 29, 2002, the NTSB classified Safety Recommendations A-85-35 through -37 "Closed—Unacceptable Action." On July 24, 2003, more than 15 years after it was originally published, the FAA withdrew the original NPRM 88-11 and stated, "we find the costs of proceeding with this rulemaking as proposed exceed the benefits to the public and that existing water survival equipment requirements are satisfactory."

Despite the drawbacks of using flotation seat cushions in a cold-water environment, they play an important role by providing a redundant source of personal flotation. This role was recognized by the FAA in NPRM 88-11, which proposed requiring, in addition to life vests, flotation seat cushions for each occupant on all flights, regardless of route.[144] More than half of the passengers on the accident flight evacuated with a flotation seat cushion, demonstrating not only their familiarity with the equipment, but also their ability and willingness to retrieve it in an emergency. Additionally, in a water accident that results in fuselage breakup and rapid cabin flooding, flotation seat cushions may break free and float to the surface, offering perhaps the only ready means of flotation available to survivors.

Because so many airports are located near bodies of water and most emergencies occur during the takeoff or landing portions of flight, life vests are critical equipment on all flights, regardless of the route. The NTSB concludes that equipping aircraft with flotation seat cushions and life vests on all flights, regardless of the route, will provide passengers the benefits of water buoyancy and stability in the event of an accident involving water. Therefore, the NTSB recommends that the FAA require that aircraft operated by 14 CFR Part 121, Part 135, and Part 91 Subpart K operators be equipped with flotation seat cushions and life vests for each occupant on all flights, regardless of the route.

2.10.3.3.2 Briefings

As noted, only about 77 passengers retrieved flotation seat cushions and evacuated with them, whereas only about 10 passengers retrieved life vests themselves after impact and evacuated with them. Passenger interviews revealed that most of the passengers were frequent travelers who were very familiar with the preflight briefing and that, over the years, the information about the seat cushions had "sunk in" to their consciousness. Several passengers stated that, even in their stressed state, they were able to specifically recall how they were supposed to hold the cushion to their chests with their arms crossed.

One probable reason that more passengers were aware that flotation seat cushions were on board the airplane than were aware that life vests were on board is that preflight briefings address the use of the flotation seat cushions on virtually all flights, whereas only briefings on EOW flights generally address the location and use of life vests.[145] Passenger interviews indicated that about 70 percent of the passengers did not watch any of the preflight safety briefing, indicating that passenger attention to the preflight briefings was generally low. However, it appears that, over time, frequent travelers have become accustomed to hearing the phrase, "your seat cushion may be used as a flotation device," and have remembered it. (See section 2.10.4 for a discussion about passenger education.)

[144] Currently, EOW-equipped airplanes are not required to carry seat cushions for auxiliary passenger flotation; however, the accident airplane was so equipped.

[145] The NTSB notes that some airlines use video presentations on certain airplanes and on all flights that show the location and use of life vests.

In Safety Study 85/02, the NTSB issued Safety Recommendation A-85-39, which asked the FAA to amend the relevant sections of Parts 121, 125, and 135 to require that all predeparture briefings include a full demonstration of correct life preserver donning procedures. The FAA took no action on Safety Recommendation A-85-39; therefore, on June 1, 1987, the NTSB classified it "Closed–Unacceptable Action." The FAA changed its position a year later and, in NPRM 88-11, proposed a requirement that "before each takeoff passengers be briefed on the location and use of required flotation equipment. In addition, a demonstration of the method of donning and inflating the life preservers would have to be given." However, NPRM 88-11 was withdrawn in 2003, and no action was taken on this issue.

Although life vests were not required for the accident flight, because they were installed on the airplane, the flight attendants were required by federal regulations to brief the passengers on their location and use.[146] However, a life vest demonstration was not required because the flight was not an EOW operation. CVR data indicated that the preflight safety briefing provided by flight attendant B included information about the flotation seat cushions but that it omitted information about the location, removal, donning, and inflation of the life vests. This omission was not in accordance with federal regulations or company procedures, which stated that this information should be provided.

The NTSB concludes that briefing passengers on, and demonstrating the use of, all flotation equipment installed on an airplane on all flights, regardless of the route, will improve the chances that the equipment will be effectively used during an accident involving water. The NTSB recommends that the FAA require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators to brief passengers on all flotation equipment installed on an airplane, including a full demonstration of correct life vest retrieval and donning procedures, before all flights, regardless of route.

2.10.3.3.3 Stowage and Retrieval

Although the accident flight attendants did not command passengers to don their life vests before the water impact, two passengers realized that they would be landing in water and retrieved and donned their life vests before impact, and a third passenger attempted to retrieve his life vest but was unable to do so and, therefore, abandoned his attempt. Many passengers reported that their immediate concern after the water impact was to evacuate as quickly as possible, that they forgot about or were unaware that a life vest was under their seat, or that they did not want to delay their egress to get one.[147] Other passengers stated that they wanted to retrieve their life vest but could not remember where it was stowed.

[146] On an airplane equipped with both flotation seat cushions and life vests (such as the accident airplane), flight attendants were required to brief passengers on both types of equipment.

[147] Many of the passengers who stated that they were aware that the airplane was equipped with life vests indicated that they knew this because of information they had received on previous flights, indicating that they believed all airplanes were equipped with life vests on all flights.

Overall, 19 passengers physically attempted to obtain a life vest from under a seat, and 10 of these passengers reported difficulties retrieving it. Of those 10 passengers, only 3 were persistent enough to eventually obtain the life vest; the other 7 either retrieved a flotation seat cushion or abandoned the idea of retrieving flotation equipment altogether.

As noted in NTSB Safety Study 85/02, life vest stowage is addressed in various ways in FAA regulations. The study stated that, taken together:

> these regulations require that each life preserver have its own stowage compartment, that a stowed life preserver be within easy reach[148] of each seated occupant, that it be easily accessible in a ditching without appreciable time for preparatory procedures, that the stowage compartment be conspicuously marked and be approved, and that the stowage compartment protect the life preserver from inadvertent damage.

In the safety study, the NTSB noted that, despite the requirements for life vest accessibility, several accident investigations had revealed that passengers have repeatedly had difficulty retrieving life vests from their usual stowage location under the seat. For example, the safety study stated that, in the 1970 Overseas National Airways ditching, passengers spent about 5 to 7 minutes from the time they were told of a possible ditching to the moment of impact trying to retrieve their life vests from under their seats and to unpackage and don them. Some of the passengers had to get on their hands and knees to get the life vests out of their stowage compartments, and some passengers never got them out of the compartments at all. According to the safety study, not being able to access or don a life vest contributed to several of the 23 deaths that resulted from this accident. The investigation of several other accidents revealed that passengers had similar problems retrieving their life vests.[149] As noted in the safety study, the problems identified during the investigation of these accidents were confirmed during timing tests at CAMI in 1983. In those tests, which were conducted under ideal conditions, adults took from 9 to 80 seconds (an average of 17 seconds) to retrieve a life vest from beneath their seat.

In May 2003, CAMI tested four different configurations of under-seat life vest stowage pouches.[150] Although none of the configurations were identical to the one in the economy-class section of the accident airplane, the average retrieval time for the most similar configuration was 8.5 seconds. Another configuration, which was similar to the first-class containers on the accident airplane, resulted in an average retrieval time of 7.4 seconds. Both of these retrieval times were considered to be in the "easy range."

[148] The term "easy reach" is not defined in any published FAA guidance or policy documents.

[149] These accidents include the 1978 crash of National Airlines into Escambia Bay, Florida; the 1982 World Airways runway overrun; and the 1983 Eastern Air Lines L-1011 near-ditching offshore of Miami, Florida. See Safety Study 85/02 for more information.

[150] See V. Gowdy and R. DeWeese, *Human Factors Associated With The Certification of Airplane Passenger Seats: Life Preserver Retrieval,* FAA Office of Aerospace Medicine, Report No. AM-03/9 (Oklahoma City, Oklahoma: 2003).

The experiences from the accident flight validate the results of the 1983 and 2003 CAMI tests and confirm that many passengers may take at least 7 to 8 seconds to retrieve a life vest and that many passengers will not wait that long before abandoning the retrieval attempt and evacuating without a life vest. Additionally, if water enters the cabin after a water impact, which is likely, passengers will also be deterred from retrieving their life vests because doing so would delay evacuation. The FAA stated the following in NPRM 88-11:

> Accident experience and research testing have demonstrated that typical airline passengers have difficulty in retrieving life preservers and that such stowage beneath a passenger's seat makes the life preservers vulnerable to water impact damage, seat collapse, and post-impact flooding.

Despite this, the FAA stated that "the advantages that would be gained by prohibiting under seat stowage of life preservers would not outweigh the disadvantages." The FAA stated that there was insufficient basis to conclude that passenger safety would be increased by relocating life preserver stowage. However, the FAA did propose a rule revision that would have required an approved stowage pocket that "allows the passenger, using only one hand, to readily locate the pocket, open it, grasp the life preserver, and retrieve it." As noted, NPRM 88-11 was withdrawn in 2003, and no action was taken on this issue.

The NTSB concludes that passenger behavior on the accident flight indicated that most passengers will not wait 7 to 8 seconds, the reported average life vest retrieval time, before abandoning the retrieval attempt and evacuating without a life vest. Therefore, the NTSB recommends that the FAA and EASA require modifications to life vest stowage compartments or stowage compartment locations to improve the ability of passengers to retrieve life vests for all occupants.

2.10.3.3.4 Donning

Most of the passengers who eventually donned, or attempted to don, life vests did so after they were outside the airplane while they were seated in a slide/raft or standing on a wing. Of the estimated 33 passengers who reported eventually having a life vest,[151] only 4 confirmed that they were able to complete the donning process by securing the waist strap themselves. Most of passengers who had life vests either struggled with the strap or chose not to secure it at all for a variety of reasons.

The NTSB has a long history of issuing recommendations to simplify life vest donning. In Safety Study 85/02, the NTSB noted that it had issued several safety recommendations to the FAA as a result of the 1970 Overseas National Airways ditching, the 1978 National Airlines

[151] By the time the last passengers reached the overwing exits, some of the passengers outside the airplane realized that they did not have a flotation device and called back into the airplane for assistance. Subsequently, several passengers who were still in the airplane began retrieving life vests from beneath the seats and passing them to the passengers on the wings. Further, the captain and first officer handed out life vests to some of the passengers in the forward slide/raft.

crash, and the 1983 near-ditching of Eastern Airlines L-1011 to improve "the requirements for life vests to make them easily and quickly usable in the actual environment of a water impact." The safety recommendations that resulted from these accidents led the FAA to revise TSO-C13c in January 1983 to include a requirement that an adult can don a life vest within 15 seconds (unassisted) while seated.[152]

The safety study noted that the revision to the TSO had little effect on the donning of life vests, as confirmed by the 1983 CAMI tests.[153] These tests were conducted on life vests newly certified under TSO-C13d, and test results showed that passengers still had difficulty donning vests. Of 100 attempts to don the vests, only 4 were successfully completed within 15 seconds, and, in 21 attempts, users either did not don the life vests correctly within 2 minutes or gave up trying altogether. The CAMI report indicated that the life vests' waist straps were the major obstacle to correct donning and that "users fail to tighten the straps, or do not fasten them correctly, or do not fasten them at all."

CAMI also tested two unapproved[154] experimental devices, both modified from "angler's vests." These devices proved much easier to don, with 29 of 50 users donning them correctly within 15 seconds. CAMI attributed the improved performance to the fact that the device looked like a vest (and was meant to be donned like one), had an obvious front-to-rear position, and had no straps (just a plastic-tooth zipper up the front). Despite these promising results, the NTSB is not aware of any further development of this type of device.

As a result of these findings, the NTSB issued numerous safety recommendations to amend TSO-C13d (currently version TSO-C13f) to make it easier for passengers to don life vests. (These safety recommendations included A-85-42 through -44, which are discussed in detail in section 1.18.3.2.) Although the FAA implemented some of the recommended changes, the circumstances of this accident again demonstrate that passengers have problems correctly donning life vests.

The NTSB concludes that the current life vest design standards contained in TSO-C13f do not ensure that passengers can quickly or correctly don life vests. Therefore, the NTSB recommends that the FAA revise the life vest performance standards contained in TSO-C13f to ensure that they result in a life vest that passengers can quickly and correctly don.

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[152] TSO-C13f currently states, "It must be demonstrated…that at least 75% of the total number of test subjects and at least 60% of the test subjects in each age group…can don the life preserver within 25 seconds unassisted, starting with the life preserver in its storage package."

[153] The NTSB notes that, although the life vests had been newly certified under the revised TSO, the life vest design was essentially unchanged.

[154] At the time, two inflation chambers were required, and the unapproved vest only had one. Currently, TSO C13f allows single-chamber devices.

2.10.4 Passenger Education

Passenger attention on the accident flight was even worse than that reported in Safety Study 00/01. As noted previously, about 70 percent of the passengers did not watch any of the preflight safety demonstration. In addition, more than 90 percent did not read the safety information card before or during the flight. The NTSB believes that these responses clearly indicate that passenger safety information is still routinely ignored by most travelers. The most frequently cited reason for this was that the passengers flew frequently and were familiar with the equipment on the airplane, making them complacent.

The NTSB has previously issued several safety recommendations addressing the improvement of passenger attention to preflight safety briefings and safety information cards.[155] The NTSB reexamined the issue most recently in Safety Study 00/01, which indicated that, of 377 responding passengers, 13 percent reported that they did not watch any of the briefing, and 39 percent reported that they watched less than 75 percent of the briefing. Worse still, 68 percent of the responding passengers indicated that they did not read the safety information card meant to supplement the oral briefing.[156] The NTSB concluded that the problem of passenger inattention to briefings continued to exist and that "passengers…need to pay attention to the safety information." The NTSB noted that, with the exception of using videotaped briefings, little had changed in how safety information was presented to passengers. Therefore, the NTSB issued Safety Recommendation A-00-86, which recommended that the FAA do the following:

> Conduct research and explore creative and effective methods that use state-of-the-art technology to convey safety information to passengers. The presented information should include a demonstration of all emergency evacuation procedures, such as how to open the emergency exits and exit the aircraft, including how to use the slides.

In response, the FAA stated that the current state-of-the-art technology (video safety briefings) was effective and already being used in the aviation industry. On May 6, 2004, the NTSB classified Safety Recommendation A-00-86 "Closed—Unacceptable Action" because the

[155] For example, in 1974, the NTSB issued Safety Recommendation A-74-113, which recommended that the FAA issue an AC that would provide standardized guidance to the air transport industry on effective methods and techniques for conveying safety information to passengers. On September 27, 1977, the NTSB classified Safety Recommendation A-74-113 "Closed—Acceptable Action" based on the FAA's issuance of AC 121-24. In 1985, the NTSB issued Safety Recommendation A-85-101, which recommended that the FAA require that recurrent flight attendant training programs contain instructions on the use of the PA system and techniques for maintaining effective safety briefings and demonstrations that will improve the motivation of passengers to pay attention to the oral briefings and demonstrations. Although the FAA issued AC 121-24A, the NTSB classified Safety Recommendation A-85-101 "Closed—Unacceptable Action" on August 21, 1991, because the AC did not meet the intent of the recommendation.

[156] Of those who did not read the safety information card, 89 percent indicated that their reason for not doing so was that they had read the card on previous flights.

FAA did not conduct any research on creative and effective methods to use new technology to address the problem of passenger inattention to briefings.[157]

The NTSB concludes that most of the passengers did not pay attention to the oral preflight safety briefing or read the safety information card before the accident flight, indicating that more creative and effective methods of conveying safety information to passengers are needed because of the risks associated with passengers not being aware of safety equipment. Therefore, the NTSB recommends that the FAA conduct research on, and require 14 CFR Part 121, Part 135, and Part 91 Subpart K operators to implement, creative and effective methods of overcoming passengers' inattention and providing them with safety information.

2.10.5 Summary

The NTSB notes that many of the issues addressed in this section were previously addressed in Safety Study 85/02; however, the FAA did not take many of the recommended actions because operators expressed concerns about the financial burden. The circumstances of this accident demonstrate that even a non-EOW flight can be ditched, resulting in significant fuselage breaching. Therefore, all passengers, regardless of whether or not their flight is an EOW operation, need to be provided with adequate safety equipment to ensure their greatest opportunity for survival if a ditching or other water-related event occurs. The NTSB believes that this accident demonstrates the continued validity of the following statement from Safety Study 85/02:

> The infrequency of water accidents is sometimes cited as a reason for not improving water survival equipment or not requiring that more types of air carrier operations provide survival equipment…despite the infrequency of water impact accidents, there are requirements for water survival equipment and crew training, and the aviation community has made a rather substantial commitment to meeting the requirements. The Safety Board believes that to be worthwhile the regulatory requirements should result in the most effective water survival measures feasible.

[157] The NTSB notes that public hearing testimony indicated that US Airways had deactivated and/or removed the video equipment from their entire A320 fleet for "financial considerations."

3. Conclusions

3.1 Findings

1. The flight and cabin crewmembers were properly certificated and qualified under federal regulations. No evidence indicated any preexisting medical or physical condition that might have adversely affected the flight crew's performance during the accident flight.

2. The accident airplane was equipped, dispatched, and maintained in accordance with federal regulations.

3. The LaGuardia Airport departure controller's decision to display only correlated primary radar targets on his radar display was appropriate.

4. Examinations of the recovered components revealed no evidence of any preexisting engine, system, or structural failures. The airplane met the structural ditching certification regulations in effect at the time of its certification, and the engine met the bird-ingestion certification regulations in effect at the time of its certification, as well as an anticipated additional regulation that it was not required to meet at that time.

5. The airframe damage was caused by the high-energy impact at the aft fuselage and the ensuing forward motion of the airplane through the water.

6. Both engines were operating normally until they each ingested at least two large birds (weighing about 8 pounds each), one of which was ingested into each engine core, causing mechanical damage that prevented the engines from being able to provide sufficient thrust to sustain flight.

7. If the accident engines' electronic control system had been capable of informing the flight crewmembers about the continuing operational status of the engines, they would have been aware that thrust could not be restored and would not have spent valuable time trying to relight the engines, which were too damaged for any pilot action to make operational.

8. The size and number of the birds ingested by the accident engines well exceeded the current bird-ingestion certification standards.

9. The current small and medium flocking bird tests required by 14 *Code of Federal Regulations* 33.76(c) would provide a more stringent test of the turbofan engine core resistance to bird ingestion if the lowest expected fan speed for the minimum climb rate were used instead of 100-percent fan speed because it would allow a larger portion of the bird mass to enter the engine core.

10. Additional considerations need to be addressed related to the current 14 *Code of Federal Regulations* 33.76(d) large flocking bird certification test standards because they do not

require large flocking bird tests on smaller transport-category airplane engines, such as the accident engine, or a test of the engine core; the circumstances of the accident demonstrate that large birds can be ingested into the core of small engines and cause significant damage.

11. Although engine design changes and protective screens have been used or considered in some engine and aircraft designs as a means to protect against bird ingestion, neither option has been found to be viable on turbofan engines like the accident engine.

12. Although the Engine Dual Failure checklist did not fully apply to the accident event, it was the most applicable checklist contained in the quick reference handbook to address the event, and the flight crew's decision to use this checklist was in accordance with US Airways procedures.

13. If a checklist that addressed a dual-engine failure occurring at a low altitude had been available to the flight crewmembers, they would have been more likely to have completed that checklist.

14. Despite being unable to complete the Engine Dual Failure checklist, the captain started the auxiliary power unit, which improved the outcome of the ditching by ensuring that a primary source of electrical power was available to the airplane and that the airplane remained in normal law and maintained the flight envelope protections, one of which protects against a stall.

15. The captain's decision to ditch on the Hudson River rather than attempting to land at an airport provided the highest probability that the accident would be survivable.

16. The captain's difficulty maintaining his intended airspeed during the final approach resulted in high angles-of-attack, which contributed to the difficulties in flaring the airplane, the high descent rate at touchdown, and the fuselage damage.

17. The captain's difficulty maintaining his intended airspeed during the final approach resulted, in part, from high workload, stress, and task saturation.

18. The captain's decision to use flaps 2 for the ditching, based on his experience and perception of the situation, was reasonable and consistent with the limited civilian industry and military guidance that was available regarding forced landings of large aircraft without power.

19. The professionalism of the flight crewmembers and their excellent crew resource management during the accident sequence contributed to their ability to maintain control of the airplane, configure it to the extent possible under the circumstances, and fly an approach that increased the survivability of the impact.

20. Comprehensive guidelines on the best means to design and develop emergency and abnormal checklists would promote operational standardization and increase the likelihood of a successful outcome to such events.

21. Training pilots how to respond to a dual-engine failure occurring at a low altitude would challenge them to use critical thinking and exercise skills in task shedding, decision-making, and proper workload management to achieve a successful outcome.

22. The flight crewmembers would have been better prepared to ditch the airplane if they had received training and guidance about the visual illusions that can occur when landing on water and on approach and about touchdown techniques to use during a ditching, with and without engine power.

23. The guidance in the ditching portion of the Engine Dual Failure checklist is not consistent with the separate Ditching checklist, which includes a step to inhibit the ground proximity warning system and terrain alerts.

24. Training pilots that sidestick inputs may be attenuated when the airplane is in the alpha-protection mode would provide them with a better understanding of how entering the alpha-protection mode may affect the pitch response of the airplane.

25. The review and validation of the Airbus operational procedures conducted during the ditching certification process for the A320 airplane did not evaluate whether pilots could attain all of the Airbus ditching parameters nor was Airbus required to conduct such an evaluation.

26. During an actual ditching, it is possible but unlikely that pilots will be able to attain all of the Airbus ditching parameters because it is exceptionally difficult for pilots to meet such precise criteria when no engine power is available, and this difficulty contributed to the fuselage damage.

27. This accident was not a typical bird-strike event; therefore, this accident demonstrates that a bird strike does not need to be typical to be hazardous.

28. The accident bird strike occurred at a distance and altitude beyond the range of LaGuardia Airport's (LGA) wildlife hazard responsibilities and, therefore, would not have been mitigated by LGA's wildlife management practices.

29. A proactive approach to wildlife mitigation at 14 *Code of Federal Regulations* Part 139-certificated airports would provide a greater safety benefit than the current strategy of waiting for a serious event to occur before conducting a wildlife hazard assessment.

30. Although currently no technological, regulatory, or operational changes related to wildlife mitigation, including the use of avian radar, could be made that would lessen the probability of a similar bird-strike event from occurring, considerable research is being conducted in this area.

31. Research on the use of aircraft systems such as pulsating lights, lasers, and weather radar may lead to effective methods of deterring birds from entering aircraft flightpaths and, therefore, reduce the likelihood of a bird strike.

32. The emergency response was timely and efficient because of the proximity of the emergency responders to the accident site, their immediate response to the accident, and their training before the accident.

33. Flight attendant B was injured by the frame 65 vertical beam after it punctured the cabin floor during impact, and, because of the beam's location directly beneath the flight attendant's aft, direct-view jumpseat, any individual seated in this location during a ditching or gear-up landing is at risk for serious injury due to the compression and/or collapse of the airplane structure.

34. The Federal Aviation Administration's (FAA) current recommended brace positions do not take into account newly designed seats that do not have a breakover feature, and, in this accident, the FAA-recommended brace position might have contributed to the shoulder fractures of two passengers.

35. The flight attendants initiated the evacuation promptly, and, although they all encountered difficulties at their exits, they still managed an effective and timely evacuation.

36. Although the airplane was not required by Federal Aviation Administration regulations to be equipped for extended overwater operations to conduct the accident flight, the fact that the airplane was so equipped, including the availability of the forward slide/rafts, contributed to the lack of fatalities and the low number of serious cold-water immersion-related injuries because about 64 occupants used the forward slide/rafts after the ditching.

37. The determination of cabin safety equipment locations on the A320 airplane did not consider that the probable structural damage and leakage sustained during a ditching would include significant aft fuselage breaching and subsequent water entry into the aft area of the airplane, which prevents the aft slide/rafts from being available for use during an evacuation.

38. Given the circumstances of this accident and the large number of airports located near water and of flights flown over water, passenger immersion protection needs to be considered for nonextended-overwater (EOW) operations, as well as EOW operations.

39. If the life lines had been retrieved, they could have been used to assist passengers on both wings, possibly preventing passengers from falling into the water.

40. Equipping aircraft with flotation seat cushions and life vests on all flights, regardless of the route, will provide passengers the benefits of water buoyancy and stability in the event of an accident involving water.

41. Briefing passengers on, and demonstrating the use of, all flotation equipment installed on an airplane on all flights, regardless of the route, will improve the chances that the equipment will be effectively used during an accident involving water.

42. Passenger behavior on the accident flight indicated that most passengers will not wait 7 to 8 seconds, the reported average life vest retrieval time, before abandoning the retrieval attempt and evacuating without a life vest.

43. The current life vest design standards contained in Technical Standard Order-C13f do not ensure that passengers can quickly or correctly don life vests.

44. Most of the passengers did not pay attention to the oral preflight safety briefing or read the safety information card before the accident flight, indicating that more creative and effective methods of conveying safety information to passengers are needed because of the risks associated with passengers not being aware of safety equipment.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the ingestion of large birds into each engine, which resulted in an almost total loss of thrust in both engines and the subsequent ditching on the Hudson River. Contributing to the fuselage damage and resulting unavailability of the aft slide/rafts were (1) the Federal Aviation Administration's approval of ditching certification without determining whether pilots could attain the ditching parameters without engine thrust, (2) the lack of industry flight crew training and guidance on ditching techniques, and (3) the captain's resulting difficulty maintaining his intended airspeed on final approach due to the task saturation resulting from the emergency situation.

Contributing to the survivability of the accident was (1) the decision-making of the flight crewmembers and their crew resource management during the accident sequence; (2) the fortuitous use of an airplane that was equipped for an extended overwater flight, including the availability of the forward slide/rafts, even though it was not required to be so equipped; (3) the performance of the cabin crewmembers while expediting the evacuation of the airplane; and (4) the proximity of the emergency responders to the accident site and their immediate and appropriate response to the accident.

4. Safety Recommendations

4.1 New Recommendations

The National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Work with the military, manufacturers, and National Aeronautics Space Administration to complete the development of a technology capable of informing pilots about the continuing operational status of an engine. (A-10-62)

> Once the development of the engine technology has been completed, as asked for in Safety Recommendation A-10-62, require the implementation of the technology on transport-category airplane engines equipped with full-authority digital engine controls. (A-10-63)

> Modify the 14 *Code of Federal Regulations* 33.76(c) small and medium flocking bird certification test standard to require that the test be conducted using the lowest expected fan speed, instead of 100-percent fan speed, for the minimum climb rate. (A-10-64)

> During the bird-ingestion rulemaking database (BRDB) working group's reevaluation of the current engine bird-ingestion certification regulations, specifically reevaluate the 14 *Code of Federal Regulations* (CFR) 33.76(d) large flocking bird certification test standards to determine whether they should 1) apply to engines with an inlet area of less than 3,875 square inches and 2) include a requirement for engine core ingestion. If the BRDB working group's reevaluation determines that such requirements are needed, incorporate them into 14 CFR 33.76(d) and require that newly certificated engines be designed and tested to these requirements. (A-10-65)

> Require manufacturers of turbine-powered aircraft to develop a checklist and procedure for a dual-engine failure occurring at a low altitude. (A-10-66)

> Once the development of the checklist and procedure for a dual-engine failure occurring at a low altitude has been completed, as asked for in Safety Recommendation A-10-66, require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators of turbine-powered aircraft to implement the checklist and procedure. (A-10-67)

Develop and validate comprehensive guidelines for emergency and abnormal checklist design and development. The guidelines should consider the order of critical items in the checklist (for example, starting the auxiliary power unit), the use of opt outs or gates to minimize the risk of flight crewmembers becoming stuck in an inappropriate checklist or portion of a checklist, the length of the checklist, the level of detail in the checklist, the time needed to complete the checklist, and the mental workload of the flight crew. (A-10-68)

Require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators to include a dual-engine failure scenario occurring at a low altitude in initial and recurrent ground and simulator training designed to improve pilots' critical-thinking, task-shedding, decision-making, and workload-management skills. (A-10-69)

Require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators to provide training and guidance to pilots that inform them about the visual illusions that can occur when landing on water and that include approach and touchdown techniques to use during a ditching, with and without engine power. (A-10-70)

Work with the aviation industry to determine whether recommended practices and procedures need to be developed for pilots regarding forced landings without power both on water and land. (A-10-71)

Require applicants for aircraft certification to demonstrate that their ditching parameters can be attained without engine power by pilots without the use of exceptional skill or strength. (A-10-72)

Require Airbus operators to amend the ditching portion of the Engine Dual Failure checklist and any other applicable checklists to include a step to select the ground proximity warning system and terrain alerts to OFF during the final descent. (A-10-73)

Require Airbus operators to expand the angle-of-attack-protection envelope limitations ground-school training to inform pilots about alpha-protection mode features while in normal law that can affect the pitch response of the airplane. (A-10-74)

Require all 14 *Code of Federal Regulations* Part 139-certificated airports to conduct wildlife hazard assessments (WHA) to proactively assess the likelihood of wildlife strikes, and if the WHA indicates the need for a Wildlife Hazard Management Plan (WHMP), require the airport to implement a WHMP into its airport certification manual. (A-10-75)

Work with the U.S. Department of Agriculture to develop and implement innovative technologies that can be installed on aircraft that would reduce the likelihood of a bird strike. (A-10-76)

Require Airbus to redesign the frame 65 vertical beam on A318, A319, A320, and A321 series airplanes to lessen the likelihood that it will intrude into the cabin during a ditching or gear-up landing and Airbus operators to incorporate these changes on their airplanes. (A-10-77)

Conduct research to determine the most beneficial passenger brace position in airplanes with nonbreakover seats installed. If the research deems it necessary, issue new guidance material on passenger brace positions. (A-10-78)

Require, on all new and in-service transport-category airplanes, that cabin safety equipment be stowed in locations that ensure that life rafts and/or slide/rafts remain accessible and that sufficient capacity is available for all occupants after a ditching. (A-10-79)

Require quick-release girts and handholds on all evacuation slides and ramp/slide combinations. (A-10-80)

Require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators to provide information about life lines, if the airplane is equipped with them, to passengers to ensure that the life lines can be quickly and effectively retrieved and used. (A-10-81)

Require that aircraft operated by 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators be equipped with flotation seat cushions and life vests for each occupant on all flights, regardless of the route. (A-10-82)

Require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators to brief passengers on all flotation equipment installed on an airplane, including a full demonstration of correct life vest retrieval and donning procedures, before all flights, regardless of route. (A-10-83)

Require modifications to life vest stowage compartments or stowage compartment locations to improve the ability of passengers to retrieve life vests for all occupants. (A-10-84)

Revise the life vest performance standards contained in Technical Standard Order-C13f to ensure that they result in a life vest that passengers can quickly and correctly don. (A-10-85)

> Conduct research on, and require 14 *Code of Federal Regulations* Part 121, Part 135, and Part 91 Subpart K operators to implement, creative and effective methods of overcoming passengers' inattention and providing them with safety information. (A-10-86)

The National Transportation Safety Board makes the following recommendation to the U.S. Department of Agriculture:

> Develop and implement, in conjunction with the Federal Aviation Administration, innovative technologies that can be installed on aircraft that would reduce the likelihood of a bird strike. (A-10-87)

The National Transportation Safety Board makes the following recommendations to the European Aviation Safety Agency:

> Modify the small and medium flocking bird certification test standard in *Joint Aviation Regulations*–Engines to require that the test be conducted using the lowest expected fan speed, instead of 100-percent fan speed, for the minimum climb rate. (A-10-88)

> During the bird-ingestion rulemaking database (BRDB) working group's reevaluation of the current engine bird-ingestion certification regulations, specifically reevaluate the *Joint Aviation Regulations*–Engines (JAR-E) large flocking bird certification test standards to determine whether they should 1) apply to engines with an inlet area of less than 3,875 square inches and 2) include a requirement for engine core ingestion. If the BRDB working group's reevaluation determines that such requirements are needed, incorporate them into JAR-E and require that newly certificated engines be designed and tested to these requirements. (A-10-89)

> Require manufacturers of turbine-powered aircraft to develop a checklist and procedure for a dual-engine failure occurring at a low altitude. (A-10-90)

> Require applicants for aircraft certification to demonstrate that their ditching parameters can be attained without engine power by pilots without the use of exceptional skill or strength. (A-10-91)

> Require Airbus to redesign the frame 65 vertical beam on A318, A319, A320, and A321 series airplanes to lessen the likelihood that it will intrude into the cabin during a ditching or gear-up landing and Airbus operators to incorporate these changes on their airplanes. (A-10-92)

> Require, on all new and in-service transport-category airplanes, that cabin safety equipment be stowed in locations that ensure that life rafts and/or slide/rafts remain accessible and that sufficient capacity is available for all occupants after a ditching. (A-10-93)

> Require quick-release girts and handholds on all evacuation slides and ramp/slide combinations. (A-10-94)

> Require modifications to life vest stowage compartments or stowage compartment locations to improve the ability of passengers to retrieve life vests for all occupants. (A-10-95)

4.2 Previously Issued Safety Recommendation Resulting From This Accident

As a result of this investigation, the National Transportation Safety Board issued the following safety recommendation to the Federal Aviation Administration on October 7, 2009:

> Modify [FAA] radar data processing systems so that air traffic controllers can instruct the systems to process the discrete transponder code of an aircraft experiencing an emergency as if it were an emergency transponder code. (A-09-112)

> For additional information about this safety recommendation, see section 1.18.2.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

DEBORAH A.P. HERSMAN
Chairman

ROBERT L. SUMWALT
Member

CHRISTOPHER A. HART
Vice Chairman

Adopted: May 4, 2010

Member Sumwalt filed the following concurring statement on May 6, 2010.

Board Member Statement

Member Sumwalt, Concurring:

I sincerely appreciate the hard work that the NTSB's staff has done to complete this investigation, and I fully support the findings, probable cause, and recommendations of this report. I truly believe the recommendations contained in this report, if implemented, will improve safety for the flying public.

Through this concurring statement, I would like to amplify why I believe this event was a "forced landing on water" rather than a "ditching."

My persistence on this matter is not one of merely arguing semantics; I know the public and the transportation community turn to the NTSB to get it right. As evidenced by many of the party submissions and comments I have heard – both before and after the Board Meeting – it is apparent some believe, that, on this issue, we may have fallen short of getting it entirely right.

When I asked staff during the Board Meeting why they believed this was a ditching instead of a forced landing, they replied that the crew had available options, but chose to land in the water. To the contrary, however, the captain of US Airways 1549 testified that landing on the Hudson River was his only viable option. If other options were available that would have ensured the same level of safety for his passengers and crew, I highly suspect he would have chosen those options before committing to land on the Hudson.

Admittedly, we are constrained by the lack of a formal regulatory definition of ditching, but in a footnote of a 1985 safety study, the NTSB stated:

"[Ditching] usually means a planned event in which the flight crew, with the aircraft under control, knowingly attempts to land in water. In contrast to an inadvertent water impact, in which there is no time for passenger or crew preparation, ditching allows some time for donning life preservers, etc."

The circumstances of this accident defy the NTSB's own criteria for use of the term. Those criteria state that a ditching allows "some time" for preparation. In the case of US Airways 1549, there was insufficient time for much of anything. For example, only two of the 155 aircraft occupants donned life preservers prior to the water landing. It is clear in my mind that the lack of sufficient time was the constraining factor; had more time existed, and had the occupants been made aware of the impending water landing, many more – if not all - would have located and donned the life preservers.

The US Airways Flight Attendant Inflight Emergency Manual states that, "[a] planned emergency allows time to prepare the passengers, aircraft and airport…." The manual further says that the captain will inform flight attendants of the emergency situation, using the acronym

"TEST." When asked in the Board Meeting why this was not done, staff conceded this could have been due to lack of available time.

The flight crew did not complete the "Engine Dual Failure" checklist which contained procedures on ditching, nor did they initiate the separate "Ditching" checklist. Section 2.3 of the accident report says that the crew was not able to complete the checklist "because of the airplane's low altitude and the limited time available."

There was only one minute, fifteen seconds from the time the captain told the air traffic controller that he couldn't make Teterboro Airport and uttered those bone-chilling words, "We're gonna be in the Hudson," until the actual touchdown.

I question whether having one minute, fifteen seconds is sufficient to consider a landing as "planned." I believe they reacted to their only viable option and landed where they could, instead of a "planned water event in which the flight crew… knowingly attempts to land in water."

Testimony from the public hearing indicated that there are unique attributes of a planned ditching that include the flight crew going through checklists, preparing the cabin crew, and having the passengers prepared. In the case of US Airways 1549, the crew didn't have time to go through the ditching checklist, they didn't have time to prepare the cabin, and the passengers were not prepared for the water landing.

For the above reasons, I believe US Airways 1549 was a forced landing on water as opposed to a ditching.

This point aside, whether we call this event a forced landing or a ditching, the objective of this investigation and its ensuing report is to help improve the outcome should future crews find themselves in the situation faced by this crew. The report produced by staff does exactly that. Therefore, I support the report's findings, probable cause, and recommendations.

5. Appendixes

Appendix A

Investigation and Public Hearing

Investigation

The National Transportation Safety Board (NTSB) was initially notified of this accident on January 15, 2009. A go-team was assembled in Washington, D.C., and traveled to the accident scene. The go-team was accompanied by former Board Member Kitty Higgins.

The following investigative groups were formed: Operations and Human Performance, Aircraft Systems, Aircraft Structures, Aircraft Powerplants, Maintenance Records, Aircraft Performance, Air Traffic Control, Wildlife Factors, Survival Factors, and Emergency Response. Also, specialists were assigned to conduct the readout of the flight data recorder and transcribe the cockpit voice recorder at the NTSB's laboratory in Washington, D.C.

Parties to the investigation were the Federal Aviation Administration (FAA), US Airways, US Airline Pilots Association (USAPA), Airbus Industrie, CFM International (CFM), International Association of Machinists, Association of Flight Attendants (AFA), and National Air Traffic Controllers Association. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Bureau d'Enquêtes et d'Analyses participated in the investigation as the representative of the State of Design and Manufacture (Airframe and Engines).

Public Hearing

A public hearing was held from June 9 through 11, 2009, in Washington, D.C. Board Member Robert Sumwalt presided over the hearing.

The issues presented at the public hearing were pilot training regarding ditching and forced landings on water; bird detection and mitigation efforts; certification standards for ditching and forced landings on water for transport-category airplanes; cabin safety, including training, procedures, and equipment; and certification standards for bird ingestion into transport-category airplane engines. Parties to the public hearing were the FAA, US Airways, USAPA, Airbus Industrie, CFM, and AFA.

Appendix B

Cockpit Voice Recorder Transcript

The following is the transcript of the Allied Signal/Honeywell cockpit voice recorder, serial number 2878, installed on the Airbus A320-214 airplane that experienced an almost total loss of thrust in both engines and was subsequently ditched on the Hudson River.

LEGEND

ATIS	Radio transmission from the Automated Terminal Information System
RDO	Radio transmission from accident aircraft, US Airways 1549
CAM	Cockpit area microphone voice or sound source
PA	Voice or sound heard on the public address system channel
HOT	Hot microphone voice or sound source[158]
INTR	Interphone communication to or from ground crew

For RDO, CAM, PA, HOT and INTR comments:

-1	Voice identified as the Captain
-2	Voice identified as the First Officer
-3	Voice identified as cabin crewmember
-4	Voice identified as groundcrew
-?	Voice unidentified

FWC	Automated callout or sound from the Flight Warning Computer
TCAS	Automated callout or sound from the Traffic Collision Avoidance System
PWS	Automated callout or sound from the Predictive Windshear System
GPWS	Automated callout or sound from the Ground Proximity Warning System

[158] This recording contained audio from Hot microphones used by the flightcrew. The voices or sounds on these channels were also, at times, heard by the CVR group on the CAM channel and vice versa. In these cases, comments are generally annotated as coming from the source (either HOT or CAM) from which the comment was easiest to hear and discern.

EGPWS	Automated callout or sound from the Enhanced Ground Proximity Warning system
RMP	Radio transmission from ramp control at LaGuardia
GND	Radio transmission from ground control at LaGuardia
CLC	Radio transmission from clearance delivery at LaGuardia
TWR	Radio transmission from the Air Traffic Control Tower at LaGuardia
DEP	Radio transmission from LaGuardia departure control
4718	Radio transmission from another airplane (Eagle flight 4718)
CH[1234]	CVR Channel identifier 1=Captain 2= First Officer 3= PA 4= Cockpit Area Microphone
*	Unintelligible word
@	Non-Pertinent word
&	Third party personal name (see note 5 below)
#	Expletive
-, - - -	Break in continuity or interruption in comment
( )	Questionable insertion
[ ]	Editorial insertion
...	Pause

Note 1: Times are expressed in Eastern Standard Time (EST), based on the clock used to timestamp the recorded radar data from the Newark ASR-9.

Note 2: Generally, only radio transmissions to and from the accident aircraft were transcribed.

Note 3: Words shown with excess vowels, letters, or drawn out syllables are a phonetic representation of the words as spoken.

Note 4: A non-pertinent word, where noted, refers to a word not directly related to the operation, control or condition of the aircraft.

Note 5: Personal names of 3rd parties not involved in the conversation are generally not transcribed.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:00:32 [Start of Recording]			
15:00:32 [Start of Transcript]			
		15:00:32 **ATIS**	expressway visual runway three one approach in use. depart runway four, bravo four hold line in use. LaGuardia class bravo services available on frequency one two six point zero five. all pilots read back all hold short instructions and assigned altitudes. advise on initial contact you have information papa... LaGuardia airport information papa. one nine five one zulu. winds three four zero at one three, visibility one zero. ceiling three thousand five hundred broken. temperature minus six dewpoint minus one four. altimeter three zero two three. remarks A O two sea level pressure two three four. [ATIS repeats on ch2 until time 15:02:44.]
15:02:19 **CAM-1**	yes, thank you.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:02:21 **CAM-1**	so we should have two open seats (cause) the jumpseaters are gonna sit in the back.		
15:02:25 **CAM-?**	thank you.		
15:02:26 **CAM-1**	all right anytime.		
15:02:27 **CAM-?**	cool you bet.		
15:02:30 **CAM-?**	ok.		
15:02:35 **HOT-2**	the seats uh-		
15:02:37 **HOT-1**	there you go.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:02:45 **CAM-?**	do you mind if I keep my bag(s) up here?		
15:02:47 **CAM-1**	no not at all.		
15:02:48 **CAM-?**	thank you so much.		
15:02:51 **PA-1**	a quick hello from the cockpit crew, this is fifteen forty nine bound for Charlotte. its a nice day for flying, be at thirty eight thousand feet mostly smooth about an hour and forty five minutes takeoff to landing, welcome aboard.		
15:03:12 **CAM-2**	quite a difference in the flight time pretty incredible, huh? fifty six minutes.		
15:03:15 **HOT-1**	well we had a hundred and sixty knots of wind all the way up here. its a average headwind on this lists minus one ten.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:03:34 **HOT-1**	all right.		
15:03:34 **PA-3**	if everyone would please take their seats.		
15:03:39 **HOT-1**	* *.		
		15:03:40 **INTR-4**	hello cockpit ground's ready.
		15:03:42 **INTR-1**	we'll give them a call.
		15:03:42 **RDO-2**	(ground) fifteen forty nine like to push at uh gate twenty one.
		15:03:47 **RMP**	Cactus (fifteen) forty nine....gate twenty one, spot twenty eight, ground * for your taxi.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:03:55 **RDO-2**	ok uh. that's uh * what's wrong here. [may be multiple mic keys]
15:03:57 **HOT-1**	ok... clear to push?		
15:04:00 **HOT-2**	yeah.		
		15:04:01 **INTR-4**	yes sir, you say you are clear to push?
		15:04:02 **INTR-1**	clear to push, spot twenty eight, brakes released.
		15:04:03 **RDO-2**	and that's uh spot twenty eight for Cactus uh nine- er fifteen forty nine, excuse me and over to ground twenty one seven.
		15:04:05 **INTR-4**	twenty eight, brakes released.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:04:09 **RMP**	affirmative.
15:04:09 **CAM-?**	seated and stowed.		
15:04:11 **HOT-1**	thank you, all set.		
15:04:13 **CAM**	[sound similar to cockpit door closing]		
15:04:20 **HOT-1**	ok. that # door again.		
15:04:23 **HOT-2**	what's wrong?		
15:04:24 **HOT-1**	this-		
15:04:25 **HOT-2**	oh.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:04:25 **CAM-1**	(you) have to slam it pretty hard.		
15:04:29 **CAM**	[sound similar to cockpit door closing]		
15:04:52 **HOT-1**	got the newest Charlotte.		
15:05:04 **PA-3**	ladies and gentlemen all electronic devices have to be turned off at this time, anything with an on off button must be in the off position.		
15:05:07 **HOT-1**	yeah too bad they aren't still using three one... for takeoff.		
15:05:10 **HOT-2**	yeah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:05:11 **HOT-1**	I was hoping we could land on four and takeoff on three one, but it didn't quite work out that way.		
15:05:22 **HOT-2**	well we can make an attempt to beat Northwest here anyways.		
15:05:25 **HOT-1**	what's that?		
15:05:26 **HOT-2**	so we can make an attempt to beat Northwest but he's already starting isn't he.		
15:05:29 **HOT-1**	yeah. and we have to pull up before we can even start on this.		
15:05:32 **HOT-2**	they start their number two engine first.		
15:05:34	good afternoon ladies and gentlemen welcome on		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
PA-3	board US Airways flight fifteen forty nine, with service to Charlotte. please take a moment to listen to this important safety information, in preparation for departure be certain that your seat back is straight up and your tray table is stowed. all carryon items must be secured completely underneath the seat in front of you, or stowed in an overhead compartment. please use caution when placing items in or removing them from the overhead bins. please ensure that all electronic devices are turned off, some devices such as cell phones, TVs, radios and any device transmitting a signal may not be used at anytime during flight. however you may be certain * * use other electronic devices when advised by your crew. please direct your attention to the flight attendants in the cabin, for everyone's safety regulations require your compliance with all lighted signs, placards, and crewmember instructions. whenever the seatbelt sign is illuminated please make sure that you seatbelt is fastened low and tight around your hips. to fasten insert the metal fitting into the buckle and tighten by pulling loose end away from you. to release lift the metal flap. during the flight the Captain may turn off the fasten seatbelt sign, however for safety we recommend that you keep your seatbelt fastened at all times. please review the safety instruction card in the seatback pocket in front of you, it explains the safety features of this aircraft as well as the location and		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
	operation of the exit and flotation devices. your seat cushion serves as a flotation device, to remove your cushion, (pla)- take it with you to the nearest usable exit, when exiting the-[sound similar to power interruption 15:07:01] place both arms through the straps and hug it to your chest. flight attendants are pointing out there are a total of eight exits on this aircraft, two door exits in front of the aircraft, four window exits over the wings, and two door exits in the rear of the aircraft. once again, two door exits at the front of the aircraft, four window exits over the wings, and two door exits in the rear of the aircraft. each door is equipped with an evacuation slide if directed to exit... the aircraft jump onto the slide and move away from the aircraft. take a moment to locate the exit nearest you keeping in mind that the closest usable exit may be located behind you. if there is a loss of electrical power low level lighting will guide you to the exits indicated by illuminated exit signs. if needed oxygen masks will be released from the overhead, to start the flow of oxygen, reach up and pull the mask toward you, fully extending the plastic tubing. place the mask over your nose and mouth, place the elastic band over your head. to tighten pull the tab on each side of the mask. the plastic bag does not inflate when oxygen is flowing. secure your mask before assisting others. as a reminder smoking is prohibited in all areas of the aircraft including the		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
	lavatories. federal regulations prohibit tampering with disabling or destroying a lavatory smoke detector. on behalf of your entire crew, its our pleasure to have you on board.... thank you for flying US Airways.		
15:05:34 **HOT-1**	that's interesting.		
15:05:41 **HOT-2**	did you always start number one or is that a uh America West thing?		
15:05:44 **HOT-1**	no that's no its been that way ever since I've been on it, for six and a half years anyway.		
		15:06:09 **INTR-1**	confirm we're clear to start?
		15:06:10 **INTR-4**	uh, one second.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:06:13 **HOT-1**	he told me to wait.		
15:06:15 **HOT-2**	he did?		
15:06:16 **HOT-1**	yeah, this guy was giving the signal but I asked and he said no wait just a second.		
15:06:17 **HOT-2**	yeah.... OK.		
		15:06:25 **INTR-4**	kay. clear to start.
		15:06:26 **INTR-1**	clear to start.
15:06:26 **HOT-1**	start engines.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:06:44 **HOT-2**	wonder how the Northwest and Delta pilots are gettin on.		
15:06:47 **HOT-1**	I wonder about that too, I have no idea.		
15:07:01 **CAM**	[sound similar to power interruption]		
15:07:01 **CAM**	[sound similar to increase in engine noise/frequency]		
15:07:04 **HOT-1**	yeah hopefully better than we and West do.		
15:07:11 **HOT-2**	be hard to do worse.		
15:07:13 **HOT-1**	yeah... well I hadn't heard much about it lately but I can't imagine it'd be any better.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:07:20 **HOT-2**	I think that's just cause we're separate..... and there's nothing going on right now.		
15:07:25 **HOT-1**	right.		
		15:07:28 **INTR-4**	kay set the parking brake.
		15:07:32 **INTR-1**	parking brake set. disconnect.
		15:07:34 **INTR-4**	brake set, disconnect.
15:08:15 **HOT-1**	okay wands up, wave off.		
15:08:16 **HOT-2**	wands up.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:08:17 **HOT-1**	flaps two, taxi.		
		15:08:36 **RDO-2**	ground Cactus uh fifteen forty nine spot twenty eight, taxi please.
		15:08:40 **GND**	Cactus fifteen forty nine LaGuardia ground runway four uh, turn left alpha, short of golf, and uh did you call clearance?
		15:08:48 **RDO-2**	(I'm) sorry forgot.
15:08:48 **HOT-1**	*.		
15:08:52 **HOT-1**	uh thirty five two. so its alpha short of golf is that right?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:08:56 **HOT-2**	yup.		
15:08:57 **HOT-1**	yeah I'll start taxiing while you do that.		
15:08:58 **HOT-2**	ok.		
		15:09:35 **RDO-2**	Cactus fifteen forty nine is uh over BIGGY seven one three four, and three sixty and up to five thousand.
15:09:44 **HOT-1**	you put it here.		
15:09:46 **HOT-2**	what was that?... am I on the wrong one?		
15:09:53 **HOT-1**	you switched me off of ground.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:09:55 **HOT-2**	oh, sorry.		
15:09:57 **HOT-?**	* you wanna be there [heard on CH2]		
15:10:04 **HOT-1**	you were talking on number two but you switched number one.		
15:10:07 **HOT-2**	ok.		
		15:10:11 **RDO-2**	I'm sorry I messed up my radio here Cactus fifteen forty nine, seven one three four and we're three sixty up to five thousand.
		15:10:40 **RDO-2**	Cactus-

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:10:41 **RDO-2**	Cactus fifteen forty nine is uh squawking seven one three four and were uh runway four three sixty and five thousand.
		15:10:48 **CLC**	(kay it's) fifteen forty nine LaGuardia clearance read *back correct, ground point seven verify information papa.
		15:10:53 **RDO-2**	we have papa.
		15:10:54 **RDO-2**	we have papa thank you Cactus uh * fifteen forty nine.
		15:10:58 **CLC**	ground point seven.
15:11:05 **HOT-2**	ok.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:11:06 **HOT-1**	ok no change.		
15:11:08 **HOT-2**	I don't think my uh MIC switch works all the time here.		
15:11:12 **HOT-1**	your trigger, your trigger?		
15:11:12 **CAM-2**	* * transmit.		
15:11:14 **CAM-2**	what's that?		
15:11:15 **HOT-1**	your trigger on the stick? ... I'll write that up too.		
15:11:18 **CAM-2**	so you don't hear me transmit... you might wanna jump in.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:11:21 **HOT-1**	ok.... got it.		
		15:11:25 **RDO-1**	and OPS, fifteen forty nine.
15:11:28 **HOT-1**	I'm calling on number two.		
		15:11:31 **OPS**	yeah, (sixteen) forty nine go ahead.
		15:11:33 **RDO-1**	yeah fifteen forty nine if you want uh weight and balance uh corrected to total of passenger one forty eight and ACM [additional crew members] two.
		15:11:42 **OPS**	ok one forty eight.
		15:11:51 **RDO-1**	yeah for fifteen forty nine passenger count is one four eight, plus ACM two.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:12:00 **RDO-1**	so one forty eight, plus two ACM's.
		15:12:02 **OPS**	ok. copy that.
15:12:08 **HOT-1**	all right... I'm still holding short of golf, and they're correcting the passenger count to one forty eight.		
		15:12:25 **GND**	Cactus fifteen forty nine taxi foxtrot, bravo hold short echo, just gotta hold you there for about three minutes uh for your uh in trail into Charlotte.
		15:12:31 **RDO-2**	foxtrot, bravo, short of echo, Cactus fifteen forty nine.
15:12:35 **HOT-1**	ok, foxtrot, bravo, hold short of echo... and once we stop then, I'll do the flight control check.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:12:57 **HOT-1**	did it uh, did it not uplink?		
15:13:01 **HOT-2**	(well) I figured it was the old one.		
15:13:04 **HOT-1**	what's that?		
15:13:06 **HOT-2**	umm.... ok.		
15:13:18 **HOT-2**	so do you want me to use this one?		
15:13:19 **HOT-1**	oh... oh I see what you're saying, yeah I uh you can wait if you want I just thought we'd have something in there.		
15:13:37 **HOT-1**	yeah we can wait, that's fine.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:13:38 **HOT-2**	go with this one? ok.		
15:13:40 **HOT-1**	cause we're going to be holding here for a minute anyway.... all right foxtrot, bravo, hold short of echo.		
15:14:15 **HOT-1**	where is the uh, the portion of the release the- of the weight and balance part of it that was below what you tore off to put on here... or was there part of it.		
15:14:24 **HOT-2**	there was, I think I threw it away it just had names on it... its right here.		
15:14:26 **HOT-1**	ok thank you. I need this number, yeah I wanted this part... I'm gonna just call this guy directly cause I don't think this OPS guy knows what the # he's doin.		
15:15:04 **HOT-1**	I'm just gonna call our load control agent directly, it's his number right here.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:15:12 **FWC**	[sound of single chime]		
15:15:15 **HOT-1**	yeah I'm the Captain on fifteen forty nine aircraft one zero six if you'll if you will please correct the passenger count we have a total of one four eight, plus two plus two ACM. [sounds as if this communication is by cellular telephone]		
		15:15:19 **GND**	Cactus fifteen forty nine follow the Northwest you can monitor tower.
		15:15:23 **RDO-2**	Cactus fifteen forty nine follow Northwest monitor tower, thank you.
15:15:32 **HOT-1**	that's it... thank you. runway four, thank you, bye. [sounds as if communication is by cellular telephone]		
15:15:38 **HOT-1**	what did I miss?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:15:40 **HOT-2**	follow Northwest.		
15:15:41 **HOT-1**	all right here we go.		
15:15:49 **HOT-1**	* I talked to CLP [Central Load Plan] he's gonna send it.		
15:15:54 **HOT-1**	all right, flight control check.		
15:15:57 **CAM-2**	full up........full down.		
15:16:01 **HOT-2**	neutral.		
15:16:03 **HOT-2**	full left.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:16:06 **HOT-2**	full right.		
15:16:07 **HOT-2**	neutral.		
15:16:09 **HOT-2**	full left.		
15:16:11 **HOT-2**	full right.		
15:16:13 **HOT-2**	neutral.		
15:17:26 **HOT-1**	I'll go ahead and sit them down.		
15:17:30 **PA-1**	flight attendants please be seated for takeoff.		
15:17:33 **HOT-2**	kay.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:18:03 **HOT-1**	okay, taxi check.		
15:18:07 **HOT-2**	* *.		
15:18:19 **HOT-2**	departure briefing, FMS. [Flight Management System]		
15:18:21 **HOT-1**	reviewed runway four.		
15:18:22 **HOT-2**	flaps verify. two planned, two indicated.		
15:18:24 **HOT-1**	two planned, two indicated.		
15:18:46 **HOT-2**	um. takeoff data verify... one forty, one forty five, one forty nine, TOGA. [Takeoff/Go Around]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:18:53 **HOT-1**	one forty, one forty five, one forty nine, TOGA.		
15:18:56 **HOT-2**	the uh weight verify, one fifty two point two.		
15:19:00 **HOT-1**	one fifty two point two.		
15:19:02 **HOT-2**	flight controls verify checked.		
15:19:03 **HOT-1**	check.		
15:19:04 **HOT-2**	stab and trim verify, thirty one point one percent... and zero.		
15:19:08 **HOT-1**	thirty one point one percent, zero.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:19:11 **HOT-2**	the uh.... engine anti-ice.		
15:19:13 **HOT-1**	is off.		
15:19:16 **CAM-2**	ECAM [Electronic Centralized Aircraft Monitoring] verify takeoff, no blue, status checked.		
15:19:19 **HOT-1**	takeoff, no blue, status checked.		
15:19:22 **PA-2**	ladies and gentlemen at this time we're number one for takeoff, flight attendants please be seated.		
15:19:25 **HOT-1**	* *.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:19:27 **HOT-2**	takeoff min fuel quantity verify. nineteen thousand pounds required we got twenty one point eight on board.		
15:19:32 **HOT-1**	nineteen thousand pounds required, twenty one eight on board.		
15:19:35 **HOT-2**	flight attendants notified, engine mode is normal, the taxi checklist is complete sir.		
15:19:40 **HOT-1**	below the line... oh you finished it all * * -		
15:19:42 **CAM-2**	yeah.		
15:19:42 **HOT-1**	-yeah kay thank you. we're good. holding short.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:20:03 **HOT-1**	still possible.		
15:20:06 **CAM-2**	oh yeah.		
		15:20:37 **TWR**	Cactus fifteen forty nine, LaGuardia runway four position and hold. traffic to land three one.
		15:20:40 **RDO-2**	position and hold runway four, Cactus uh fifteen forty nine.
15:20:42 **HOT-1**	on the hold.		
15:20:44 **CAM**	[sound similar to increase then decrease in engine noise/frequency]		
15:21:27 **HOT-1**	your brakes, your aircraft.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:21:30 **HOT-2**	my aircraft.		
15:21:48 **HOT-1**	he's gotta *.		
		15:24:54 **TWR**	Cactus fifteen forty nine runway four clear for takeoff.
		15:24:56.7 **RDO-1**	Cactus fifteen forty nine clear for takeoff.
15:25:06 **CAM**	[sound similar to increase in engine noise/speed]		
15:25:09 **CAM-2**	TOGA.		
15:25:10 **HOT-1**	TOGA set.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:25:20 **HOT-1**	eighty.		
15:25:21 **HOT-2**	checked.		
15:25:33 **HOT-1**	V one, rotate.		
15:25:38 **HOT-1**	positive rate.		
15:25:39 **HOT-2**	gear up please.		
15:25:39 **HOT-1**	gear up.		
		15:25:45 **TWR**	Cactus fifteen forty nine contact New York departure, good day.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:25:48 **RDO-1**	good day.
15:25:49 **HOT-2**	heading select please.		
		15:25:51.2 **RDO-1**	Cactus fifteen forty nine, seven hundred, climbing five thousand.
		15:26:00 **DEP**	Cactus fifteen forty nine New York departure radar contact, climb and maintain one five thousand.
15:26:02 **CAM**	[sound similar to decrease in engine noise/speed]		
		15:26:03.9 **RDO-1**	maintain one five thousand Cactus fifteen forty nine.
15:26:07 **HOT-1**	fifteen.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:26:08 **HOT-2**	fifteen. climb.		
15:26:10 **HOT-1**	climb set.		
15:26:16 **HOT-2**	and flaps one please.		
15:26:17 **HOT-1**	flaps one.		
15:26:37 **HOT-1**	uh what a view of the Hudson today.		
15:26:42 **HOT-2**	yeah.		
15:26:52 **HOT-2**	flaps up please, after takeoff checklist.		
15:26:54 **HOT-1**	flaps up.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:27:07 **HOT-1**	after takeoff checklist complete.		
15:27:10.4 **HOT-1**	birds.		
15:27:11 **HOT-2**	whoa.		
15:27:11.4 **CAM**	[sound of thump/thud(s) followed by shuddering sound]		
15:27:12 **HOT-2**	oh #.		
15:27:13 **HOT-1**	oh yeah.		
15:27:13 **CAM**	[sound similar to decrease in engine noise/frequency begins]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:27:14 **HOT-2**	uh oh.		
15:27:15 **HOT-1**	we got one rol- both of 'em rolling back.		
15:27:18 **CAM**	[rumbling sound begins and continues until approximately 15:28:08]		
15:27:18.5 **HOT-1**	ignition, start.		
15:27:21.3 **HOT-1**	I'm starting the APU.		
15:27:22.4 **FWC**	[sound of single chime]		
15:27:23.2 **HOT-1**	my aircraft.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:27:24 **HOT-2**	your aircraft.		
15:27:24.4 **FWC**	[sound of single chime]		
15:27:25 **CAM**	[sound similar to electrical noise begins]		
15:27:26.5 **FWC**	priority left. [auto callout from the FWC. this occurs when the sidestick priority button is activated on the Captain's sidestick]		
15:27:26.5 **FWC**	[sound of single chime]		
15:27:28 **CAM**	[sound similar to electrical noise ends]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:27:28 **HOT-1**	get the QRH... [Quick Reference Handbook] loss of thrust on both engines.		
15:27:30 **FWC**	[sound of single chime begins and repeats at approximately 5.7 second intervals until 15:27:59]		
		15:27:32.9 **RDO-1**	mayday mayday mayday. uh this is uh Cactus fifteen thirty nine hit birds, we've lost thrust (in/on) both engines we're turning back towards LaGuardia.
		15:27:42 **DEP**	ok uh, you need to return to LaGuardia? turn left heading of uh two two zero.
15:27:43 **CAM**	[sound similar to electrical noise begins]		
15:27:44 **FWC**	[sound of single chime, between the single chimes at 5.7 second intervals]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:27:46 **RDO-1**	two two zero.
15:27:50 **HOT-2**	if fuel remaining, engine mode selector, ignition.* ignition.		
15:27:54 **HOT-1**	ignition.		
15:27:55 **HOT-2**	thrust levers confirm idle.		
15:27:58 **HOT-1**	idle.		
15:28:02 **HOT-2**	airspeed optimum relight. three hundred knots. we don't have that.		
15:28:03 **FWC**	[sound of single chime]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:28:05 **HOT-1**	we don't.		
		15:28:05 **DEP**	Cactus fifteen twenty nine, if we can get it for you do you want to try to land runway one three?
15:28:05 **CAM-2**	if three nineteen-		
		15:28:10.6 **RDO-1**	we're unable. we may end up in the Hudson.
15:28:14 **HOT-2**	emergency electrical power... emergency generator not online.		
15:28:18 **CAM**	[sound similar to electrical noise ends]		
15:28:19 **HOT-1**	(it’s/is) online.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:28:21 **HOT-2**	ATC notify. squawk seventy seven hundred.		
15:28:25 **HOT-1**	yeah. the left one's coming back up a little bit.		
15:28:30 **HOT-2**	distress message, transmit. we did.		
		15:28:31 **DEP**	arright Cactus fifteen forty nine its gonna be left traffic for runway three one.
		15:28:35 **RDO-1**	unable.
15:28:36 **TCAS**	traffic traffic.		
		15:28:36 **DEP**	okay, what do you need to land?

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:28:37 **HOT-2**	(he wants us) to come in and land on one three...for whatever.		
15:28:45 **PWS**	go around. windshear ahead.		
15:28:45 **HOT-2**	FAC [Flight Augmentation Computer] one off, then on.		
		15:28:46 **DEP**	Cactus fifteen (twenty) nine runway four's available if you wanna make left traffic to runway four.
		15:28:49.9 **RDO-1**	I'm not sure we can make any runway. uh what's over to our right anything in New Jersey maybe Teterboro?
		15:28:55 **DEP**	ok yeah, off your right side is Teterboro airport.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:28:59 **TCAS**	monitor vertical speed.		
15:29:00 **HOT-2**	no relight after thirty seconds, engine master one and two confirm-		
		15:29:02 **DEP**	you wanna try and go to Teterboro?
		15:29:03 **RDO-1**	yes.
15:29:05 **TCAS**	clear of conflict.		
15:29:07 **HOT-2**	-off.		
15:29:07 **HOT-1**	off.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:29:10 **HOT-2**	wait thirty seconds.		
15:29:11 **PA-1**	this is the Captain brace for impact.		
15:29:14.9 **GPWS**	one thousand.		
15:29:16 **HOT-2**	engine master two, back on.		
15:29:18 **HOT-1**	back on.		
15:29:19 **HOT-2**	on.		
		15:29:21 **DEP**	Cactus fifteen twenty nine turn right two eight zero, you can land runway one at Teterboro.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:29:21 **CAM-2**	is that all the power you got? * (wanna) number one? or we got power on number one.		
		15:29:25 **RDO-1**	we can't do it.
15:29:26 **HOT-1**	go ahead, try number one.		
		15:29:27 **DEP**	kay which runway would you like at Teterboro?
15:29:27 **FWC**	[sound of continuous repetitive chime for 9.6 seconds]		
		15:29:28 **RDO-1**	we're gonna be in the Hudson.
		15:29:33 **DEP**	I'm sorry say again Cactus?

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:29:36 **HOT-2**	I put it back on.		
15:29:37 **FWC**	[sound of continuous repetitive chime for 37.4 seconds]		
15:29:37 **HOT-1**	ok put it back on... put it back on.		
15:29:37 **GPWS**	too low. terrain.		
15:29:41 **GPWS**	too low. terrain.		
15:29:43 **GPWS**	too low. terrain.		
15:29:44 **HOT-2**	no relight.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:29:45.4 **HOT-1**	ok lets go put the flaps out, put the flaps out.		
15:29:45 **EGPWS**	caution. terrain.		
15:29:48 **EGPWS**	caution terrain.		
15:29:48 **HOT-2**	flaps out?		
15:29:49 **EGPWS**	terrain terrain. pull up. pull up.		
		15:29:51 **DEP**	Cactus uh....
		15:29:53 **DEP**	Cactus fifteen forty nine radar contact is lost you also got Newark airport off your two o'clock in about seven miles.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:29:55 **EGPWS**	pull up. pull up. pull up. pull up. pull up. pull up.		
15:30:01 **HOT-2**	got flaps out.		
15:30:03 **HOT-2**	two hundred fifty feet in the air.		
15:30:04 **GPWS**	too low. terrain.		
15:30:06 **GPWS**	too low. gear.		
15:30:06 **CAM-2**	hundred and seventy knots.		
15:30:09 **CAM-2**	got no power on either one? try the other one.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		15:30:09 **4718**	two one zero uh forty seven eighteen. I think he said he's goin in the Hudson.
15:30:11 **HOT-1**	try the other one.		
15:30:13 **EGPWS**	caution terrain.		
		15:30:14 **DEP**	Cactus fifteen twenty nine uh, you still on?
15:30:15 **FWC**	[sound of continuous repetitive chime begins and continues to end of recording]		
15:30:15 **EGPWS**	caution terrain.		
15:30:16 **HOT-2**	hundred and fifty knots.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:30:17 **HOT-2**	got flaps two, you want more?		
15:30:19 **HOT-1**	no lets stay at two.		
15:30:21 **HOT-1**	got any ideas?		
		15:30:22 **DEP**	Cactus fifteen twenty nine if you can uh....you got uh runway uh two nine available at Newark it'll be two o'clock and seven miles.
15:30:23 **EGPWS**	caution terrain.		
15:30:23 **CAM-2**	actually not.		
15:30:24 **EGPWS**	terrain terrain. pull up. pull up. ["pull up" repeats until the end of the recording]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
15:30:38 **HOT-1**	we're gonna brace.		
15:30:38 **HOT-2**	* * switch?		
15:30:40 **HOT-1**	yes.		
15:30:41.1 **GPWS**	(fifty or thirty)		
15:30:42 **FWC**	retard.		

15:30:43.7 [End of Recording]

15:30:43.7 [End of Transcript]

Appendix C

US Airways Engine Dual Failure Checklist

ENG DUAL FAILURE

1. **If no fuel remaining:**
   a. THR LEVERS .... Confirm .... IDLE
   b. EMER ELEC PWR (if EMER GEN not on-line) .... MAN ON
   c. FAC 1 .... OFF then ON

   [Resetting FAC 1 enables the recovery of characteristic speeds displayed on the PFD, and enables rudder trim recovery, even if no indication is available. Once hydraulic power is lost, the right aileron is lost, and is in the up float position. Rudder trim may be used to compensate for this up floating aileron.]

   d. Optimum speed .... Green Dot
   e. Landing Strategy .... Determine

   [Determine most appropriate place for forced landing/ditching.]

   f. ATC (VHF1, HF1, ATC1) .... Notify
      (1) If unable to contact ATC on assigned frequency:
         (a) ATC Code A7700
         (b) Distress Message .... Transmit

         [Use one of the following frequencies: VHF 121.5 MHz, HF 2182 KHz or 8364 KHz]

   g. Oxygen Masks (above 10,000') .... Verify .... ON
   h. Go to step 2.

or

If fuel remaining:
   a. ENG MODE Selector .... IGN
   b. THR LEVERS .... Confirm .... IDLE
   c. Airspeed .... Optimum relight speed 300 kts(CFM)/280 kts(IAE)

   (1) If A319 or A320:

   [For airspeed indication failure (volcanic ash) the pitch attitude for optimum relight speed is 4.5°(CFM)/ 2.5°(IAE) nose down. Add 1° nose up for each 22,000 lbs. above 110,000 lbs.

   CFM: At 300 kts, the aircraft can fly approximately 2.0 nautical miles per 1000 feet (no wind)

   IAE: At 280 kts, the aircraft can fly approximately 2.2 nautical miles per 1000 feet (no wind)]

   or

   If A321:

   [For airspeed indication failure (volcanic ash) the pitch attitude for optimum relight speed is 4.5° nose down.Add 1° nose up for each 22,000 lbs. above 132,000 lbs.

   At 300 kts, the aircraft can fly approximately 2.0 nautical miles per 1000 feet (no wind)]

   d. Landing Strategy .... Determine

   [Determine most appropriate place for forced landing/ditching.]

   e. EMER ELEC PWR (if EMER GEN not on-line) .... MAN ON
   f. ATC (VHF1, HF1, ATC1) .... Notify
      (1) If unable to contact ATC on assigned frequency:
         (a) ATC Code A7700
         (b) Distress Message .... Transmit

         [Use one of the following frequencies: VHF 121.5 MHz, HF 2182 KHz or 8364 KHz]

Cont'd

g. FAC 1 .... OFF then ON

[Resetting FAC 1 enables recovery of characteristic speeds displayed on the PFD and permits recovery of rudder trim even if no indication is available.]

If no relight after 30 seconds:

h. ENG MASTER 1 and 2 .... Confirm .... OFF

Wait 30 seconds:

i. ENG MASTER 1 and 2 .... ON

Note: Unassisted start attempts can be repeated until successful or until APU Bleed is available.

If unsuccessful:

j. CREW OXYGEN MASKS (Above 10,000')Verify .... ON

When below FL250:

k. APU .... START

l. WING ANTI ICE .... OFF

When below FL200:

m. APU BLEED .... ON

Note: If APU Bleed is available, APU Bleed assisted starts may be accomplished at Green Dot Speed.

n. ENG MASTER 1 and 2 .... Confirm .... OFF

Wait 30 seconds:

o. ENG MASTER 1 and 2 (one at a time) .... ON

2. **If engine restart is successful:**

   a. Proceed to nearest suitable airport for landing.

   b. Engine Dual Failure Checklist complete and

   - Clear non-applicable ECAM actions and review SYS Status page(s).
   - Establish and communicate a plan.

or

If engine restart is considered impossible:

a. Airspeed .... Optimum speed Green Dot

[Green dot is displayed on Captain's PFD. It represents best L/D. At Green dot speed the aircraft can fly up to approximately 2.5 nautical miles per 1000 feet with no wind. Average rate of descent is 1600 feet per minute.]

b. Early in approach:

(1) Cabin Secure .... Order

(2) CABIN SIGNS .... ON

(3) GALY & CAB (GALLEY) .... OFF

(4) COMMERCIAL pb (if installed) .... OFF

(5) Use rudder with care.

[Avoid large or rapid rudder deflection, as only blue hydraulic power is available from the RAT.]

(6) For landing .... Use FLAPS 3

[Only slats will extend and operating time is noticeably increased, as only blue hydraulic power is available from the RAT.]

Cont'd

Below 15000':

c. RAM AIR .... ON
d. BARO .... Set

Below 10000':

e. CREW OXYGEN MASKS .... OFF
f. OXYGEN CREW SUPPLY .... OFF
g. V_{APP} .... Determine

Note: A319/320 V_{REF} + 25/150 kts minimum

A321 V_{REF} + 30/160 kts minimum

3. **If Forced Landing is anticipated:**

Prior to 3000' AGL:

a. FLAPS .... Configure for Landing

Note: Final Descent slope when configured (CONF 3 and Gear Down) will be approximately 800-900 feet per minute with no wind.

When in CONF 3 and at V_{APP}:

b. GRAVITY GEAR EXTEN .... PULL & TURN

Note: Disregard "USE MAN PITCH TRIM" on the PFD. The stabilizer is frozen due to insufficient hydraulic power.

When L/G downlocked:

c. L/G Lever .... DOWN
d. GND SPOILER .... ARM
e. Max Brake Press .... 1000 psi

[Brakes on Accumulator only]

At 500'AGL:

f. Brace Signal .... Command

At touchdown:

g. ENG MASTER 1 and 2 .... OFF |
h. APU MASTER SW .... OFF
i. ENG DUAL FAILURE Checklist complete, and

☛ If required, go to "Evacuation" Checklist, on page i.

or

If Ditching is anticipated:

Prior to 3000' AGL:

a. FLAPS .... Configure for Landing
b. L/G Lever .... Check Up

At 2000' AGL:

c. Ditching pb .... ON

Note: In case of strong crosswind, ditch facing into the wind. In the absence of strong crosswind, ditch parallel to the swell. Touchdown with approximately 11 degrees of pitch and minimum vertical speed.

At 500'AGL:

d. Brace Signal .... Command

At touchdown:

e. ENG MASTER 1 and 2 .... OFF |
f. APU MASTER SW .... OFF
g. ENG DUAL FAILURE Checklist complete, and

☛ If required, go to "Evacuation" Checklist, on page i.

Appendix D

Bureau d'Enquetes et d'Analyses' Comments

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

Ministère
de l'écologie, de l'énergie,
du développement durable
et de la mer,
en charge des technologies vertes
et des négociations sur le climat

BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

1 Background

The BEA considers this event to be an emergency maneuver that led to ditching into the Hudson River. The crew had time to decide the strategy to follow but was not able to reach and apply the part of the check-list related to aircraft preparation and configuration for entry into water. For this reason, the BEA considers that this emergency ditching was not planned. The investigation showed that the regulations and procedures related to ditching situations are only partially adapted to this kind of situation.

The BEA comments are in no way intended to criticize the crew's actions. However, we wish that a clear distinction be made between crew actions that were adapted to the situation and ones that could be improved if a similar event occurred again.

For these reasons, the BEA suggests completing section 2.1 with the following paragraph :
"The crew's decision-making ensured the airplane occupants' survival, despite the unforeseeable nature of this event and the short time available for the preparation of the airplane. The investigation brought to light crew actions that favorably contributed to the outcome of this event, but also highlighted actions that could increase the chances of success, should a similar event occur again."

2 Ditching certification standards

2.1 Available thrust

Paragraph 1.6.7 describes the ditching certification criteria that are mentioned in section 25.801 of Part 25. During certification, it is required to investigate the probable behavior of the aircraft in a water landing either by tests with model or by comparison with other airplanes of similar configuration.
In other sections of Part 25, when the aircraft flight characteristics have to be demonstrated with one engine inoperative, it is specifically mentioned. Since section 25.801 does not mention any alteration of aircraft performance, the regulation assumes that the required demonstration shall be made on an aircraft with all engines operative.

Even if emergency situations other than a dual engine failure could require ditching, we consider that this kind of event should be taken into consideration in the certification regulations.

The BEA requests to have the factual part and analysis completed with the aforementioned considerations. We also request that the NTSB recommends to the FAA and EASA to complete the sections

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of Part 25 related to ditching so that the required demonstrations take into account situations where no thrust is available.

2.2 Comparison between the certification and the event

The factual section describes the certification criteria and the way the certification trials were conducted. However, there is some confusion in the use of the different sets of parameters. The report should clearly distinguish the parameters that were determined during certification in order to minimize the structural damage from the recommended parameters, mentioned in the QRH check-list.

The certification regulations only consider general and not quantitative criteria that are mentioned in paragraph 1.6.7. The manufacturer ditching values for speed, FPA and pitch are not the only ones that would allow these criteria to be met. In fact, the event shows that with significantly different values, the number of injuries was minimized and the floatation time was sufficient to allow the evacuation of all the occupants.

Nevertheless, the aft structural damage likely prevented the passengers from evacuating through the aft emergency exits, which confirms the interest of the discussion related to descent rate reduction before impact. However the comparison between certification and this unique event should be mitigated by taking into account the fact that the speed and configuration were very different from the ones recommended by the manufacturer.

To allow a better understanding of the relationship between the certification criteria and the event, the BEA requests that the aforementioned information be explicitly mentioned in the report analysis, before any consideration on the airspeed, the configuration and the flight envelope protection.
The BEA also requests that paragraph 2.6.3 be placed before paragraph 2.6. The discussions related to compliance with the ditching certification criteria are not directly related to the ones related to flight envelope protection (see following section).

The manufacturer considers that, in this type of situation, the structure should necessarily deform, and even sustain internal damage, in order to absorb the energy from the collision, as long as there is no risk of injury for the occupants and this damage does not impede the evacuation.

For this reason, the BEA considers that the « assumption of an intact fuselage » in paragraph 2.6.3 is erroneous and should be replaced by « the assumption that the structural damage will be limited enough to meet the certification criteria, such as those mentioend in section 25.801. »

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We also request that the phrase « the A320 was certificated for a ditching descent rate of 3.5 fps. » in paragraph 2.3.3 be reworded in this way: "During the certification trials, the manufacturer demonstrated that, during a ditching, an optimal FPA (-0.5°) and a low airspeed (130 kt) (which correspond to a sink rate of 3.5 fps) made it possible to minimize the structural damages. The damage simulations performed by the manufacturer for a ditching at a sink rate of 12.5 fps are consistent with the damage observed on the aircraft." and the results of this damage simulations be included in the factual part.

2.3 Compliance with the recommended parameters

In the QRH check-list, the manufacturer recommends only a "minimal vertical speed" at impact for the following reasons:

- The preservation of fuselage integrity is not strictly associated with compliance with the ditching certification trial parameters, such as a FPA of -0.5°. Furthermore, as stated in p aragraph 2.2, this preservation is not a certification criteria in itself;
- The hydrodynamic trials showed that the pitch and bank are more critical parameters than the FPA for the entry into water. The risks associated with an inadequate pitch angle and a non null bank angle are the aircraft turning upside down and complete structural breakup.

The BEA requests that the importance of the other parameters be underlined in the analysis, in order that pilots confronted with a similar event do not focus on vertical speed reduction to the detriment of compliance with recommended pitch and bank angles.

The simulations performed by the NTSB attempted to assess the feasibility of an emergency ditching compliant with the ditching certification trial parameters. Based on the conclusions of these simulations, the analysis states several times that it is highly likely that the fuselage will break at impact and it is exceptionally difficult for a pilot to meet the ditching certification parameters.

The BEA wishes these statements to be mitigated for the following reasons:

- the simulations showed that all the pilots could enter the water with a vertical speed which was significantly lower than that of the event;
- The perception of the water surface and outside visual references are very different on a simulator, which was not designed for this kind of training;
- One of the pilots managed to meet the ditching certification criteria using an energy management method. The low number of simulation sessions does make it possible to state that, if the

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other pilots had used the same method, they would not have achieved a significant reduction in the descent rate.

For these reasons, the BEA requests that the analysis be modified in this way:

- **Remove the word "exceptionally" from the sentence "[…] it is exceptionally difficult for pilots to meet such precise criteria with no power." (paragraph 2.1),**
- **Remove the word "exceptionally" from "Attaining the touchdown flight condition targets is an exceptionally difficult flight maneuver that pilots cannot be expected to conduct proficiently." (paragraphe 2.6.3).**

The BEA considers that the sentence beginning with "During an actual ditching" in paragraph 2.6.3 is incorrect, as it is not required that pilots meet the ditching certification trial parameters in an actual ditching situation. We request that this sentence be reworded this way:
"During an actual ditching it is possible to reach a minimal vertical speed, as recommended by the manufacturer. However meeting the design ditching conditions without engine thrust is a demanding task and this difficulty may contribute to the severity of the damage."

The BEA agrees that the recommendation in paragraph 2.6.3 contributes to the improvement of the certification process. On the other hand, we do not consider that the absence of validation of the operational feasibility of a ditching without engines, matching the parameters determined by the manufacturer, contributed to the severity of the fuselage damage in this event.
Actually, several simulations performed by the manufacturer showed that it is possible to meet the certification trial parameters during a ditching without engine, with adequate airspeed management and configuration. It is very likely that the FAA would have been able to check the operational feasibility of such a ditching, without any changes in the aircraft design or in the manufacturer's recommendations.

There is no reason to think that this check, performed more than 25 years ago, would have had any effect on the crew's airspeed and configuration management in this particular event. The vertical speed at impact would still have been far above the one tested during certification and the structural damage would have been identical.

The BEA therefore requests that this non-contributive factor be removed from paragraph 3.2.

3 Vertical speed reduction at impact

The section of the analysis related to vertical speed reduction at impact mainly focuses on the fact that the flight envelope protections did not

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allow an increase in AoA. Although this issue must be dealt with, the BEA considers that it is secondary in the understanding of the actions that should be performed in order to reduce the descent rate at impact: airspeed and configuration management.

3.1 Airspeed management

The analysis describes the possible reasons why the airspeed dramatically decreased during the descent. On the other hand, it does not explain the correlation between this airspeed decrease and the vertical speed at impact.

The "Engine dual failure" requires that the crew keep the "green dot" speed until flap extension. The report underlines that the crew did not have time to follow this instruction. In this type of situation, the maximum range speed may not be the most appropriate and the manufacturer considers that the choice of airspeed belongs to the crew. However, the report should stress that the chosen airspeed must be high enough to allow vertical speed reduction during the flare.

For these reasons, the BEA requests that:

- **the "green dot" speed be added to the list of characteristic and protection speeds in paragraph 1.6.2, stressing that this airspeed makes it possible to maximize the range and to maintain sufficient energy to significantly reduce the vertical speed before impact. (The definition of this airspeed, important for the understanding of the event, currently appears only in a footnote);**
- **paragraph 1.16.1.1 mention the airspeed evolution after 15 h 30 and compare this airspeed to the "green dot " speed and the successive F speeds;**
- **the conclusion of paragraph 2.3.3 be completed with : "Choosing a sufficiently high airspeed makes it possible to maintain sufficient energy to significantly reduce the descent rate during the flare. When the airspeed value is high enough, such as the one recommended in the QRH, the AoA never reaches the flight envelope protection activation threshold."**

3.2 Choice of configuration

Paragraph 2.3.4 discusses the Captain's decision to use flap configuration 2 and concludes that this choice, based on his experience and perception of the situation, was "reasonable".

As this decision had an impact on the airspeed during the descent and on the vertical speed at impact, and as this configuration is not the one recommended by both the manufacturer and the airline, the BEA is afraid that this conclusion leads the readers to think that the captain's decision was consistent with the recommended practices.

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For this reason, the BEA requests that conclusion of paragraph 2.3.4 be modified in this way :

> **"The NTSB concludes that the flight crew did not have sufficient time to initiate the ditching portion of the Engine Dual Failure checklist and that the captain's decision to use flaps 2 for the ditching was based on his experience and perception of the situation.**
>
> **And that the following be added:**
>
> **" In this type of situation, the decision to use a higher configuration (flaps 3 or 4) at a greater height makes it possible to keep the airspeed high enough to significantly reduce the descent rate during the flare."**

3.3 High AoA protection

The high AoA protection played a positive role in this event. As stressed in paragraph 2.3.1, if the Captain had not switched on the APU, the aircraft would not have stayed in normal law. In alternate law, considering the airspeed management and flap configuration, it is likely that stall alarms would have been triggered several times during the descent, and the risk of actually stalling would have been high. A stall alarm during the flare would have had severe consequences, the only way to avoid stall being to reduce the pitch angle[1]. Furthermore, this system helped in reducing the crew workload during the descent.

The BEA requests that the aforementioned positive roles of high-AoA protection be recalled at the beginning of paragraph 2.6.2 and in the "Findings" section.
The BEA also requests that the recommendation in paragraph 2.6.2 be completed with "while staying in normal law", in order to avoid any ambiguity on the fact that the pilot is not asked to manually switch to alternate law.

The report states "However, this accident demonstrates that, by offsetting the pilot's ANU sidestick inputs, the phugoid-damping feedback function of the alpha-protection mode could make flaring the airplane to attain the recommended ditching touchdown parameters more difficult."
The BEA considers that this statement is incomplete. In fact, the phugoid oscillation damping function only prevented the pilot from increasing the AoA, because the energy management during the descent did not make it possible to reduce the vertical speed at impact. If the airspeed had been high enough, it is likely that during the flare, the high-AoA protection would not have been activated.
Furthermore, it is not certain that, without this function, it would have been possible to meet all the recommended parameters. In reality, phugoid oscillations induce pitch variations that can have more severe consequences than a high vertical speed when entering water.

[1] See paragraph 2.3 for the discussion about the importance of the pitch angle during a ditching.

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The BEA requests that the previous sentence be completed with: "However, without this function, uncontrolled pitch variations may occur. Hydrodynamic trials showed that such variations may have severe consequences on the aircraft behavior when entering water, and on the structural integrity."

The BEA considers that the statement beginning with "If the flight crewmembers" is incorrect and not supported by the factual information gathered. In fact, independently of the systems equipping an aircraft, the pilots are aware of the necessity to stay in the middle of the flight envelope, even in an emergency situation. Moreover the captain stated that he chose an airspeed "safely above Vls", which shows that he knew the risks associated with an airspeed decrease. The reasons why the crew did not manage to apply this knowledge and let the airspeed decrease are explained in paragraph 2.3.3 of the report.
For these reasons, the BEA requests that this sentence be removed.

4 Survival factors

During the descent, the flight crew were not available to inform the cabin crew about the decision to perform an emergency ditching in the Hudson River. Therefore the cabin crew could not inform the passengers about the brace position, the location and use of safety jackets and the use of the main emergency exits.
The BEA requests that these facts be recalled in paragraph 2.9 to explain the non standard use of the survival and evacuation equipment.

Paragraph 2.9.3.1.2 mentions the use of wing slides by passengers who evacuated through wing exits. The NTSB recommends to the FAA to equip wing slides of type IV emergency exits with handles that would allow a rapid release of the slides.
The BEA considers that this conclusion and recommendation are premature. Since wing slides were not designed to be used as life rafts, this non-standard use may generate other risks that are currently not known.
For this reason, the BEA suggests replacing the recommendation in paragraph 2.9.3.1.2 with a recommendation requesting a feasibility study and potential safety benefits from the use of wing slides as temporary slide rafts and to define the means of use.

5 Additional comments

The BEA also wishes the following comments to be taken into account:

- Since the aircraft sustained significant damage and was submerged, we consider that it was "destroyed" and not that it was "substantially damaged".
- We wish the CVR model to be mentioned, as it is for the FDR.

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- We consider that the damage on the upper part of the radome, mentioned in paragraph 1.12.1, may also result from the collisions with the ferries and with the pier to which the aircraft was attached for a while.
- The sentence in paragraph 1.6.3 beginning with “The high-AOA protection also limits […]” is incorrect. The bank and trim protections are not part of the high-AoA protections.