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BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

Contribution to the analysis of the accident to the Airbus A320 registered N106US operated by US Airways on January 15th 2009, at Weehawken

This paper is intended to contribute to the analysis of the accident that occurred on January 15th 2009, to an Airbus A320 operated by US Airways that performed an emergency landing in the Hudson River near Weehawken, New Jersey. The BEA represented the State of Manufacture for this accident, in accordance with the provisions of ICAO Annex 13. At the end of the Technical Review Meeting in November 2009, the NTSB requested that the parties provide a submission for the analysis of this accident. Although the BEA is not a party to the investigation, it was also invited to make a contribution. The BEA is pleased to provide the following analysis, outside of the provisions of Annex 13 for official comments, which we hope may help the NTSB in its investigation process.

The content of the contribution has been limited to the analysis of the accident, even if at some stages, some factual information has been included for comprehension purposes.

Two main sections have been defined:

- The scenario, which describes the history of the flight and the sequence of events leading to the accident.
- The discussion, which deals in more details with specific topics related to the accident.

This accident was originally caused by the ingestion of large birds post initial climb, leading to a significant loss of thrust on both engines and to an emergency landing in the river.

Zone Sud – Bâtiment 153
200 rue de Paris
Aéroport du Bourget
93352 Le Bourget Cedex
France
Tél. : +33 1 49 92 72 00
Fax : +33 1 49 92 72 03
www.bea.aero

1 Scenario

All times in the document are UTC times, defined as NTSB ASR EST + 5 h.
Note: The FDR UTC time is actually 2 seconds ahead of this UTC time.

On January 15th 2009, the Airbus A320 registered N106US operated by US Airways as flight 1549 was scheduled to fly from New York La Guardia to Charlotte, NC..

At 20 h 00 min 32 s, the crew listened to the ATIS Papa information message. Runway 04 was in use. No presence of birds was mentioned.

At 20 h 05 min 34 s, the cabin crew made the safety briefing to the passengers. The use of seat cushions as floatation devices and the position of emergency exits were explained.

At 20 h 06 min 25 s, the crew was cleared to start the engines.

At 20 h 08 min 25 s the aircraft's configuration was set to "FLAP 2".

At 20 h 08 min 40 s, the crew requested the taxi clearance. The controller informed the crew that runway 04 was in use and, at 20 h 12 min 25 s, gave the departure clearance.

At about 20 h 16 min the crew started the flight control checklist and, at 20 h 18 min, the taxi checklist.

At 20 h 21 min 27 s, when the aircraft was on hold, the FO became PF.

At 20 h 24 min 54 s, the crew was cleared for take off. It lined up on runway 04 and started the take off. At 20 h 25 min 21 s, the N1 of both engines reached 88% (TOGA). At 20 h 25 min 33 s, the captain announced V1 and VR.

At 20 h 25 min 40 s, the captain retracted the landing gear. At 20 h 25 min 42 s, the FO commanded a left turn to the heading 360°.

At 20 h 26 min 00 s, the departure controller cleared the crew for to 15 000 ft.

At 20 h 26 min 03s, the engine throttle levers were positioned on the CLIMB detent. Subsequently the ATS was engaged in N1 mode. A second later, N1 started to decrease to 80%.

At 20 h 26 min 19 s, the aircraft's configuration was set to "FLAP 1".

At 20 h 26 min 52 s, the FO requested "flaps up" and the "after take off" check list. At 20 h 27 min 06 s, the aircraft was in clean configuration.

At 20 h 27 min 10 s, at an altitude of about 2 700 ft, the captain caught sight of birds. This was immediately followed by the ingestion of birds in both engines, resulting in the following events:

- The left engine N1 quickly decreased to 35% within 6 seconds;
- The right engine N1 quickly decreased to 15% in 13 seconds. After that it slowly decreased to reach 8% when the aircraft landed into water;
- The left engine N2 decreased from 94% and stabilized around 84%.
- The right engine N2 decreased and stabilized around 35%. After 20 h 28 min 30 s, it slowly decreased to reach 0% at 20 h 30 min 24 s.

At 20 h 27 min 15 s, the captain observed that both engines were "rolling back". At 20 h 27 min 20 s, he started the APU. He took over the controls at 20 h 27 min 23 s.

The thrust on both engines was insufficient to allow the aircraft to maintain levelled flight. The captain requested the "Loss of thrust on both engines" checklist on the QRH at 20 h 27 min 28 s. One second later, at an altitude of about 3 100 ft, the aircraft started to descend. At 20 h 27 min 33 s, the captain declared in emergency. The DEP controller cleared the crew for a return to La Guardia. The aircraft turned left towards heading 230° and started to fly over the Hudson River at 20 h 28 min 55 s.

At 20 h 27 min 50 s, the FO positioned the ENGINE MODE selector on IGN. The left and right engine throttle levers were positioned on IDLE, which disengaged the ATS. The left engine N1 and N2 decreased to respectively 22% and 63%. The FO said that the airspeed optimum relight was 300 kt and that the actual airspeed was below this value.
After 20 h 28 min 14 s, the left engine throttle lever was progressively moved back to the CLIMB position. The left engine N1 and N2 increased again.

At 20 h 28 min 36 s a TCAS traffic advisory was generated. At 20 h 28 min 45 s a wind shear warning message was generated.

At 20 h 29 min 07 s, the FO made an unassisted start attempt. He positioned the right engine MASTER switch on the OFF position then back on the ON positioned.

At 20 h 29 min 11 s, at an altitude of about 900 ft, the captain requested the passengers to brace for impact.

At 20 h 29 min 27 s the FO positioned the left engine MASTER switch on the OFF position. Subsequently, the left engine N1 and N2 dropped respectively to 14% and 38%. The FO positioned the left engine MASTER switch back on the ON position and observed no relight. After that, the left engine N1 remained around 14% and the N2 slowly increased up to 50%.

After 20 h 29 min 36 s, the EGPWS generated several ground proximity warnings and alerts.

At 20 h 29 min 45 s, the captain ordered to “put the flaps out”. The FO selected the “FLAP 2” configuration at 20 h 29 min 49 s. This configuration was reached at 20 h 30 min 04 s. It resulted in a height increase from 250 ft to 370 ft.

At 20 h 29 min 56 s, the right engine throttle lever was pushed forward from the IDLE position. It reached the CL detent 4 seconds later. This did not result in any significant change in N1 or N2.

At 20 h 30 min 07 s, the right engine lever was brought back to IDLE during 4 seconds, and then placed again to CL detent.

At 20 h 30 min 17 s, the FO asked the captain if he to further extend the flaps. The captain declined.

The flap extension is correlated with a reduction of airspeed from 190 kt to 125 kt and a progressive increase of the angle of attack from 6° to 15°.

At 20 h 30 min 39 s, both throttle levers were placed in the IDLE detent.

At 20 h 30 min 43 s, the aircraft collided with the surface of the Hudson River with the following parameters:

- airspeed 125 kt;
- vertical rate of descent 13 ft/s;
- pitch 9.5°;
- flight path angle -3.4°;
- angle of attack 13°.

2 Discussion

2.1 Engine performance and certification

Part 33 regulations describe the airworthiness standards that engines are required to comply with to obtain FAA TC. The CFM56-5B4/P engine was certified on June 20, 1996. At this time, the certification standards for bird ingestion were the following:

- the ingestion of seven 1.5-pound birds volleyed into the engine in less than one second shall induce no more than a 25%-reduction of thrust for five minutes, generate no hazard for the aircraft and cause no change in handling characteristics;
- the ingestion of a single 4-pound bird shall not result in an uncontained failure.

The ingested birds were identified as Canada geese by the Smithsonian Institution. The weight of these birds is usually comprised between 7 and 9 lbs and can reach more than 13 lbs. Most likely the weights of the ingested birds were far above four pounds and it was shown that the left engine ingested at least two birds (one male, one female). Furthermore the examination of the engines showed that their failures were contained. The FDR and CVR data confirmed that the crew had no difficulty to control the attitude and trajectory of the aircraft after the bird ingestion.

These considerations prove that, during the event, the engines fully complied with the certification standards. Further amendments of FAA and EASA regulations changed the weight criterion to four, six or eight pounds, depending on engine size. However these certification standards do not require the thrust to be maintained after the ingestion of a large bird.
The BEA considers that it is unrealistic to recommend modifying the certification requirements to ensure that new types of engine will be able to ingest birds of this weight without thrust reduction. However this event stresses the necessity for engine manufacturers to continue to improve the bird ingestion capability of their products.

2.2 Electrical supply

The aircraft is designed so that, 500 ms after the value of N2 drops below 53.6% on both engines and the APU generator is off, the Ram Air Turbine is extended to provide emergency electrical supply. Since the left engine N2 stabilized around 84% after the bird ingestion, it could still supply all the systems with electrical power.
After the impact, the captain quickly decided to start the APU generator on, well before the corresponding item in the “engine dual failure” checklist could be reached. This action helped to maintain the electrical supply, especially after the relight attempt of the left engine. At this time, the left engine N2 went below 53.6%, and if the APU generator had not been on, the electrical supply would have switched to emergency mode.

This switch could also have occurred just after the bird impact if the left engine had been more severely damaged.

The switch to emergency mode would not have any effect on the manoeuvrability of the aircraft. However the control law would have switched to alternate mode. The most effective protections against stall would have been disabled[1]. Also, the captain and FO screen configuration would have changed. All these modifications could have disturbed the crew significantly, during an emergency descent which was already generating high stress and workload. Furthermore, the FDR data shows that the alpha protection value was reached several times during the descent, which seems to imply that the captain was not really aware that the angle of attack was close to its maximum value. In this context, the use of alternate law may not have been a sufficient protection against stall, or the triggering of a stall alert may have induced inadequate reflex actions from the pilot at low height.

The APU start time is about one minute. Furthermore, most of the collisions with birds occur at low heights. Therefore, in case of an dual engine failure due to bird ingestion, the crew does not have much time to start the APU. The NTSB report could discuss the appropriateness of changing the SOP of twin engine aircraft so that the APU is switched on from take off, up to a height where the risk of collision with birds becomes sufficiently low or give enough time to start the APU again in case of dual engine failure.

2.3 Decision to perform an emergency landing on water

The discussions between the crew and ATC show that, after the collision with birds, the captain considered several courses of action: returning to La Guardia airport, performing an emergency landing in the Hudson River or landing at Terterboro airport.
The simulations performed in the manufacturer's facilities showed that landing on runway 13 of La Guardia airport was theoretically feasible. However the captain seemed to have pondered the risk of not reaching the runway and considered the high urbanization of the airport surroundings. Considering the height at which the collision with the birds occurred, trying to reach Teterboro would have presented a high risk of collision with buildings or with the ground.
Therefore, the captain decided to perform an emergency landing in the Hudson River.

2.4 Emergency procedures

After the bird ingestion, the captain took over the controls and asked the FO to perform the "engine dual failure" checklist on the QRH. He most likely had a look at the engine parameters, showing that both engines N1 were decreasing.

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[1] Low speed stability, which introduces a progressive nose down signal, and an audio stall warning would still have been available. However, with this law, it is possible to exceed alpha max.

The manufacturer considered the risk of the loss of electrical supply when both engines fail and, for this reason, the “engine dual failure” checklist is an ECAM exception: the QRH checklist is used instead. Thus the captain’s decision was compliant with the recommendations of the manufacturer.

At this time, the single engine failure was displayed on the ECAM. The logic of engine failure detection is based on the N2 value: the ECAM could not detect the failure on the left engine since the N2 of this engine was still high. This design may prevent the crew from properly identifying a dual engine failure and lead them to a wrong course of action. The BEA suggests that the ECAM logic takes into account additional parameters to determine an engine failure, such as, for instance, a lasting discrepancy between the commanded and actual N1 values.

The aircraft descended quickly and the crew had only 3 min 15 s to perform the “engine dual failure” checklist, which also includes the ditching checklist. During this time, about thirty items had to be covered, including an item requiring to “wait 30 seconds” to attempt a restart.
In order to assess the feasibility of the checklist in the conditions of the accident, the accident scenario was performed in a full motion simulator. Only twice could pilots reach the items requesting to start the APU bleed and to switch the engine master off and on. After that, they skipped the remaining relight checklist items and performed the ditching checklist for engines without power. The instructors also stated that “it was hard to find the relevant items”.

These considerations confirm that the “engine dual failure” and ditching checklist was designed for dual engine failures occurring at cruise levels. It is inappropriate for a quick descent which leaves time only to perform a few quick and critical actions. The testimonies from the FAA, the manufacturer and the airline, collected during the NTSB public hearing, agreed that this kind of event should be considered as an “emergency landing on water” and not a “ditching”.
The BEA also agrees with this statement. We suggest that the NTSB report mentions the existing confusion between the different terminologies and recommends the design of a specific action list, adapted to this kind of event. The use of memory items could be appropriate.

2.5 Structural damages

The pictures and videos recorded during the evacuation show that the flaps and slats were in position and seemed intact. The damages observed during the lifting of the aircraft were most likely the consequence of the rescue operations, during which the ferries hit these components several times.

On the other hand, the deformations and structural damages observed on the aft part of the fuselage were due to the collision with the surface of the water and to the friction with water during deceleration.

The FAR/JAR 25.801 states that "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". FAR/JAR 25.561(a) states that "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".

The compliance tests performed for the certification of the A300 and the extension of these results to the A320 showed that, with a pitch of 11°, a flight path angle of -0.5° and a speed of 118 kt, the aircraft should sustain no structural damage[2]. The vertical speed at impact for the accident flight (-13 ft/s) was much higher than the recommended vertical speed in this configuration (-3.5 ft/s). An additional simulation of structural damage performed by the manufacturer confirms that the observed damage is consistent with the recorded value of the vertical speed at impact. The NTSB report should mention that despite the damage, the aircraft complied with the certification standards, since the occupants were protected from major injury and were able to evacuate safely.

Taking into account the results of the certification tests, the manufacturer recommended the following parameters at impact in the "Engine dual failure" checklist:

- FLAP 3 with slats only;
- pitch 11°, and
- "minimum vertical speed".

The value of the "minimum vertical speed" is not mentioned, which may lead pilots to think that the rate of descent for a normal landing is sufficiently low. Surprisingly, the ditching certification standards do not state that the parameters recommended by the manufacturer shall be reached with no thrust on both engines. The NTSB report should recommend the authorities to modify the ditching certification standards accordingly.

The intensity of the collision also had the effect of making a metal rod pass through the cabin floor and probably injure the leg of a flight attendant seated in the aft of the aircraft. This metal rod is not part of the structure and there is no specific certification requirement to ensure that it remains in position in case of collision. Although the impact was significantly more intense than the ones performed during the A320 certification test, the event has shown that the position of the rod could

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[2] The manufacturer mentioned that the A320 fuselage was designed to resist an impact with a flight path angle of -1°. However the recommended FPA for a ditching is still -0.5°.

potentially represent a hazard for the cabin occupants. The BEA suggests that the manufacturer studies the possibility of changing the design or the position of this rod.

2.6 Vertical speed control

The simulations performed by the manufacturer showed that the recommended vertical speed at impact was reachable in the conditions of the accident flight, although during most sessions, the flight path angles at touchdown ranged from -0.8° to -2.5°. The most efficient technique to reduce the vertical speed was the one provided in the manufacturer QRH:

- just after the bird impact, follow the green dot speed (221 kt for the flight of the accident);
- use the “FLAP 3” with slats only configuration;
- follow the VAPP speed (164 kt for a 152 lbs aircraft).

When the birds were ingested, the airspeed was 220 kt. It decreased to reach 185 kt at 15 h 27 min 35 s. During the left turn, the airspeed increased again to reach 210 kt then slowly decreased during about two minutes. In this interval the aircraft flew several times in alpha protection mode. After the selection of “FLAP 2” configuration, the airspeed dropped below the recommended VAPP value and the angle of attack increased. During the flare, the angle of attack reached the “FLAP 2” alpha protection value. At this moment, the pilot had no airspeed margin to significantly increase the pitch and reduce the vertical speed.

It seems that the captain was focused on the search for an appropriate area for an emergency landing and on the management of the descent. During the approach he probably looked mostly outside, which may explain the variations of airspeed. During the simulations, several pilots also expressed their difficulties in maintaining the green dot speed while looking outside, due to the unusual attitude of the aircraft. Some of them also stressed that it was difficult to assess the height above water.

The QRH checklist recommends a landing configuration, i.e. “FLAP 3” or “FLAP 4”. Selecting these configurations would have helped to increase the airspeed margin and therefore to decrease the vertical speed during the flare. However this action would have been efficient only if performed early during the descent. At the time the captain chose not to extend the configuration from “FLAP 2”, the height and airspeed were already low. Changing the configuration at this time would probably have generated an additional constraint on the pitch control while not helping.

Interviews with the staff in the US Airways training centre in Charlotte confirm that no ditching scenario is performed during the training simulation sessions. A ditching, let alone an emergency landing into water following a dual engine failure, is rightly considered to be a rare event. However, although most airline pilots are aware that the “engine dual failure" procedure includes items about ditching, the accident flight and the simulation sessions showed that few of them are aware of the airspeed, vertical speed and configuration management issues or are able to perform this exercise properly. The NTSB report should study the appropriateness of performing additional simulation sessions for ditching and emergency landing into water training, taking into consideration the rareness of this kind of event.

2.7 Survival factors

2.7.1 Aircraft equipment

The aircraft was equipped as an Extended Overwater (EOW) airplane, as defined in FAR 121.339 for operations over water at a horizontal distance of more than 50 NM from the nearest shoreline. Since the New York La Guardia – Charlotte flight was not an overwater flight, this equipment was not required. However, their presence on board favourably influenced the outcome of this accident. The temperature of the Hudson River water was very low and would not have allowed the survival of the aircraft occupants in the water for more than a few minutes. The use of slide rafts allowed several occupants to evacuate while keeping out of the water.

The NTSB report should study the possibility of installing EOW equipment for flights departing from or arriving to airports close to large expanses of water, especially where the surrounding land areas do not allow a safe emergency landing.

2.7.2 Briefing to passengers

Since this was not an over water flight, the briefing to passengers did not include information about the evacuation of the aircraft after a ditching and the use of life jackets and slide rafts. However, even if the flight was not overwater, some information about the use of seat cushions as floatation devices was provided, which probably helped the evacuation.

This event shows that it could be advisable to systematically demonstrate the use of all the EOW safety equipment to the passengers, even if the flight is not over water.

2.7.3 Communications between pilots and cabin crew

After the bird ingestion, the captain did not inform the cabin crew about his intention to perform an emergency landing in the Hudson River. He forgot to do so, most probably due to his high workload during the emergency descent. Furthermore, the related item in the "engine dual failure" procedure could not be reached, for the reasons explained in paragraph 2.4. Thus the flight attendants did not have the possibility to quickly inform the passengers and provide them with proper evacuation instructions.

2.7.4 Use of emergency and evacuation equipment

The lack of a proper briefing to passengers, in particular to the ones located near over wing emergency exits, and the late understanding by the cabin crew that the aircraft was floating on water, led to a non standard use of the emergency and evacuation equipments:

- Most passengers evacuated through over wing exits. The manufacturer states that in case of a ditching, over wing exits are not primary exits, since they are not equipped with slide rafts. The safety leaflet provided to the passengers shows that these exits shall not be used. This evacuation on the wings did not lead to dire consequences because the stability and the floatability of the aircraft were sufficient for the passengers to stay on the wings. However several passengers fell into the water and suffered from hypothermia. It is to be noted that some passengers used the wing slides as rafts because their floatability was sufficient.
- Since most of the passengers evacuated through the over wing exits, the slide rafts were not used at their full capacity.
- The passengers who evacuated through the over wing exits were not aware of the existence and of the location of the lifelines which would have help them to keep their balance. Since the flight attendants did not evacuate onto the wings, they did not have the opportunity to give the passengers instructions about the use of this equipment.
- The passengers used either life jackets, either floating cushions. Since they were not briefed on the use of life jackets, several passengers experienced difficulties in finding them and to choose the most adequate equipment for survival in water.
- The occupants of the slide rafts did not use the knives which equipped the rafts to cut the mooring ropes[3]. The pilots and cabin crew did not remember the existence and the location of these knives.

The NTSB report should recommend the evolution of airline SOP to better take into consideration the use of the emergency and evacuation equipment. It should also recommend improving the training of the crew about the use of this equipment.

The fact that the emergency landing on water occurred in the Hudson River near New York allowed many ferries to take part in the evacuation of aircraft occupants. The aircraft stability and floatability, despite the sustained major damages, also assisted the rescuing operations.
However, in slightly different circumstances, especially if the rescue operations had been delayed, it is likely that the aircraft would have sunk and that most of the passengers on the wings would eventually been into the water. Even with life jackets they would not have survived more than a few minutes in the icy water. Only boarding on slide rafts could significantly increase the survival time.

The aircraft was equipped with four slide-rafts located on primary exits. Each of them could contain 44 passengers, 55 in overload. Therefore it was possible to evacuate all the occupants on three rafts, which is

[3] The mooring ropes are equipped with mechanical fuses which are broken in case of aircraft sinking.

consistent with the certification standards. These standards also state that the evacuation of the aircraft shall be possible even if at least 50% of the emergency exits are unusable. To comply with this criterion, the manufacturer designed a system allowing the separation of the slide raft from a door and its installation on any other cabin door. All the flight attendants have to watch a video explaining the use of this device.
During the evacuation, only the two slide rafts of the front exits were used, thus potentially allowing the evacuation of only 110 occupants. Due to the structural damage on the aft fuselage, the aft doors and their slide rafts quickly became submerged and the flight attendant located at the rear of the aircraft could not easily access them. Furthermore, although the transport of a slide raft from an aft exit to a front exit is feasible, it is impractical because of the weight of the slide, requiring at least two persons to carry it or drag it, and because of the width of the central alley and its likely congestion in an emergency situation.

As mentioned in paragraph 2.6, the control of the vertical speed to reach a minimum value at impact without engine thrust, though feasible, is difficult for most pilots. Furthermore, in real situations, other factors such as a strong wind, the water surface condition, the difficulty of maintaining visual references over water may increase these difficulties. Therefore it seems reasonable to consider that, in most emergency landing into water or ditching situations without thrust, either both aft or both front exits may be unusable.
These considerations should not lead to a revision of the current A320 evacuation logic, because the use of automatically inflatable slides and slide rafts has been shown to be quick and efficient during the certification tests and during other events. However, the NTSB report should recommend an evolution of certification standards in order to take into account the situations where either both aft or both front exits are unusable. In particular, the addition of portable rafts could be considered.