US Airways Flight 1549

Post-Hearing Submission
of
US Airways, Inc.

Party Coordinator
Captain Paul Morell
Vice President, Safety and Regulatory Compliance
US Airways, Inc.

January 15, 2010

TABLE OF CONTENTS

SECTION 1. INTRODUCTION

On January 15, 2009, at approximately 1527 Eastern Standard Time (EST), US Airways Flight 1549, an Airbus A320-214 registered as N106US, suffered bird ingestion into both engines, lost engine thrust and landed in the Hudson River following take off from New York City's LaGuardia Airport.

The pilots of the flight were Captain Chesley Sullenberger and First Officer Jeffrey Skiles. The flight attendants were Sheila Dail, Donna Dent and Doreen Welsh. In addition to the five crew members, 150 passengers were on board. All crewmembers and passengers were evacuated from the airplane and rescued by ferry boats operating in the vicinity of the landing. The flight was conducted under 14 CFR part 121 and was enroute to Charlotte Douglas International Airport in North Carolina.

SECTION 2. FACTUAL INFORMATION

2.1 History of Flight

After take off from New York City's LaGuardia Airport, at an altitude of approximately 2700 feet, Flight 1549 encountered a large flock of Canada geese. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Robert Benzon ("Benzon Test.") pp. 17-18; 20. Geese were ingested into both engines.[1] Benzon Test. p. 20. The airplane sustained an immediate loss of thrust in both engines. Operations/Human Performance Group Factual Report ("Oper. Fact.") p. 4; *see also* Oper. Fact., Attachment 1, Interview with Captain Chesley Sullenberger ("Sullenberger Int.") p. 12.

The initial takeoff was completely normal until First Officer Skiles spotted a line of dark birds slightly to the right of the flight path. Oper. Fact., Attachment 1, Interview with First Officer Skiles ("Skiles Int.") p. 1; *see also* Benzon Test. p. 18. The Captain stated that an instant later a flock of large birds filled his windscreen. Sullenberger Int. p. 10; *see also* Benzon Test. p. 18. There was no time to react before the birds collided with the airframe. Sullenberger Int. p. 10.

The Captain turned on the engine ignition, started the auxiliary power unit (APU), took over control of the airplane by saying "my aircraft," and called for the Dual Engine Failure checklist procedure. Oper. Fact. p. 4; *see also* Sullenberger Int. p. 10. The Captain explained that, based on his experience, turning on the ignition and starting the APU would provide the most immediate assistance in the situation. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Captain Sullenberger ("Sullenberger Test.") p. 24.

---

[1] Canada goose remains were found in both engines. DNA studies revealed that at least one male and one female goose were ingested into the left engine and at least one male goose was ingested into the right engine. Benzon Test. p. 20. Each goose weighs approximately 8 pounds. NTSB Public Hearing Transcript, June 11, 2009, Testimony from Robert Ganley ("Ganley Test.") p. 489. Accordingly, the left engine ingested a total bird mass of at least 16 pounds and the right engine ingested a total bird mass of at least 8 pounds. Id.

The Captain maintained control of the airplane and declared an emergency with Air Traffic Control. Oper. Fact. p. 4; *see also* Sullenberger Int. p. 12. The First Officer attempted to restore thrust by following the Dual Engine Failure relight procedures. Sullenberger Int. pp. 12, 17. The extensive damage to the engines precluded the recovery of thrust lost due to the bird strikes. NTSB Public Hearing Transcript, June 11, 2009, Testimony from Les McVey, Flight Safety Investigation Engineer, CFM International ("McVey Test.") pp. 509-510. Further, the aircraft speed was too slow to perform a windmill restart of the engines; the speed was not in the relight envelope. Sullenberger Int. p. 10; *see also* Skiles Int. p. 3. Attempts to recover thrust from both engines were unsuccessful. Sullenberger Int. p. 12.

The Captain and First Officer worked well together in this emergency situation, implementing their Crew Resource Management ("CRM") and Threat and Error Management ("TEM") training. Their training in CRM and TEM allowed the Captain and First Officer to communicate with each other, understand each other and work together as a team without the need for words. Id. at p. 19. This was critical considering the extreme time factor. The time that elapsed from the bird strikes to touchdown in the Hudson River was only three and a half minutes. Benzon Test. p. 17.[2]

Due to the low altitude of the flight when the dual engine failure occurred, the First Officer was not able to complete the Dual Engine Failure checklist. Sullenberger Int. p. 12.

At approximately 1,000 feet and ninety seconds before touchdown, the Captain gave the command to the passengers and crew to "brace for impact." *See* CVR Group Factual Report ("CVR Fact.") pp. 42-47; Flight Path Animation; *see also* Sullenberger Int. p. 10. All three flight attendants assumed their brace positions and began shouting brace commands "brace, brace, heads down, stay down" and repeated those commands continuously through impact. Survival Factors Group Factual Report ("Surv. Fact.") pp. 5, 8, 10. The Captain's focus was outside and the speed tape. Sullenberger Int. p. 10. The Captain planned to touchdown next to vessels in the water. Id. He called for flaps 2. Id. He maintained aft stick and achieved maximum aircraft performance at touchdown with the flaps in configuration 2. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Captain Terry Lutz, Airbus Experimental Test Pilot ("Lutz Test.") p. 330. The nose went down and the water came up over the windshield. Sullenberger Int. p. 10. The aircraft came suddenly to a stop. Id.

The airplane landed in the Hudson River at about 1531. Oper. Fact. p. 4. The Captain opened the flight deck door and issued a verbal "Evacuate" command. Id. at p. 24; *see also* Sullenberger Int. p. 20.

The cabin crew had already begun evacuation of the airplane. Sullenberger Int. p. 10. All three flight attendants assessed the outside conditions, as they were taught in training, prior to opening the doors. Surv. Fact. pp. 5, 8, 11. When the flight attendants looked out the windows and noticed the water, they realized it had been a water landing. Id.; *see also* Benzon Test. p. 19. Although the flight attendants did not realize they were going to be landing on water, they responded to the situation quickly and swiftly. Surv. Fact. pp. 5, 8, 11. The front two flight attendants, Donna Dent and Sheila Dail, opened the front two doors, door 1R and door

[2] "The time from the bird strikes to touchdown in the water was about three and a half minutes."

1L. Id. at pp. 5, 11. Ms. Dent and Ms. Dail assisted passengers into the front two slide rafts at doors 1R and 1L. Id. In realizing they were making a water evacuation, both Ms. Dent and Ms. Dail shouted commands to passengers to "come this way, don life vests." Id. Thereafter, Ms. Dent noticed a bottleneck at the over wing exits and directed those passengers forward into the front slide rafts. Id. p. 6.

There were several issues that complicated the evacuation effort. Benzon Test. p. 19. One strut supporting the cargo compartment linings had been pushed through the cabin floor of the rear of the airplane which may have resulted in the injury to the aft flight attendant, Doreen Welsh. Id. The impact damage to the lower portion of the aft fuselage enabled water to immediately enter the cabin area. Id.

Ms. Welsh initiated the evacuation process in the rear of the aircraft. Surv. Fact. p. 8. First, she assessed the water level and determined it to be too high to open the 2L door. Id. The water in the rear of the aircraft precluded the use of the two aft emergency exits and slide rafts. Benzon Test. p. 19. Accordingly, as taught in training, Ms. Welsh directed passengers forward. Surv. Fact. p. 9. Ms. Welsh began improvising commands and told passengers to climb over seats in order to move passengers away from the water. Id. Several male passengers complied with her commands. Id. When she reached the over wing exits she shouted the commands "leg, body, leg" to assist those passengers exiting onto the wings. Id.

The Captain and First Officer also assisted with the evacuation. Oper. Fact. p. 24. The Captain instructed passengers in the back of the cabin to move forward. Sullenberger Int. p. 10. The Captain was concerned because many of the passengers did not take life vests. Skiles Int. p. 2. The Captain and First Officer obtained life vests from under passenger seats and passed them to passengers on the wings. Oper. Fact. p. 24; *see also* Skiles Int. p. 2. The Captain described the evacuation as expeditious and orderly. Sullenberger Int. p. 10. Before exiting the aircraft, Captain Sullenberger inspected the cabin to ensure no passengers or crewmembers were still on board. Oper. Fact. p. 24.

Ferries in the Hudson River at the time of the incident responded to the scene and rescued all on board. Id. at p. 4. The first ferry arrived at the airplane approximately three minutes after the water landing had occurred. Benzon Test. p. 16. The Captain directed the ferries to first rescue the passengers standing on the wings. Skiles Int. p. 2.

2.2 Injuries to Persons

Only one flight attendant and four passengers were seriously injured. Oper. Fact. p. 2. A male passenger, seated in seat 1C, age 55, who exited door 1L sustained a cracked sternum. Surv. Fact. pp. 22-23; *see also* Surv. Fact., Attachment 7, Injury Chart ("Injury Chart"). Two female passengers sustained fractures. The first, seated in seat 11A, age 58, who opened and then exited through one of the over wing exits, sustained a nondisplaced fracture of the left humerus. Surv. Fact. pp. 65-66; *see also* Injury Chart. The second, seated in seat 13D, age 56, who also exited over wing, sustained a fracture of the right humerus and a muscle tear. Surv. Fact. pp. 81-82; *see also* Injury Chart. Another female passenger, seated in seat 13 C, age 38, sustained hyperthermia from exposure to the water. Surv. Fact. pp. 80-81; *see also* Injury Chart.

Finally, flight attendant Doreen Welsh, age 58, sustained a 12 cm laceration and a 5 cm deep cut involving the anterior tibialus muscle. Surv. Fact. p. 9; *see also* Injury Chart; Benzon Test. p. 19. Id. She required surgery. Surv. Fact. p. 9; *see also* Injury Chart.

2.3 Damage to Aircraft

Examinations of the structure of the aircraft following the accident revealed significant damage to the underside of the rear fuselage. Benzon Test. p. 21. The emergency condition of US Airways Flight 1549 led to rate of descent of 13 feet per second at water impact. NTSB Public Hearing Transcript, June 10, 2009, Testimony from David Fitzsimmons, Structure Senior Engineer, Airbus ("Fitzsimmons Test.") p. 264. The damage to the aircraft is consistent with this high energy impact at the rear fuselage and the ensuing post-impact motion through the water. Id.

2.4 Personnel Information

2.4.1 Captain Sullenberger

Captain Chesley Sullenberger, 57 years old, learned to fly in 1967 and had a private, commercial, instrument, and certified flight instructor certificate prior to completing college. Oper. Fact. p. 5. He flew F-4 airplanes in the US Air Force prior to being hired by Pacific Southwest Airlines on February 25, 1980, which merged with US Airways in 1988. Id. Captain Sullenberger had a total time of 19,633 flight hours and total A320 time of 4,765 hours at the time of the incident. Id. at p. 6. Captain Sullenberger's initial Airbus A320 training was completed on August 7, 2002. Id. His last recurrent training was on February 20, 2008. Id.

2.4.2 First Officer Skiles

First officer Jeffrey Skiles, 49 years old, learned to fly when he was around 16 years of age. Id. at p. 7. He was hired by US Airways in 1986. Id. First Officer Skiles had a total time of 15,643 flight hours and a total A320 time of 36 hours at the time of the incident. Id. at p. 9. First Officer Skiles' initial Airbus A320 training was completed on December 31, 2008. Id. The Captain commented that the First Officer displayed abilities and knowledge that made the Captain believe the First Officer had more experience flying the A320. Sullenberger Int. p. 18.

2.4.3 Flight Attendants

All three flight attendants were highly experienced and highly trained, each flying for over 25 years. Surv. Fact. p. 3. Flight Attendant Donna Dent had her Initial Ground Training on June 22, 1982, her Initial Extended Overwater ("EOW") Training on August 20, 1990, and her last recurrent training was on January 31, 2008. Id. Flight Attendant Doreen Welsh had her Initial Ground Training on September 15, 1970, her Initial EOW Training on September 18, 1989, and her last recurrent training was on July 17, 2008. Id. Flight Attendant Sheila Dail had her Initial Ground Training on February 27, 1980, her Initial EOW Training on October 17, 1989, and her last recurrent training was on January 31, 2008. Id.

2.5 US Airways Training

2.5.1 Advanced Qualification Training ("AQP")

US Airways has been operating under the Advanced Qualification Program ("AQP") since 2002. Oper. Fact. p. 24. AQP is a voluntary program approved and overseen by the FAA that seeks to improve aviation safety through customized training and evaluation in Part 121 operations. Id. AQP is a program that allows US Airways to modify its training in order to prepare for the most significant risks and hazards experienced by its pilots. Under AQP, data is analyzed in order determine areas where reinforcement is needed and where training would be most effective. NTSB Public Hearing Transcript, June 9, 2009, Testimony from John Duncan, Manager, Air Transportations Division, FAA ("Duncan Test.") p. 145. US Airways utilizes that data to tailor training to its specific flying environment. Id. This level of flexibility was not available under prior Part 121 training.

In addition, under AQP, Crew Resource Management ("CRM") and Threat and Error Management ("TEM") are integrated into all aspects of training including ground school, simulator training and evaluations. TEM is based on the realization that pilots may make mistakes; it is designed to find ways to prevent those mistakes and to correct errors. Oper. Fact., Attachment 6, Interview with US Airways Instructor Pilot Kaufmann ("Kaufmann Int.") p. 11. CRM is designed to encourage crews to communicate with each other and to work together. Oper. Fact., Attachment 6, Interview with US Airways Ground School Instructor Greg Andrews ("Andrews Int.") p. 4. Flight crew communication and coordination are critical during periods of high workload. Oper. Fact. p. 30.

AQP is a scenario-based training program, where different real life scenarios are presented to pilots. It is impossible to provide for all scenarios in training; however, placing pilots into different abnormal and emergency scenarios and teaching CRM and TEM as a tool to assist them in those situations provides pilots with knowledge that is transferrable and helpful in all situations, as was displayed by the pilots of Flight 1549. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Captain Hope ("Hope Test.") p. 93.

2.5.1.1 AQP Core Curricula

The core curricula provided under AQP at US Airways consists of: (1) Indoctrination Training; (2) Qualification Training; and (3) Continuing Qualification Training.[3] Oper. Fact. p. 24; *see also* US Airways AQP vol. 1, p. 2-3.

Indoctrination Training is a 9-day course required for new hires to US Airways to provide them with an overview of the policies, procedures and practices at US Airways. Oper. Fact. p. 24. Successful completion of indoctrination training allows new hires to attend aircraft ground and flight training courses. Id.

---

[3] Requalification Training at US Airways at the time of the accident and prior thereto was incorporated as part of Qualification Training and Continuing Qualification Training. To the extent the Operations/Human Performance Group Factual Report, page 24, states that Requalification Training was not in use at the time of the accident it is, as noted above, in error.

Qualification Training ("QT") covers ground school, simulator training and Operational Experience ("OE"). The ground school and simulator portion of the training is a 23 day course which covers ground school, maneuvers validation, and line oriented evaluation. Id. Simulator training is included and is divided into two phases. Id. Phase One covers four days of maneuvers training where pilots develop proficiency of core skills and maneuvers, and a fifth day of maneuvers validation. Id. Phase Two covers three days of additional simulator training where the focus is on TEM and proficiency in line operations. Id. Simulator session 9 is a LOFT (line-oriented flight training) scenario and session 10 is an LOE (line-oriented evaluation) for certification. Id. At US Airways, both Captains and First Officers are Airline Transport Pilot ("ATP") rated, with full aircraft type certification at the conclusion of this training. Following the LOE, a flight crewmember completes OE line operations under the supervision of a company check pilot. Id. First Officers receive a minimum of fifteen hours of OE while Captains receive a minimum of twenty-five hours, non-reducible by landings.

The US Airways AQP is based on a twenty-four month cycle with a twelve month training evaluation period. Id. at p. 25. Following qualification on an airplane, a crewmember is required to complete Continuing Qualification Training on an annual basis as well as Distance Learning Modules quarterly. Id. Quarterly Distance Learning Modules allow US Airways to address hot topics in a timely manner. Id.

Continuing Qualification Training ("CQT") is a three day course which includes 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. Id. Under AQP, the CQT is revised yearly based on data and lessons learned from many different data sources. Oper. Fact., Attachment 6, Interview with US Airways Manager of AQP John Duncan ("Duncan Int.") p. 23. A new CQT program is launched on May 1 of each year and is valid for one year. Oper. Fact. p. 25.

2.5.1.2 Training Program is Approved by the FAA

All training programs are submitted by the air carrier to the FAA for approval. Duncan Test. p. 104. The FAA evaluates whether the training program meets the appropriate standards, including the manufacturer's guidance. Id. In addition, the FAA evaluates whether the program is consistent with the procedures within the air carrier. Id. After this evaluation, the FAA provides initial approval of the training program. Id. After initial approval, the FAA will monitor the carrier's application of that program. Id. After the FAA sufficiently monitors the program, it will give final approval. Id.

2.5.2 CRM and TEM Training

The TEM program offered by US Airways is built on a concept of three colors (red, yellow and green) or situation awareness markers. Oper. Fact. pp. 27-28. Instructors work with pilots to help them identify their situational awareness and task loading (the number of tasks to be completed divided by the amount of time available to complete them). Id. at p. 28.
US Airways trains and evaluates its pilots by teaching them to recognize when they are no longer

in a green situation and have entered into a yellow or red situation. Hope Test. p. 94. The Company teaches its pilots how to safely return to a green situation by utilizing tools and barriers available to them. Id. at pp. 94-95.

US Airways teaches the tools and barriers available to pilots through the "ABCs" model: Assess what the situation is and/or what the threats are, Balance available barriers to errors using policies, procedures, checklists, automation, resources and knowledge of aircraft handling, Communicate effectively and employ Standard operating procedures. Oper. Fact. p. 28. Posters in all classrooms, briefing rooms and pilot base crew rooms depict this TEM model and encourage its use during debriefings. Id. US Airways greatly values debriefing as a training tool to ensure pilots receive even higher levels of TEM understanding. Id.

By using this model, crews know what to expect from each other and can effectively communicate with each other during periods of high stress. This was effectively demonstrated by the Captain and First Officer of Flight 1549, who were able to communicate with each other, understand each other and work together as a team without the need for words. Sullenberger Int. pp. 13, 19.

Dr. Burian explained that when crews are presented with non-normal situations, it is important to shed tasks in response to task loading. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Dr. Barbara Burian, Research Psychologist, NASA ("Burian Test.") p. 110. US Airways addresses this exact issue in its TEM training. Hope Test. p. 139. US Airways teaches that task loading in itself can drive a pilot out of a green situation and closer to a red situation on the color scale. Id. By limiting tasks and increasing time, a pilot can move from the red back into the green, i.e. from an emergency to a normal situation. Id. In order to decrease a pilot's task loading, each pilot is taught to use the ABCs and the tools and barriers available to them. Hope Test. pp. 139-140.

CRM and TEM have been embedded into the US Airways training curricula since early 1991. Id. at p. 94. CRM and TEM training is taught and evaluated in all aspects of training at US Airways, in ground school and distance learning, in the simulator, in line checks and in special operational audits. The FAA has commented that they are very pleased with US Airways' CRM/TEM training. Oper. Fact., Attachment 4, Interview with Mark Mulkey, FAA Principle Operations Inspector for US Airways ("Mulkey Int.") p. 8. According to the FAA, it is a strong program that works well as was demonstrated by the CRM/TEM skills of Captain Sullenberger and First Officer Skiles. Id.

2.5.2.1 Training Syllabus and Training Scenarios in Line with Dr. Burian's Recommendations

During Dr. Burian's testimony at the NTSB Hearing, she explained that one of the issues identified during the course of her research was that crews were oftentimes presented with textbook scenarios, with cues that were clear, with the appropriate procedure always working as intended and with sufficient time to complete the entire procedure. Burian Test. p. 112. Crews were not presented with the kind of ambiguity that is often experienced in real life situations. Id.

Dr. Burian recommends that the aviation community increase the realism of its training. Id. at pp. 112-113. For example, she suggests training scenarios where the procedures do not always work, where there is not enough time to complete the procedure, or where there is not a clear-cut response or an exact checklist to be used. Id. Dr. Burian explained to the Board that the more opportunities flight crews have to "think on the fly" and develop options available to them while their task loading is increased, the better prepared they will be for handling those situations in real life. Id. at pp. 119-120.

Dr. Burian agreed that scenario-based training, such as US Airways AQP training, develops those essential decision making skills and follows her recommendations. Id. at p. 143.

Captain Sullenberger explained that his training helped him and contributed to the successful outcome of the accident, despite the fact that he had no specific training in the Airbus A320 on forced water landings after low altitude dual engine failure. Sullenberger Int. p. 13; Hope Test. p. 93. However, Captain Sullenberger did have AQP scenario-based training with a focus on CRM/TEM. Sullenberger Test. p. 27. Captain Sullenberger had been faced with different scenarios in training, especially those without a clear cut response, which provided him the opportunity to analyze and evaluate a situation and make decisions, the type of training recommended by Dr. Burian. Id.; *see also* Burian Test. pp. 142-143. US Airways' scenario-based AQP training develops decision making skills which are applicable in all emergency situations. Burian Test. p. 143; *see also* Duncan Test. p. 145.

2.5.3 US Airways Dual Engine Failure Training

US Airways Dual Engine Failure training is provided as part of its A320 initial qualification curriculum to all pilots. Hope Test. p. 91. It is covered in full flight simulation, specifically in simulator session 6. Id. The objective of the Dual Engine Failure training is for the pilot to recognize the dual engine failure, maintain aircraft control, use the appropriate checklist and implement the engine restart procedures. Id. The US Airways instructors use tools such as a PowerPoint led script with slide presentations and a virtual simulator to conduct briefings with a crew prior to the simulator session. Oper. Fact., Attachment 2, Interview with US Airways Fleet Captain John Hope ("Hope Int.") p. 4. The presentations are scripted in order to provide standardization and to ensure all pilots are receiving the same information. Id.

During the prebrief, an instructor discusses the ECAM Exceptions contained in the Quick Reference Handbook ("QRH"). Oper. Fact. pp. 26-27. The instructor discusses the entire QRH Dual Engine Failure checklist with the crew, providing training on the procedures contained in that checklist. Id.

US Airways teaches dual engine failure in a scenario-based training model in the simulator. Hope Test. p. 91. The dual engine failure simulator scenario is initiated at 25,000 feet and 300 knots. Id. at pp. 91-92. The crew is lead to attempt a windmilling relight of the engines. Oper. Fact. p. 27. The scenario was designed, and the simulator programmed, so that the windmilling relight will not be successful, leading the crew to start the APU and attempt an APU assisted restart of one of the engines. Id. The scenario is completed after a successful relight of an engine using APU bleed air. Id.; *see also* Hope Test. p. 92.

2.5.3.1 Dual Engine Failure Training is Consistent with Airbus' Training Recommendations

The US Airways Dual Engine Failure training is consistent with the manufacturer's training from Airbus. Hope Test. p. 91. US Airways modifies the scenario slightly to fit its individual operations; however, it fulfills the same objectives as the manufacturer's training. Id. at p. 98. While it is still a high altitude scenario, Airbus starts their scenario at 35,000 feet and US Airways starts at 25,000 feet. Id. US Airways follows Airbus in attempting the different engine start procedures, both wind-milling and starter assist, and the successful restart of one engine. Id.

2.5.4 ECAM System

The Airbus A320 is equipped with an Electronic Centralized Aircraft Monitor (ECAM) system which presents data on the cockpit screen. Oper. Fact. p. 12. In most situations, the aircraft can auto-detect the issue and will display the list of actions to be followed by the crew. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Captain Marc Parisis, Vice President, Flight Operations Support and Services, Airbus ("Parisis Test.") pp. 81-82. If there is more than one procedure to be completed, the ECAM will display the procedures in the correct order. Id. at p. 81.

While the ECAM provides appropriate, specific procedural guidance for most non-normal, system-related situations, it is unable to display the correct procedure for every possible event. Therefore, it is incumbent upon the pilot to understand the limitations of the electronic non-normal checklists and upon the airline to develop non-normal methodology with those limitations in mind. These limitations fall into three categories:

1. Non-Normal Situations that Cannot be Detected by Aircraft Systems

Many non-normal situations are not system-related or the Flight Warning Computer ("FWC"), which provides data to support the ECAM, is unable to detect certain system abnormalities. For example, if the crew senses smoke that is not detected by an onboard smoke detector, the ECAM cannot display a procedure. In this case, the crew would use a paper QRH procedure to identify the source of the smoke and take steps to mitigate the situation.

2. Non-normal Situations which Require Judgment that is Beyond what ECAM can Provide

The second type of ECAM limitation is where the correct procedure is displayed on the ECAM, but the flight crew needs to apply judgment or employ a complex decision process to apply the correct procedure. This decision process may be beyond the capability of the ECAM to efficiently display and, therefore, it is more appropriate for the crew to refer to a paper QRH procedure. A dual engine failure is an example of this situation, as the procedure to follow may be determined by the cause of the failure (fuel related or not), the surface upon which a landing will occur (water or land) and the altitude at which the failure occurred.

3. <u>ECAM Procedures that are not Correct and have not yet been Updated on the FWC</u>

Certain ECAM procedures may be found, through testing or actual airline experience, to be incorrect or less than optimal in certain circumstances. When Airbus identifies these procedures, airlines are notified with Operating Engineering Bulletins (OEBs) if there is a need for fast transmission of updated non-normal procedures. These OEBs can serve as paper guidance in lieu of ECAM guidance for the subject circumstances until the manufacturer's updated information can be added to the FWC or the subject aircraft system can be corrected.

US Airways incorporates OEBs into the QRH list of "ECAM Exceptions" that are used to quickly reference the proper paper procedure. US Airways routinely evaluates these paper procedures to ensure their suitability for all aircraft in the fleet, and removes them once compliance with the corrective action associated with the subject OEB is assured.

2.5.4.1 <u>Dual Engine Failure is an ECAM Exception</u>

Airbus designates Dual Engine Failure as an ECAM exception procedure to be set forth in the QRH. Parisis Test. pp. 83-84. Accordingly, US Airways follows Airbus' recommendation and also designates Dual Engine Failure as an ECAM exception. Hope Test. p. 96.

The Dual Engine Failure checklist presents a number of items in order to account for the variety of situations that could be occurring when a crew experiences a dual engine failure. By using the QRH, the crew can skip through unnecessary items not applicable to their current situation and go directly to the appropriate section of the checklist. Parisis Test. pp. 83-84. With the ECAM, the crew would be forced to go through a number of unnecessary steps on the cockpit screen until the presented scenario appears. <u>Id.</u>

The US Airways Dual Engine Failure checklist is designed as a get in/stay in checklist. Burian Test. p. 115. This allows the crew to refer to only one checklist when presented with the high stress situation of a dual engine failure. This is in line with Dr. Burian's recommendations. <u>Id.</u>

Designating Dual Engine Failure as an ECAM exception and presenting the procedure as a paper checklist set forth in the QRH organizes the information in a clearer format, reduces cognitive processing by requiring only one checklist and saves the crew valuable time in a high stress situation.

2.5.5 <u>US Airways QRH</u>

The US Airways QRH is carried on board the airplane and includes abnormal and emergency procedures for those situations where an ECAM exception is more effective. Oper. Fact. p. 13. It is based on the Airbus checklist but is designed by US Airways personnel and approved for use by the FAA. <u>Id.</u> at p. 14; *see also* Parisis Test. p. 84.

Airbus has four ECAM exceptions; however, the US Airways QRH includes six ECAM exceptions. Hope Test. p. 97. This is because US Airways operates over 200 Airbus aircraft. Id. These aircraft consist of many different models with different configurations. In order to have a single QRH for the entire fleet and account for the differences in models, US Airways includes six ECAM exceptions. Id. This allows one QRH with standard procedures applicable to all aircraft and facilitates use of the QRH by the pilots. Id.

Further, one of the enhancements US Airways has implemented is not to have ECAM exceptions be memory items. Hope Test. p. 92. As Dr. Burian commented, it is essential in emergency situations to limit memory items. Burian Test. pp. 124-125. On the back of the QRH is an alphabetical list of the ECAM exceptions with reference to page numbers where each procedure is located. Oper. Fact. p. 13. In this particular case, the Dual Engine Failure checklist is located on page 27. Hope Test. pp. 92-93. The pilot would simply refer to the back cover where the procedures are alphabetized, find that the Dual Engine Failure checklist is on page 27 and open the QRH to page 27. Id.

Captain Sullenberger commented during his interview that the US Airways QRH previously had tabbed pages, but for the last several years pages with printed numbers were being used instead, which he believed made it more difficult to locate the necessary procedures. Sullenberger Int. p. 30. There are a number of reasons for the switch from tabbed QRH pages to pages with printed numbers, including flexibility and speed afforded by publishing the QRH in-house and eliminating issues that arose with multiple rows of tabs.

US Airways started printing its QRH in-house. This dramatically improved the revision turn around time, allowing pilots to receive revised procedures almost immediately. Previously, when printed by a vendor, the turn around time was much greater, necessitating printing the revised procedures in a separate paper bulletin to ensure issuance in a timely manner to the pilots. This required pilots to memorize the fact that the specific non-normal procedure at issue was referenced in a separate paper bulletin rather than in the QRH. Further, it took pilots a longer period of time to locate procedures printed in the paper bulletins. In emergency situations, because of high cognitive processing loads placed on pilots, it is essential to limit memory items and to reduce difficulty in locating proper procedures. Burian Test. pp. 110-111; 124-125.

Further, US Airways found that locating non-normal procedures in the prior tabbed version of the QRH was faster if the non-normal procedures were located in the first row of tabs; however, it took longer to locate the procedures if they were located in the second or third row of tabs. Every QRH had multiple rows because only 25 tabs were possible per row. It took even longer to locate the procedures if they were located on an even numbered page which required that the QRH be flipped around to the backside in order to see the numbers. The in-house QRH does not have tabs and, therefore, it is easy for a pilot to "fan" through the pages. The page numbers are large and located on the outer edges of each page, so the correct page is quickly and easily located.

Prior to switching to the new version of the QRH, US Airways conducted tests to ensure that the time it took pilots to locate the procedures would not be affected by the change. Pilots and representatives from the FAA participated in the tests where the amount of time to locate the non-normal procedures in the different versions of the QRH was evaluated. Regardless of the version, non-normal procedures were always located within a few seconds. It was determined that the reason for this was the US Airways indexing system, which was designed after extensive research and collaboration with NASA human factors personnel. This indexing system remained the same in both versions.

Extensive research and testing was conducted in designing the in-house QRH to ensure that the time it would take pilots to locate the necessary procedures was not affected and that safety was not compromised in any way.

Following the bird strikes, the Captain called for the Dual Engine Failure checklist. Sullenberger Int. p. 12. First Officer Skiles quickly and easily found the Dual Engine Failure checklist. Id. The First Officer did not experience any delay in locating the checklist due to the fact that the revised version of the QRH was in use at the time of the accident.

2.5.5.1 Dual Engine Failure Checklist

The US Airways Dual Engine Failure procedure is set forth in three parts. Oper. Fact. p. 14. Part 1 of the procedure requires the crew to differentiate between a "no fuel remaining" and a "fuel remaining" condition. Id. For the "fuel remaining condition," steps are included to attempt an engine restart. Id. The flight crew followed the steps for a fuel remaining condition. Id.

Part 2 of the procedure includes guidance to follow in the event an engine restart is successful and guidance and procedures to configure airplane systems in the event that an engine restart is not possible. Id.

Part 3 of the procedure contains guidance and procedures to follow in the event a forced landing is anticipated, or in the event a ditching is anticipated. Id.

Due to the low altitude and limited time available, the crew was unable to initiate part 2 or part 3 of the Dual Engine Failure checklist. Id.

The US Airways Dual Engine Failure checklist is based on Airbus' Dual Engine Failure checklist. The Airbus checklist also differentiates between a "no fuel remaining" and a "fuel remaining" condition. Id. at p. 17. The Airbus checklist also includes steps to attempt an engine restart, and in the event an engine restart is not possible steps to configure the airplane for a forced landing and for a ditching. Id.

2.5.5.2 Design of Dual Engine Failure Checklist - High Altitude Only

Airbus designed the Dual Engine Failure checklist to cover the most probable scenario. Parisis Test. p. 86. Based on worldwide aviation experience, dual engine failure is usually caused by fuel starvation or by conditions such as volcanic ash, both of which occur at a high altitude. Id. Airbus has not considered low altitude dual engine failure, as this scenario has not previously been presented. Id.

US Airways follows Airbus' design and training of dual engine failure at high altitude. Hope Test. p. 98. Prior accidents involving dual engine failure have occurred at high altitudes and US Airways trains its pilots for the most likely scenario. Id.

2.5.6 Ditching

2.5.6.1 Ditching v. Unplanned Forced Emergency Landing on Water

There are two types of water landing: planned and unplanned. A planned water landing, also known as ditching, is characterized by at least some preparation time. Oper. Fact., Attachment 2Z, DOT/FAA/AR-95-54 Transport Water Impact and Ditching Performance pp. 1-2; *see also* Surv. Fact. p. 15; Parisis Test. 149. In an unplanned forced emergency landing on water, such as in the case of Flight 1549, there is no time to prepare. Surv. Fact. p. 15.

Ditching is predicated on having engine thrust available. Parisis Test. p. 84. Ditching is a planned event with time to go through all the procedures. Id. at p. 148. There is time to prepare the aircraft and the cabin. Id. at pp. 148-149. In Flight 1549, there was very limited, if any, time to prepare the aircraft and the cabin. Id. at p. 149. Captain Sullenberger had no time to refer to the ditching procedures. Id. The Captain was rapidly running out of options; he had to land the aircraft and the only viable option was the river. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Gene Arnold, FAA Flight Test Pilot, Seattle Aircraft Certification Office ("Arnold Test.") p. 310.

Accordingly, Airbus and US Airways are in agreement that Flight 1549 was an unplanned forced emergency landing on water. Parisis Test. p. 133; *see also* Hope Test. p. 133.

Airbus does provide a procedure for a ditching situation, assuming there is available preparation time. Parisis Test. p. 152. The ditching procedure assumes there is some engine thrust available. Id. at p. 84. Further, there is the procedure for dual engine failure, which assumes a high altitude and time to prepare. Id. at pp. 86; 148-149; 152-153. Flight 1549 was a unique event beyond both the ditching procedure and the dual engine failure procedure as there was no altitude, no time to prepare and loss of engine thrust. Id. at pp. 152-153.

2.5.6.2 Ditching Training

Ditching training is covered in ground school initial qualification training and in distance learning over the internet. Hope Test. p. 95. Ditching training at US Airways is covered on the first day of initial qualification ground school and consists of a PowerPoint presentation that reviews the US Airways QRH Ditching checklist. Oper. Fact. p. 26. It is divided into two phases: the preparation phase, which discusses communication and procedures, and the approach phase, which provides procedures for below 2,000 feet. Hope Test. pp. 95-96. The ground school also includes training on airplane systems and airplane specific equipment including the use of slides, life vests, and life rafts. Oper. Fact. p. 26. The function and use of the ditching button is discussed in ground school lecture and also in the QT curriculum and CQT curriculum. Id.

Distance learning over the internet, provided by graphics, audio and scripted text, discusses the procedures in the QRH. Hope Test. p. 96.

Captain Sullenberger explained that in annual recurrent training at US Airways, they are taught to land near vessels when ditching to expedite rescue efforts. Sullenberger Int. p. 29. When landing Flight 1549, the Captain observed boat traffic in the river and attempted to land as close as possible to those vessels. Sullenberger Test. p. 26. The Captain utilized this training to ensure a fast emergency response. Id.

2.5.6.3 Ditching Checklist

Ditching assumes there is reasonable time to prepare the aircraft and passengers for landing. Parisis Test. p. 80. Airbus has designed the Ditching checklist assuming a planned ditching, with available engine thrust, and time to prepare the aircraft. Id. at p. 84.

US Airways follows Airbus' recommendations. The US Airways QRH Ditching checklist assumes at least one engine is running. Oper. Fact. p. 26. If there is time to prepare for a ditching, there is specific guidance to pilots on aircraft configuration, landing direction and variables regarding landing on water. Sullenberger Int. p. 13.

2.5.6.4 No Flight Simulation for Ditching/Emergency Landing on Water

Ditching scenarios are not included in the simulator training curriculum at either US Airways or Airbus. Oper. Fact. p. 26. This is for several reasons: (1) the fidelity of the simulator is inadequate; (2) there is the potential for negative training to pilots; and (3) even if it was possible, it would require an inordinate about of time to reset the simulator. Hope Test. pp. 98-99, 130.

The simulator does not have the capacity to recreate water. Duncan Int. p. 26. Limited data is available in the industry for touching down on water. Hope Test. p. 99. When a pilot is landing on a runway environment in the simulator, there are a number of cues available. Lutz Test. p. 337. From approximately one hundred feet, a pilot will be able to observe the runway, runway lights, the runway markings, the control tower, and the hangars. Id. As the pilot approaches close to the runway, the runway stripes begin to disappear beyond the airplane and the pilot has a very good feeling for the surface. Id. at pp. 337-338. In contrast, for a water approach, a simulator would not be able to depict the waves on the water, the wakes from the boats, the boats themselves, or wharfs or buildings on the edge of the water. Id. at p. 338. The simulator is limited to a monolithic presentation of a surface. Id. It is very difficult to achieve consistent results on the water. Id.

Whatever simulator scenario could be created for pilots, it would not be realistic and could have the effect of providing incorrect learning resulting in negative training. Hope Test. p. 130. Negative training is when a person is set up for one kind of situation where something else actually occurs in reality. Burian Test. p. 135. There are so many variables that are involved with water entry. Arnold Test. p. 308. It is possible that if a scenario is taught with certain cues that those cues may not be available in a real life situation. Parisis Test. p. 130. The pilots would expect the procedure to work as it did in training, but it would not. Id. "[W]e have to be very careful of the possibility of negative training in this kind of situation when you go beyond the capacity of the simulator." Id. at pp. 130-131.

Further, a hard reset of the simulator, requiring a significant amount of time, is necessary when landing on any surface other than asphalt. Hope Test. p. 99. Spending significant time performing a task that does not have reliable data and resetting the simulator would take away from valuable time that could be spent preparing for other events with reliable data.

2.5.7 Flight Attendant Training

US Airways flight attendants receive basic indoctrination training which covers FAA requirements, passenger handling and company procedures. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Jodi Baker ("Baker Test.") p. 405. After their initial training, flight attendants receive recurrent and re-qualification training. Id. at p. 406. US Airways flight attendants also participate in emergency training, during which they learn about safety equipment installed on the aircraft. Id. at pp. 407-408. US Airways uses scenario based training sessions where the flight attendants respond to simulated emergency situations. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Robert Hemphill ("Hemphill Test.") p. 413.

US Airways' initial training program is five weeks. Id. At the end of the initial training program, there is a required five hour initial operating experience whereby flight attendants must be observed by an air transportation supervisor and qualified based on their performance in actual flight. Id. In the initial training program, flight attendants complete four hours of CRM and TEM training. Id. Further, the flight attendants perform a wet ditch drill, where they are taken to a pool and board a life raft using all of the techniques on which they have been trained. Id. In addition, as part of initial training, US Airways conducts planned emergency cabin preparations in the cabin simulator. Id. at pp. 413-414. This is for a planned ditching scenario where there is altitude available and time to prepare the cabin. Id. at 414. In the planned ditching training, flight attendants obtain familiarity with life vests, seat cushions and other flotation devices. Id. Lastly, US Airways conducts evacuation drills. Id.

Instruction goes from presentations to scenario-based training with evaluation and remedial training, if required, until a flight attendant is proficient enough to perform his/her responsibilities. Id. at p. 411.

US Airways recurrent training is a twelve hour program that consists of one day of distance learning and then one day of classroom learning. Id. at p. 414. The Company trains on ditching and evacuation every year. Id. at pp. 411; 414. A dry ditch drill is performed every year. Id. at p. 414. In a dry ditch drill, the flight attendants again become completely familiar with the slide rafts, although this is not performed in a pool as in initial training. Id. The flight attendants again review all the emergency equipment associated with a ditching, including life vests, seat cushions and lifelines. Id. In addition, every year, flight attendants conduct an emergency evacuation drill. Id. The emergency evacuation drill includes a complete evacuation on all aircraft door types on which flight attendants are qualified. Id. at p. 411.

2.5.7.1 Training Equipment

US Airways has full cabin fixed based simulators that have smoke and video capability for the A319, A320 and A321 aircraft. Id. at p. 412. These full cabin simulators support the Company's scenario-based training. Id. at p. 413.

US Airways has evacuation slide rafts in all locations for use during training exercises as well. Id.

2.5.7.2 Joint Training

Captain Sullenberger explained that CRM and TEM is something that has been deeply ingrained in the US Airways pilot and flight attendant group. Sullenberger Test. p. 37. Over the years, US Airways has provided joint training in handling just the kind of situation the crew faced on Flight 1549. Id.

During US Airways' recurrent training, there is one hour of joint training. Hemphill Test. p. 414. US Airways believes this is a great benefit to any emergency situation. Id. Dr. Burian commented during her presentation to the Board at the NTSB hearing that combined training is of significant value. Burian Test. pp. 113-114. It allows pilots and flight attendants to be trained in the same room, applying TEM and CRM together to real life scenarios. Hemphill Test. at p. 414. US Airways teaches pilots and flight attendants to understand that an unlimited variety of situations could occur in flight. Id. at p. 412. By teaching a thought process and providing tools for dealing with such situations, US Airways is able to better equip its crews to deal with them. Id.

SECTION 3. ANALYSIS OF ISSUES INVOLVED IN THIS INCIDENT

3.1. Role of AQP Training and CRM/TEM in Achieving a Successful Outcome

During the NTSB Hearing, Dr. Wilson asked Captain Sullenberger: "What lessons do you think that we can learn from this accident?" Captain Sullenberger responded by saying:

> I think it's the importance of CRM. The importance of a dedicated, well-experienced, highly trained crew that can overcome substantial odds and working together as a team can bring about a good outcome.
>
> (Sullenberger Test. pp. 29-30.)

The crew of Flight 1549 faced a dire situation on January 15, 2009. The likelihood of this accident was extremely remote. NTSB Public Hearing Transcript, June 9, 2009, Testimony from Dr. Richard Dolbeer, US Department of Agriculture ("Dolbeer Test.") pp. 164-165; 181;

127-128. Accordingly, the crew had not been trained for this specific emergency. Hope Test. p. 93.

With loss of thrust and rapid deceleration, the crew had three and a half minutes from the time the engines failed to the time the aircraft touched down in the Hudson to respond to this crisis. Benzon Test. p. 17. The fact that this crew successfully landed the aircraft in the water and that every single person on board the aircraft walked away from this accident is a true testament to the training US Airways' pilots receive and the focus US Airways places on CRM and TEM.

As Captain Sullenberger stated, the fact that this was a highly trained crew working together as a team was one of the determining factors in achieving this successful outcome in the face of almost insurmountable odds. Sullenberger Test. pp. 29-30.

US Airways has a long history of implementing CRM and TEM in its training. Sullenberger Test. p. 37. Under the AQP program, CRM and TEM are imbedded in all aspects of training. Oper. Fact. p. 27; *see also* Hope Test. pp. 101-102. Although the training provided to the crew was for dual engine failure at a high altitude, by using CRM/TEM, the crew was able to adapt the skills learned to the lower altitude situation presented to them on January 15, 2009, and achieve the successful outcome they did. Hope Test. p. 93.

The Captain credited the CRM training provided at US Airways that gave the crew the skills and tools they needed to build a team quickly, open lines of communication, share common goals and work together. Oper. Fact. p. 30. Captain Sullenberger and First Officer Skiles did not have time to consult all the written guidance or to complete the appropriate checklist due to the severe time constraints presented by this emergency situation. Id. at p. 17; *see also* Sullenberger Test. p. 26; Skiles Int. p. 3. The Captain explained that he and the First Officer had to work almost intuitively together because time did not allow the verbalization of every decision or the discussion of every part of the situation. Sullenberger Test. pp. 26-27; *see also* Oper. Fact. p. 30. Because of the time pressure, the Captain and the First Officer had to observe each other's actions and implement their training in CRM and TEM in order to be on the same page. Sullenberger Test. pp. 26-27. The Captain described the coordination between him and the First Officer as "amazingly good considering how suddenly the event occurred, how severe it was, and the little time they had." Oper. Fact. p. 30; *see also* Sullenberger Int. p. 13. The manner in which CRM and TEM were employed by the crew is textbook and clearly led to the successful landing of Flight 1549. Hope Test. p. 147.

In addition to US Airways CRM and TEM training, Captain Sullenberger mentioned US Airways' AQP training as being helpful to him in achieving a successful outcome. Sullenberger Test. p. 27. Specifically, the Captain mentioned that US Airways' annual recurrent training, the CQT under the AQP program, during which many different scenarios are practiced with a focus on CRM, was helpful in managing this emergency. Id. Captain Sullenberger commented that he believed it was important to train people in the process of overcoming emergencies. Sullenberger Int. p. 21. Every accident will be different, and learning to apply the process of CRM and TEM is helpful in handling real life emergency situations.

Chairman Sumwalt asked Captain Sullenberger what made the critical difference in the outcome of this event. Sumwalt Exam. p. 46. In response, in addition to CRM/TEM training, Captain Sullenberger mentioned the culture at US Airways. Sullenberger Test. p. 48. He explained as follows:

> It's important to note that nothing happens in isolation, that culture is important in every organization, and there must exist a culture from the very top of the organization permeating throughout, that values safety in a way that it's congruent, that our words and our actions match and that people feel free to report safety deficiencies without fear of sanction. So, all these things must happen together. We must balance accountability with safety.

Id.

Captain Sullenberger explained that US Airways has this culture and works "very hard to make it what it needs to be every day." Id. at p. 49.

The positive outcome of Flight 1549 highlights the success of US Airways' training program and the need for continued emphasis on CRM/TEM. Stanley Pavkovitch, A320 Aircrew Program Manager for the Federal Aviation Administration, said that he felt the US Airways training program was second to none. Oper. Fact., Attachment 4, Stanley Pavkovitch Interview ("Pavkovitch Int.") p. 2. US Airways could not be more pleased with the actions of its crew and the role that its training program played in saving the lives of the 155 people on board Flight 1549.

3.2 Captain's Decisions

All of Captain Sullenberger's decisions had to be made in three and a half minutes. Benzon Test. p. 17. In that time he had to control the airplane, make decisions to achieve maximum aircraft performance, evaluate landing options, inform Air Traffic Control of his decision, alert the passengers and flight attendants to brace for impact and configure the airplane for landing without having time to refer to written guidance, all with the lives of 155 people in his hands. To say Captain Sullenberger did a remarkable job is an understatement.

3.2.1 Captain's Authority

After the engine failures, Captain Sullenberger said "my aircraft" and took control of the aircraft from the First Officer. Sullenberger Int. p. 12. Captain Sullenberger explained that he assumed control because he realized immediately that this was a dire situation. Id. at p. 14. He was the experienced crew member and it was his responsibility as the Captain to operate the aircraft in this extreme emergency. Id. In addition, because LaGuardia Airport and the Hudson River were both on his side of the airplane and because they were at a low altitude without a lot of time, it was more expeditious for the Captain to perform the tasks needed rather than relaying them to the First Officer and having the First Officer perform them. Id. at p. 20.

3.2.2 Decision to Land in the Hudson

At the time of the bird strikes, the nearest airports were LaGuardia Airport and Teterboro Airport. Oper. Fact. p. 11. The first option was to return to LaGuardia. Sullenberger Test. p. 25. When the Captain took control of the airplane, the airplane was still in a climb attitude, but without climb thrust. Id. Consequently, the airspeed began to decrease dramatically. Id. The Captain explained that he needed to lower the nose in order to retain a safe flying speed, which caused the rate of descent to increase dramatically. Id. The Captain determined that based on the flight's position, the low altitude, the low airspeed, the fact that they were heading away from the airport, and the amount of time it took to stabilize the airplane and analyze the situation, returning to La Guardia was not possible. Oper. Fact. p. 32.

The Hudson River was considered by the crew to be the safest option for a forced landing. Oper. Fact. p. 32. The Captain explained that returning to LaGuardia would have been an "irrevocable choice." Sullenberger Test. p. 25. If he attempted to land at LaGuardia, but could not make it, he would have had no other landing options. Id. Before returning to LaGuardia, Captain Sullenberger explained that he needed to be sure he could make it without landing short or long, that he could line up the flight path with the runway, that he could stay on the runway, and that there would be a sink rate that was survivable and would not collapse the landing gear and create a post crash fire. Sullenberger Int. p. 30. The runways at LaGuardia are short, only 7000 feet long, with water on both sides leaving no room for error. Id. at p. 16. Further, to return to LaGuardia, the Captain would need to fly the aircraft over a densely populated area. Id. If he did not make it, there would be "catastrophic consequences" for those in the aircraft and on the ground. Id. at p. 17. He could simply not afford to make the wrong decision. Sullenberger Test. p. 25.

The Captain considered Teterboro, however, soon realized that they were "too far away, too low and too slow" for a successful landing at Teterboro. Oper. Fact. p. 32. Their altitude was decreasing rapidly due to loss of thrust. Sullenberger Int. p. 10. Both engines were heavily damaged and they were unable to maintain any altitude. Id. They were outside of the relight envelope. Id. The First Officer agreed that Teterboro was not a viable landing option. Skiles Int. p. 3. The only option that was long enough, smooth enough and wide enough in the highly developed New York Metropolitan area was the Hudson River. Sullenberger Test. p. 25. The Captain said he was confident that he could make a successful water landing. Sullenberger Int. p. 30. The First Officer agreed that the river was the best option. Skiles Int. p. 22. The other options were simply too risky. Id.

Captain Lutz from Airbus evaluated the risks associated with attempting to return and land at LaGuardia or another airport and the risks associated with attempting to land on the Hudson river. Lutz Test. p. 349. He stated with certainty that the greatest risk would have been trying to return to an airport. Id. Captain Lutz agrees that landing Flight 1549 in the Hudson River was the proper choice. Id.

3.2.2.1 Simulator Data on Return to LGA or Other Airports

Four airline transport rated pilot members of the Operational Factors/Human Performance Group, three of whom were type rated on the A320 and one of whom was an A320 rated Airbus test pilot, participated in an observational study at the Airbus Training Center in Tolouse, France. Oper. Fact., Attachment 28, Simulator Results Document ("Oper. Fact. Att. 28"). The purpose of the observational study was to identify and evaluate the various options available to the flight crew following the bird strikes, to attempt to land at LaGuardia and Teterboro and to determine the implications of each of those options. Id.

The conditions of the accident flight were programmed into the simulator. Id. The pilots followed the US Airways QRH Dual Engine Failure checklist and relied on their training and experience to complete the test conditions. Id.

While the group attempted to recreate as closely as possible the scenario faced by the Flight 1549 flight crew, it is not possible to recreate the true experiences of the Captain and First Officer in this dire emergency situation. Id. The pilots in the observational study knew what was going to happen, they knew they were going to be presented with a dual engine failure at 3,000 feet and they knew what their options were. The test was to actually evaluate those options. The group did not expend time to comprehend or analyze the situation, to attempt to relight the engines or to evaluate available options. Moreover, the group was not experiencing issues with cognitive processing associated with high stress situations. Burian Test. p. 110. The group did not have to fly the aircraft, make decisions, evaluate available options, communicate with ATC, and make announcements to the flight attendants and passengers. Further, none of the group had the lives of 155 people in their hands. It is impossible to recreate the experience of the Captain and First Officer on January 15, 2009.

In the simulator scenarios, there were 15 runs used for analysis in which pilots attempted to return to LaGuardia runways 13 or 22 or attempted to land at Teterboro runway 19. Oper. Fact. Att. 28. Six runs were used to LaGuardia runway 22. Id. Of those six, only two resulted in a successful runway landing. Id. These two successful landings were made following an immediate left turn after the bird strikes. Id. Due to the fact that four out of six runs were unsuccessful following an immediate turn after the bird strikes, attempts to land at LaGuardia runway 22 after a 35 second delay (which would actually be more in line with the accident scenario) were not performed. Id. It would have taken the pilots of Flight 1549 at least 35 seconds to realize what had happened, analyze the situation, attempt to restart the engines, maintain control of the aircraft and evaluate possible landing options.

All four pilots successfully landed on LaGuardia runway 13 following an immediate left turn to the airport after the bird strikes; however, the one attempt to return to LaGuardia following a 35 second delay was not successful. Id.

Two runs were attempted to determine the ability of the airplane to land at Teterboro runway 19 immediately after the bird strikes. Id. One attempt was successful and one attempt was unsuccessful. Id. Again, due to the fact that only one of the two runs was successful following an immediate turn after the bird strikes, attempts to land at Teterboro after a 35 second delay were not performed. Id.

The flight simulations revealed that a successful return to LaGuardia or a diversion to Teterboro Airport was not assured. Benzon Test. p. 18. If pilots flying these scenarios without actually being in the high stress situation could not make it safely back to an airport, it is clear that the only viable option for Captain Sullenberger was to land in the Hudson.

3.2.3 Use of APU

The airplane immediately lost thrust due to the damage in the engines. Sullenberger Int. p. 10. The First Officer attempted to restart both engines, according to the Dual Engine Failure checklist. Id. at p. 17. Captain Sullenberger, not knowing whether or not power would be available from either engine, started the auxiliary power unit ("APU"). Sullenberger Test. p. 24.

Although the engines never regained any thrust, one engine did operate at a level that provided some limited electrical power to the aircraft. Ganley Test. pp. 489-490. The electrical power being generated by the APU, coupled with the power from the engines, allowed the aircraft to maintain full electrical power. Lutz Test. p. 328. This fact was instrumental in the success of this water landing. Full electrical power allowed the Captain to retain all flight instruments and keep all flight envelope protections in place. Id. This resulted in a more controlled approach to landing. Id. at p. 330.

At the NTSB hearing, Captain Parisis commented that starting the APU was "very good" initiative of the Captain. Parisis Test. p. 132.

3.2.4 Flight Envelope Protections

The Airbus A320 incorporates flight envelope protections. Oper. Fact. p. 21. The flight envelope protections helped ensure the success of the forced water landing. Id. Because the flight envelope protections were activated, the flight computers prevented excessive maneuvers and operation outside the safe envelope in the pitch and roll axis. Id.

The flight protections improve the ability of the pilot to precisely control the airplane at a slow speed. Lutz Test. p. 325. The angle of attack protection provides positive stability at the low speed portion of the flight envelope. Id. It provides protection during dynamic angle of attack changes. Id. at pp. 325-326. The pilot has the ability to reach and maintain a high lift coefficient with full back stick without the risk of aerodynamic stall. Id. at p. 326. The flight protections allowed the pilot to pull full aft on the stick to achieve close to the maximum angle of attack and the best possible lift while minimizing the risk of stall or loss of control. Oper. Fact. p. 21. Because of the foregoing, Captain Sullenberger was able to achieve maximum aircraft performance without fear of a stall or loss of control. Lutz Test. p. 330.

In as much as the Captain started the APU prior to beginning the checklist, the APU generator was on line. Id. at p. 328. If the Captain had not started the APU, it is possible that the aircraft may have lost some of its flight envelope protections, which proved essential in the water landing.

3.2.5 Flap Configuration for Landing

The US Airways QRH and the Airbus QRH Dual Engine Failure procedure both provided guidance that indicated Flaps 3 was to be used for ditching. Oper. Fact. pp. 17-18. However, due to the limited time available, the crew did not reach the section of the checklist that provided guidance on airplane configuration. Id. at p. 18. The Captain had no time to refer to any written guidance to configure the aircraft for landing. Id.; *see also* Sullenberger Test. pp. 26-27. The decision on which flaps to use had to be made quickly, as did all decisions in this emergency scenario. Sullenberger Test. p. 26. Captain Sullenberger had to rely solely on his experience and the feel of the airplane. As a result, he decided to use Flaps 2 for landing. Oper. Fact. p. 18.

When asked about his decision to use Flaps 2 versus Flaps 3, the Captain explained that he believed there were operational advantages to using Flaps 2. Sullenberger Int. p. 27. The Captain was concerned about having enough energy remaining to successfully flare the airplane and reduce the rate of descent sufficiently for landing. Id. Without adequate thrust to maintain airspeed, the airspeed continued to decrease, limiting the energy that the Captain had available to reduce the rate of descent. Lutz Test. p. 330.

Captain Sullenberger believed that using Flaps 3 would not provide him much more of an advantage in terms of lowering the stall speed, but that drag would have increased. Sullenberger Int. p. 27. The Captain explained that by using Flaps 2, he believed he achieved almost all of the low speed stall protection that would have been achieved at Flaps 3, but with less drag. Sullenberger Test. p. 26. He wanted the least amount of drag as possible on touchdown to minimize the sink rate. Id.; *see also* Arnold Test. p. 354.

The aircraft had a touchdown vertical speed of 13 feet per second, more than three times the rate of descent for certification. Fitzsimmons Test. pp. 262-263. If the Captain had chosen Flaps 3, that may have caused considerable additional drag, which could have resulted in a higher rate of descent and a more violent touchdown. Arnold Test. p. 354.

3.2.6 Speed for Landing

The US Airways QRH and the Airbus QRH Dual Engine Failure procedures both provided guidance for the speeds to be flown if an engine relight was not possible, and for approach. Oper. Fact. p. 19. Both checklist procedures directed the crew to fly initially at Green Dot speed in clean configuration, and then to calculate an approach speed to be used after flaps were selected by using the chart provided. Id. Due to the limited time available, the crew did not reach the section of the checklist that provided guidance on speeds to be flown. Id. at p. 20; Skiles Int. p. 3.

The Captain flew just over 200 knots, until the turn to the Hudson River. Lutz Test. p. 328. The Captain flew below green dot speed, which allowed the aircraft to be airborne for the longest possible time. Id. at pp. 327-328. This provided the Captain additional time to accomplish the emergency procedures and land the aircraft safely. Id. Further, the Captain maintained a speed at which the flight envelope protections were active. Id. at pp. 329-330. As a result, he did not have to be concerned with stalling the aircraft. Id. at p. 330.

3.2.7 Pitch Attitude

The Captain was attempting to touchdown with a pitch attitude of 10 degrees or less. Oper. Fact. p. 23. This was on instinct because the Captain did not have time to reach the section of the checklist that provided guidance on pitch attitude for landing. Id.

Pitch attitude is very important in landing configuration. Fitzsimmons Test. p. 274. If the pitch is too high, the nose will slant and turn hard once the water hits the tail. Id. If the pitch is too low, the danger is that the airplane enters the water with a very strong nose down effect. Id.

Airbus recommends that pitch attitude for water entry be 11 degrees. Id. at p. 262. The aircraft entered the water at 9.5 degrees pitch attitude. Id. This was very close to the Airbus recommendation and certainly within the acceptable tolerance for entry to the water. Id.

3.2.8 Announcement of Water Landing

The Captain made the announcement "This is the Captain, brace for impact." Sullenberger Test. p. 31. The Captain spent some time, perhaps four or five seconds, to choose his words for this announcement. Id. at p. 32. His highest priority at that moment was to avoid passenger impact injury. Id. He was not certain how severe the touchdown would be and his immediate concern was to avoid passenger injury during landing. Id. He chose the words "brace for impact" to indicate to the passengers that they needed to brace themselves in order to avoid impact injury. Id.

Although the flight attendants did not realize this was a water landing, the Captain knew that the flight attendants would perform their assessment of the outside conditions before opening the aircraft doors. Id. The Captain was concerned that if he told the flight attendants this was a water landing, that they would have begun directing people to put on life vests and neither the flight attendants, nor the passengers, would be in the brace position at impact. Id. at pp. 32-33. In doing this analysis, the Captain was balancing a number of considerations for the situation they faced and the time they had available. Id. at p. 33.

3.3 Checklist Design

Dr. Burian explained at the NTSB Hearing that cognitive skills are highly affected in stressful emergency situations. Burian Test. p. 110. It is easy for crews to become task saturated and, as a result, have difficulty with cognitive processing and prioritizing. Id. One problem that is often described is that crews have difficulty finding the proper checklists in emergency scenarios. Id. at p. 111. Many times crews are required to jump from one checklist to another, or to jump to a variety of other materials and sources. Id.

Dr. Burian stressed that it is essential to look at the human performance capabilities and limitations when creating these checklists and reduce, as much as possible, the cognitive processing loads that are placed on pilots in high stress situations. Id. at p. 118.

Dr. Burian commented at the hearing that US Airways was one of the first of the United States air carriers to adopt the "get in/stay in" philosophy in the development of their checklists. Id. at p. 115. Dr. Burian explained that the "get in/stay in" checklist, where there is only one checklist, helps reduce the cognitive processing load and eliminates the confusion in high stress situations. Id.

3.4 Evacuation

3.4.1 EOW v. Non-EOW Flights/Airplanes

Routes that are 50 nautical miles or more off shore require the use of Extended Overwater ("EOW") aircraft. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Jeff Gardlin ("Gardlin Test.") p. 345. While the route of Flight 1549 did not require use of an EOW aircraft, the aircraft was EOW equipped. Sullenberger Test. p. 36. All US Airways' Airbus A320 EOW aircraft have passenger life vests at every seat, ten additional infant life vests, two emergency locator transmitters, four slide rafts, four survival kits and four lifelines. Hemphill Test. pp. 416-417. This equipment was available on Flight 1549. Id.

Demonstration of life vests is only required for extended overwater flights or when the flight is traveling 50 nautical miles or more off shore. Surv. Fact. pp. 4, 7. Flight 1549 was traveling from LaGuardia to Charlotte and was not considered an extended overwater flight. Accordingly, there was no requirement to demonstrate the use of life vests prior to the flight. Flight Attendant Doreen Welsh conducted the safety demonstration prior to the flight, but did not demonstrate the use of life vests because she was not required to do so. Id. at p. 7.

3.4.2 Emergency Equipment

3.4.2.1 Issue with the Forward Slide Raft on Flight 1549

The crew reported difficulty locating the knife in the slide raft to cut the line which attached the raft to the airplane. Skiles Int. p. 24.

The knife is actually located in a prominent, clearly marked pouch on the side of the raft. Further, crews are trained on the location of the knife every year during recurrent training. US Airways believes that the confusion of the situation contributed to the delay in locating the knife. The ferries arrived on the scene almost immediately, eliminating the need for the crew to look further for the knife. Captain Sullenberger asked a crewman on one of the rescue boats for a knife and the crewman tossed a knife to First Officer Skiles who cut the line. Id.

Airbus instructs that the raft should actually remained tethered to the aircraft so, in situations where rescue is not accomplished quickly, the raft would be more easily located. Hemphill Test. pp. 478-479. However, this was obviously not a factor in Flight 1549 due to the immediate response of rescue personnel. Further, the manner in which the Airbus is designed, if the fuselage starts to sink, that tether will break and release the raft from the aircraft. Id. at p. 479.

3.4.2.2 Use of Over Wing Exits

The over wing exits are considered secondary exits and should not be used unless one of the primary exits, the four floor level door exits, is unavailable. NTSB Public Hearing Transcript, June 10, 2009, Testimony from Hans-Jurgen Lohmann ("Lohmann Test.") pp. 397-398. There were no instructions to passengers at the over wing exits regarding evacuation because there was no time to prepare the cabin for this emergency landing. Hemphill Test. p. 427. In a planned scenario, flight attendants would brief the passengers at the over wing exits as to the appropriate exits. Id. at pp. 427-428.

Had there been time for a planned emergency landing, the flight attendants would have instructed the over wing passengers to use the two doors in front and the two doors in back of the aircraft as those would have been the safest exits from which to evacuate. Id. at pp. 441-442. These doors have slide rafts attached and are designed to move passengers from the cabin directly into a raft.

If for some reason the primary door exits are not available, the flight attendants are trained using TEM to adjust and respond by moving passengers from the primary door exits to the secondary over wing exits and to assist in the process of evacuation over wing. Id. p. 442.

3.4.2.3 Lifelines

Lifelines are lines that are intended to be mounted to the airplane fuselage and anchored to a point on the wing. Gardlin Test. p. 391. The purpose of lifelines is to assist passengers in steadying themselves on the wing. Id.

The passengers opened the over wing exits themselves. Surv. Fact. p. 6. They were not briefed on the evacuation procedure because there was no time to prepare the cabin for a water landing. Hemphill Test. p. 427. If there was time to prepare the cabin, the current procedure is to instruct passengers to use the primary four floor level door exits. Id. at pp. 441-442. The passengers would not be briefed on the use of lifelines. If a flight attendant needs to move passengers from a primary exit to one of the secondary over wing exits, that flight attendant, who has been trained in the use of lifelines, would attach them. Id. at p. 439. Lifelines would only be used if the door exits were unusable. Id.

3.4.2.4 Off Wing Slides

The A320 is equipped with off wing slides, which are both a ramp to the wing and a slide from the wing to the ground. Gardlin Test. p. 388. They are not considered part of the flotation equipment on the aircraft. Id. at p. 387. The passengers exiting onto the wing reported difficulty with the off-wing slides. Surv. Fact. p. 61. They were twisted in the water and the passengers had difficulty utilizing the off wing slides as rafts. Id. There was no malfunction of the off-wing slides. The off-wing slides are not designed to be used as rafts and were never intended to be used in the water.

3.5 Bird Strike Hazard Recognition and Mitigation

Bird strike hazard recognition and mitigation is largely an airport issue. Dolbeer Test. p. 163. The majority of bird strikes occur near or on the airport. Id.

As far as actions the airlines can take, there have not been many options available to date. However, there has been some research in utilizing pulsating lights on aircraft. Dolbeer Test. pp. 168-169. Further research needs to be done in this area. Id.

US Airways does consider and incorporate bird strike hazards into its normal operating procedures. Hope Test. p. 102. For example, US Airways requires lights on from takeoff through 10,000 feet and on again descending down from 10,000 feet to the ground. Id. In addition, in takeoff and approach briefings, US Airways crews listen to the ATIS and ATC for pertinent information and, if there is an issue regarding birds, the pilots would use their TEM training to address the situation and plan accordingly. Id. at pp. 150-151.

SECTION 4. CONCLUSIONS

4.1 Findings

1. Under the US Airways AQP program, approved by the FAA, US Airways focuses on CRM and TEM in all aspects of its training.

2. US Airways uses scenario-based training where it places its pilots into real-life situations and teaches the process of overcoming emergencies through the utilization of CRM and TEM.

3. Captain Sullenberger and First Officer Skiles did not have time to consult written guidance or to complete the Dual Engine Failure checklist due to the severe time constraints of this emergency situation.

4. The CRM and TEM training at US Airways provided the skills and tools for Captain Sullenberger and First Officer Skiles to achieve the successful outcome of Flight 1549.

5. US Airways Dual Engine Failure training is consistent with the manufacturer's training and includes a high altitude situation only, which is the most probable scenario for a dual engine failure.

6. Captain Sullenberger and First Officer Skiles only had high altitude dual engine failure training, yet they were able to adapt the skills learned to the lower altitude situation encountered by Flight 1549 by using CRM and TEM.

7. The positive outcome of Flight 1549 highlights the success of US Airways' training program and the need for continued emphasis on CRM and TEM.

8. The flight crew had about three and a half minutes from the time of the bird strikes to the touchdown in the water to evaluate the situation and available options, continue to fly the aircraft, decide on a landing strategy, communicate with ATC, flight attendants and passengers, and configure the aircraft for landing.

9. After the engine failures, Captain Sullenberger appropriately took control of the aircraft by saying "my aircraft."

10. Landing Flight 1549 in the Hudson River was the only viable option.

11. Based on the flight's position, the low altitude, the low airspeed, the fact that the aircraft was heading away from LaGuardia and the amount of time it took to stabilize the airplane and analyze the situation, returning to LaGuardia was not a viable option.

12. There were greater risks associated with attempting to return and land at LaGuardia or at another airport such as Teterboro than with attempting to land on the Hudson River.

13. The flight simulations conducted by the Operational Factors/Human Performance Group reveal that a successful return to either LaGuardia Airport or a diversion to Teterboro was not assured and could have had fatal consequences.

14. After the engine failures, the Captain started the auxiliary power unit which contributed to the fact that the aircraft maintained full electrical power throughout this emergency, allowing the Captain to retain all flight instruments and all flight envelope protections.

15. The flight envelope protections allowed Captain Sullenberger to achieve maximum aircraft performance without fear of a stall or loss of control.

16. The fact that the aircraft had electrical and hydraulic power during this emergency resulted in a more controlled approach to landing.

17. The Captain flew below green dot speed which allowed the aircraft to be airborne for the longest possible time, affording the Captain the most amount of time to prepare the aircraft for landing.

18. Although the Captain did not have time to consult written guidance, the Captain entered the water at a pitch attitude of 9.5 degrees, which is very close to the recommended 11 degrees pitch attitude in the ditching section of the QRH and Airbus' certification recommendation.

19. The Captain made the announcement "this is the Captain, brace for impact," which indicated to the crew and passengers that they needed to be in a brace position. Had the Captain announced it would be water landing, the crew and passengers may have begun preparations for a water landing including obtaining and putting on life vests, which may have resulted in the crew and passengers not being in the brace position at impact.

20. US Airways Dual Engine Failure checklist is a "get in/stay in" checklist which reduces cognitive processing loads of pilots in high stress situations.

21. Because Flight 1549 was an EOW aircraft it was equipped with life vests and slide rafts, which facilitated the evacuation and survivability of this accident.

22. As Flight 1549 was not an extended overwater flight, the passenger safety demonstration did not include the demonstration of life vests.

23. There was difficulty locating the knife in the slide raft to cut the line which attached the raft to the airplane due to the confusion of the situation. Airbus procedures recommend cutting the mooring line if the aircraft was to sink; however, as a back-up, if the line is not cut it is designed to break enabling the raft to remain afloat.

24. There was no time to prepare the cabin for a water landing.

25. As Captain Sullenberger was more properly focused on the passengers bracing for impact and due to the shortness of time and high workload, the passengers were not briefed on the proper exits or on the use of life lines. The evacuation was, nonetheless, accomplished quickly.

26. Over wing exits are considered secondary exits. The primary exits are the doors which lead to the slide rafts.

27. The impact damage to the lower portion of the aft fuselage enabled water to immediately enter the cabin area. The water in the rear of the aircraft precluded the use of the two aft emergency exits and slide rafts.

28. The flight attendants executed proper evacuation procedures and assisted and directed all passengers off the aircraft through the usable exits.

29. The passengers on Flight 1549 exited into the front two slide rafts and onto both wings.

30. There was no malfunction of the off-wing slides. The off-wing slides are not designed to be used as flotation devices and were never intended to be used in the water.

31. Bird strike hazard recognition and mitigation is an airport issue. US Airways does consider and incorporate bird strike hazards into its normal operating procedures.

4.2 Probable Cause

The probable cause of this accident was the ingestion of Canada geese into both engines while on climb out from New York's LaGuardia Airport, resulting in an immediate loss of thrust in both engines and a successful emergency landing on the Hudson River.

4.3 Contributing Factors

There were a number of factors that contributed to the success of this emergency landing on water:

- The decision of Captain Sullenberger to land in the Hudson River rather than risk returning to LaGuardia Airport or diverting to another airport;
- The decision of Captain Sullenberger to start the auxiliary power unit which assisted in retaining all flight instruments and all flight envelope protections and resulted in a more controlled landing;
- US Airways training and its emphasis on CRM and TEM through scenario-based training which resulted in a highly-trained well-prepared crew that worked together as a team to achieve this successful outcome; and
- Highly-trained and highly experienced flight attendants which executed the evacuation procedures and assisted and directed all passengers safely off the aircraft.

SECTION 5. RECOMMENDATIONS

US Airways proposes the following two recommendations to the Board:

1. The manner in which CRM and TEM was employed by the crew was instrumental in the successful emergency water landing of Flight 1549. US Airways' CRM and TEM training worked well. US Airways recommends that CRM and TEM be incorporated into all aspects of air carrier training and evaluation programs.

2. The low altitude dual engine failure of Flight 1549 was an event beyond the ditching procedure and the dual engine procedure. US Airways recommends the development of a checklist for an emergency landing due to low altitude dual engine failure which would include steps to restart the engines while preparing to land either on land or in water with time constrained.