Comparison of Eight Serious Bird Strike Accidents (Draft)

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Executive Summary
The sequence of events in eight bird strike related accidents involving large transport category jet aircraft, including the 15 January 2009 ditching of a US Airways A320, were analyzed and several common elements were found to exist in many of these accidents. After comparing the sequence of events that led to the eight accidents, it was readily apparent that the eight sequences had several elements that were common to some or all of the accidents. These common elements revealed by these comparisons are likely relevant to other classes of accidents and incidents, particularly runway incursion incidents, which is a risk that concerns the leadership of both the NTSB and FAA. Applying the lessons learned from this collection of bird strike accidents could help to address ongoing safety concerns about runway incursions.

Introduction

The NTSB investigation into the 15 January 2009 accident and subsequent ditching involving a US Airways A320 is still in its early stages but preliminary findings, based in part on information from the flight crew, point to an encounter with a flock of birds as the cause of the loss of most or all thrust from both engines. The engines could not be restarted and the crew successfully ditched the aircraft in the Hudson River.

In the days after the accident, the focus of the public's attention was on the extraordinary skills of the crew and rescuers, who collectively kept this accident from becoming a fatal event. This attention was appropriate, as was the universal praise of the actions of the crew and the rescuers. For the aviation safety community, one of the objectives of the investigation is to learn from the accident and to apply those lessons, where appropriate, to the aviation community. This bird strike accident was a rare event, but certainly not unprecedented. The US Airways events is at least the tenth large jet aircraft, including four large military jets, that have been lost since 1980 as a result of a bird strikes.

These accidents, though rare, have a surprising number of similarities. In my 2000 book *Understanding Aviation Safety Data*, I analyzed the accident reports of seven of these bird strike accidents, focusing on the sequence of events that these accident aircraft experienced, and found that there were several similarities between these events that were not apparent if only the individual events were analyzed. This paper uses the known or presumed events from the US Airways accident to show that it this accident shares many of the characteristics of the seven previously analyzed accidents. These observed similarities are likely relevant to other types of accidents, including those involving runway incursions.

In all of the seven accidents that were analyzed for *Understanding Aviation Safety Data*, birds were ingested birds into one or more engines during takeoff and in three of the accidents, crew actions directly contributed to the sequence of events that led to the accident. In the eighth event involving the US Airways A320, the aircraft encountered birds shortly after takeoff, and likely ingested birds into both of its engines. From these eight accidents, two groups of events were identified that should be part of a bird strike risk assessment. The first group included thirteen events that were directly involved in one or more of the eight accidents studied, and the second group included four events that were not directly involved in any of those eight accidents, but could be involved in future accidents. This study includes a brief overview of the event sequence analysis method and a discussion of ways to apply the insights of this study to other aviation safety issues, specifically runway excursions.

This study uses event sequence analysis to develop a risk assessment of a bird strike during takeoff that leads to a large jet transport accident. An analysis of prior bird strike studies and of eight previous bird related large jet transport accidents (seven resulting in a hull loss) revealed two things. First, flight crew action played a significant role in the outcome of these accidents and second, past major studies of bird strike effects did not deal with the role of crew actions.

This study examines past bird strike related accidents to create a minimum set of circumstances, including those involving the role of decision making, that should be included in a bird strike risk assessment model. This set is not meant to be exhaustive, but rather to serve as a foundation for further development of a risk assessment model for both bird strike related risks, and for other areas of concern to the aviation safety community.

Past Research

Most available bird strike data and research studies focus on the effect that a bird strike has on the aircraft or on the outcome of the flight. Issues such crew coordination or the adequacy of crew training are usually not a part of these research efforts. These issues are usually discussed in detail only as part of an individual accident investigation or incident report. Typical of the major studies is the 1995 FAA study *Bird Ingestion Into Large Turbofan Engines*. One section described a number of events where the crew changed the planned flight of the aircraft after a bird strike event but did not discuss the flight crew's decision making process.

Information on the human element in serious bird encounters can be inferred from other studies. In 1992, a joint industry and government effort, described in FAA Advisory Circular 120-62, investigated crew performance issues in a variety of rejected takeoff scenarios. Many of the conclusions reached, such as the need to train crews to make better rejected takeoff decisions, are directly relevant to the assessment of the risk of bird strikes during takeoff.

Method
This study relied on official accident investigation reports or other published reports from the following eight accidents to determine the sequence of events that could lead to a bird strike related large jet transport accident:

1.	12 November 1975	DC10	USA	Rejected takeoff
2.	4 April 1978	737	Belgium	Rejected takeoff
3.	20 July 1986*	737	Canada	Rejected takeoff
4.	29 September 1986	A300	India	Rejected takeoff
5.	15 September 1988	737	Ethiopia	Two engine power loss
6.	25 July 1990	707	Ethiopia	Rejected takeoff
7.	22 September 1995	707 AWACS	USA	Two engine power loss
8.	15 January 2009	A320	USA	Two engine power loss

*Only event that was not a hull loss

Factual data and conclusions of the accident reports were used as a guide to building the event sequence for the first seven events and preliminary NTSB investigation findings were used for the eighth event.

A Brief Overview of Event Sequence Analysis
As the name implies, event sequence analysis involves determining the sequence of events that lead to an accident. The events include those that directly contributed to the accident and those that did not. Event sequence analysis is a potentially useful model for bird strike risk assessment because it can include human actions and environmental conditions that influence the outcome of an aircraft encounter with birds. Event sequence analysis allows the analyst to use some judgment when ordering the sequence of events. For example, a wet runway may be placed before a crew's decision to reject a takeoff because it may be assumed that environmental conditions were considered by the crew before any takeoff is attempted.

Figure 1: Event Sequence Map Structure
Below is the basic structure of an event sequence map for a series of events that lead to a pair of unique consequences.

Event 1
- Event 2
  - Event 3A
    - Event 4A
      - Consequence 1
  - Event 3B
    - Event 4B
      - Consequence 2

In this example, each line represents one event and the indentations are a visual reminder that the events take place in a specific sequence. The rightmost indented event represents the outcome. The line connecting Events 3A and 3B in Figure 1 illustrates that the sequence branches at the point into two possible directions. The consequences at the end of these different paths can either be the same consequence arrived at through different sequences of events or they could be different consequences. In Figure 1, there is a different unique sequence associated with Consequence 1 and 2, but both sequences would share Events 1 and 2.

The probability of any one event occurring may or may not be dependent on the sequence of events that preceded it. Consider the following sequence: (1) the flight crew sees a large flock of birds during the takeoff roll, but are unable to take any kind of evasive action such as rejecting the takeoff (e.g., after V_1 but before V_r); (2) after hearing multiple impact sounds from these birds, the engine instruments indicate a substantial drop in thrust on one engine; and (3) the crew rejects the takeoff; the probability of the second event would be entirely independent of the first event, but the probability of the third event would be a function of the first two events. This is because in airline operations, pilots are trained to continue the takeoff if there is a loss of thrust on a single engine after reaching V_1, unless they have reason to believe that a rejected takeoff is a better option than continuing the takeoff.

From my industry experience where I analyzed numerous accidents and incidents involving either bird strikes or rejected takeoffs, I found that the pilots sometimes made decisions based on information that is not reflected in their cockpit instruments. In the context of bird strikes, that information may include the visual presence of birds coupled with sounds of impact on the aircraft. There have been cases, including the 1986 A300 bird strike accident analyzed in this report, where pilot sensations such as sighting birds, hearing impacts, or feeling engine vibration, led the flight crew to make a rejected takeoff decision that led to an accident, even though the cockpit instruments correctly indicated that the aircraft could safely take off.

Results
Construction of the event sequences of the first seven accidents was based on information in formal accident reports, and there was enough data from the ongoing investigation into the eighth event from 15 January 2009 to construct a preliminary event sequence and fit that accident within the context of the original seven.

Table 1 illustrates some of those similarities and differences among the eight accidents. Table 2 contains those events that had a direct effect on the final outcome of the accidents studied. Table 3 contains those elements that may have a direct effect on the outcome of future accidents involving bird strikes. Figure 2 consists of an event sequence map that is based on the information gathered from the eight accident reports and has the consequences of interest in bold type.

Table 1: Similarities and Difference in Accident Event Sequences

	12 Nov 75 DC10	4 Apr 78 737	20 Jul 86 737	29 Sep 86 A300	15 Sep 88 737	25 Jul 90 707	22 Sep 95 AWACS	15 Jan 09 AWACS
Phase of Flight When Birds Hit	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff	Climb
Birds Seen By Crew	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed at Bird Impact	< V1	Vr	< V1	Vr	Vr	< V1	Vr	>Vr
Captain Decided to Reject Takeoff	Yes	Yes	Yes	Yes	No	Yes	No	N/A
Cockpit Decisions a Factor Leading to Accident	No	Yes	No	Yes	No	Yes	No	UNK

Table 2: Events With A Direct Effect on the Outcome of the Accident

	12 Nov 75 DC10	4 Apr 78 737	20 Jul 86 737	29 Sep 86 A300	15 Sep 88 737	25 Jul 90 707	22 Sep 95 AWACS	15 Jan 09 A320
1. Engine Ingests at Least One Bird	X	X	X	X	X	X	X	X
2. Uncontained Engine Failure	X			X			X	UNK
3. Partial Thrust Loss on One or More Engines		X				X	X	Possible
4. Full Thrust Loss on One Engine	X		X	X			X	Possible
5. Full Thrust Loss on Multiple Engines					X			Likely
6. Aircraft Not Capable of Continued Flight and Safe Landing	X				X		X	X
7. Significant Loss of Stopping Capability (tires, brakes, spoilers, or thrust reversers)	X			X				
8. Non-Engine System Malfunction	X							UNK
9. Crew Coordination or Decision Problems		X		X		X		UNK
10. RTO Initiated With Aircraft Beyond V1		X	X	X				
11. Airfield Management Actions							X	
12. Air Traffic Control Actions							X	
13. Aviation Regulations			X					

Table 3: Events That May Directly Effect the Outcome of Future Accidents

	12 Nov 75 DC10	4 Apr 78 737	20 Jul 86 737	29 Sep 86 A300	15 Sep 88 737	25 Jul 90 707	22 Sep 95 AWACS	15 Jan 09 A320
14. Crew Relying on Physical Cues (visual, auditory, kinesthetic)	X	X	X	X	X	X	X	X
15. Procedures for Transferring Aircraft Control		X		X	X	X	X	X
16. Loss of Directional Control							X	
17. Aircraft Fire Before the End of the Flight	X							

Figure 2: Event Sequence Map for Eight Accidents Due to a Bird Strike

- Crew initiates normal takeoff
  - Crew aware of birds
    - Aircraft encounters one or more birds
      - Crew physically senses strike or strike effects
        - Aircraft performance degraded
          - Crew presented effects of strike damage through instruments
            - Flight crew does not coordinate actions
              - Aircraft beyond V1 speed
                - Aircraft able to complete flight
                  - Decision made to reject takeoff
                    - **Aircraft stops off runway or taxiway (Belgium, India)**
            - Flight crew coordinates actions
              - Aircraft beyond V1 speed
                - Decision made to continue flight
                  - Aircraft able to complete flight
                    - Aircraft has at least one more system failure
                      - Aircraft unable to complete flight
                        - **Aircraft lands off runway (Ethiopia 737)**
                  - Aircraft unable to complete flight
                    - **Aircraft crashes off runway (USA 707, USA A320)**
                - Decision made to reject takeoff
                  - Aircraft able to complete flight
                    - **Aircraft stops off runway or taxiway (Canada 737)**
              - Aircraft not beyond V1 speed
                - Decision made to reject takeoff
                  - Aircraft unable to complete flight
                    - Aircraft has reduced braking capability
                      - Crew unaware of full extent of braking losses
                        - **Aircraft stops off runway or taxiway (USA DC10)**
                  - Aircraft able to complete flight
                    - **Aircraft stops off runway or taxiway (Ethiopia 707)**

Conclusions

- Analysis of past bird strike related accidents identified thirteen events that were directly involved in the outcome of those accidents (Table 2).

- Analysis of past bird strike related hull loss accidents identified four events that were not directly involved in the outcome of those accidents, but could become a factor in future accidents (Table 3).

- These 17 events form a minimum set of events or conditions that should be included in any risk assessment of hull loss risks from bird strikes during takeoff.

- An event sequence map can be used to develop a concise summary of the sequences of events that led to the eight accidents studied.

- In three of the eight accidents, decisions made by the flight crew directly contributed to the accident.

Discussion

One worthwhile way to use insights from this particular event sequence analysis would be to help put the findings and recommendations of the ongoing investigation of the US Airways A320 ditching into a broader context. One broader context would be other accidents and serious incidents involving birds. For example, if the insights gained from the current investigation are largely the same as those gained in the past, then it may call into question how effective industry and government have been in taking actions that would reduce the likelihood of these kinds of risks.

Another broader context may be other safety issues that have been recognized as a serious risk by the airline industry and that have similarities to the kinds of patterns revealed in this study. One kind of risk that meets these criteria is the improvement of runway safety, specifically reducing risks from runway incursions. The FAA, NTSB, and other aviation organizations have identified reducing such incursions as a worthwhile goal. While a combination of improved technology and improved procedures have reduced the risk, there is still plenty of room for improvement. The kind of analysis performed for the eight bird strike accidents in this study can serve as a model for a similar analysis of runway incursion events.

One of the key insights from my research into bird strike related accidents is that at critical points during the accident sequence, flight crews sometimes make decisions based on their interpretation of visual, auditory, and kinesthetic sensory information generated by the presence of birds or from the effects of strikes. While such information may not be reflected in their instruments, and while many routine and emergency procedures do not incorporate these kinds of inputs, those inputs can most certainly affect a pilot's decisions.

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Appendix: Event Sequences for the Eight Bird Strike Accidents

Events that had an effect on the final outcome are **bolded**

DC10, USA, 12 November 1975
Passenger Flight
Blast fence off departure end of runway
Runway wet
Captain flying takeoff
Aircraft speed less than V1
Captain sees large rising flock of birds
Engine #3 ingests birds
Severe damage to engine #3 fan blades
Engine and nacelle design unable to contain failure and prevent further significant damage and system losses
Crew hears impacts
Crew hears bangs or explosions
Aircraft able to complete flight
Captain initiates RTO below V1
Engine #3 failure indicated
Wing and pylon fire starts
Wing and pylon fire not indicated
Hydraulic system #3 lost
50% loss of braking torque
Loss of brake system indicated
Engine #3 thrust reverser lost
2 of 10 spoilers lost
One center gear tire penetrated by foreign object and fails
Two other tires fail
Tire failures not indicated
Crew senses less effective braking
State of antiskid system not indicated
Crew aware aircraft can’t stop on runway
Crew believes aircraft under control
Aircraft turns off at last taxiway at 40 knots.
Aircraft leaves pavement during runway turnoff

737, Belgium, 4 April 1978
Training flight
Touch and go landing
First officer flying
12 knot tail wind
Aircraft always above V1
Aircraft rotates
Left engine ingests bird
Crew hears strikes
Crew feels engine vibration
First officer stops rotation
Aircraft able to complete flight
Captain takes control without coordinating with the First officer
First officer applies brakes
Captain does not get desired elevator response
Captain performs RTO
Aircraft unable to stop on available runway
Aircraft overruns runway

A300, India, 29 September 1986
Passenger flight
First officer flying takeoff
Aircraft speed above V1
Crew sees large bird on runway centerline
First officer begins rotation
Right engine ingests birds
Right engine fails
Crew hears loud noise from right side
Crew experiences severe aircraft vibration
Captain takes control of aircraft
Aircraft able to complete flight
Captain elects to reject takeoff above V1
Aircraft unable to stop on available runway

B737, Canada, 20 July 1986
Passenger flight
Light rain conditions
Aircraft tankering 5,000 lb (2,270 kg) of fuel
Runway wet, but less than ¼ inch of water
Runway friction reduced
FAA and airline procedures allow use of dry runway calculations for accelerate to stop distance and V1 speed.
V1 computed at 127 KIAS
First officer flying takeoff
First officer sees bird on runway
First officer calls "bird" at 114 KIAS
Engine one ingests 2 lb (1.8 kg) Herring Gull
Engine flames out at 126 KIAS about three seconds after bird call
Aircraft can safely complete takeoff
RTO initiated less than two seconds after V1 at 130 KIAS
Asymmetric thrust reverser (right only)
Aircraft unable to stop on runway
Aircraft exits runway off right side
Aircraft stops in bog

B737, Ethiopia, 15 September 1988
Passenger flight
First officer flying
Aircraft at V1
Crew sees flock in motion
Captain takes control of aircraft
Aircraft rotates
Both engines ingest numerous pigeons
Crew hears strikes
Crew continues takeoff
Partial thrust losses in both engines
Crew aware of thrust losses
Crew firewalls engines
Aircraft gains altitude
Crew initiates return to land
Crew aware of high EGT
Engine thrust reduced
Engine 1 loses power
Engine 2 loses power
Aircraft unable to complete flight

B707, Ethiopia, 8 September 1990
Cargo flight
Wet runway
Crew can't see past hump in runway
Runway has 0.2% down slope after hump
V1 computed at 131 KIAS
First officer performs takeoff
Crew sees a group of pigeons on runway at about 80 KIAS
First officer shouts "oh birds" at about 82 KIAS
Captain decides to continue takeoff
Captain takes positive control of aircraft
Birds take to the air
Aircraft hits birds at about midpoint of runway about 6 to 8 seconds after first sighting
Crew hears a bang at about 92 KIAS
Crew hears two more bangs two seconds later at about 97 KIAS
N1 drops on two engines
Captain initiates RTO
Throttles chopped at 117 KIAS, about 10 seconds after first bang
Aircraft reaches 118 KIAS
Thrust reversers activated 5 seconds after throttle chop
Aircraft sways to right, then skids to left
Antiskid selected off
Aircraft unable to stop on runway
Aircraft overruns runway at about 20 knots
Aircraft overruns stopway
Aircraft breaks up after hitting approach lights and going down an incline

B707 AWACS, USA, 22 September 1995
Military training flight
Rising terrain beyond runway
Airfield bird control and bird hazard warning process not well coordinated or managed
ATC observed large flock of geese close to runway took steps to order their dispersal
ATC did not advise the aircraft of the presence of geese near the runway
Co-pilot (First Officer) flying
Aircraft at Vr
Crew sees flock in motion
Aircraft rotates
Engines 1 and 2 ingest both ingest one or more birds beyond certification limits
Crew aware of strikes
Crew continues takeoff
Engine 2 has uncontained failure
Engine 1 stalls and loses 50-70% of thrust
Crew aware of thrust losses
Crew initiates return to land
Pilot (Captain) takes control of aircraft
Aircraft unable to maintain directional control
Aircraft unable to gain airspeed
Aircraft unable to gain altitude
Aircraft unable to clear rising terrain and complete flight

Note: In the AWACS event, Pilot is equivalent to Captain and Co-pilot is equivalent to First Officer

A320, USA, 15 January 2009
Passenger flight
First officer is the pilot flying the takeoff
Aircraft in initial climb
First officer sees formation of birds to starboard, captain looks up in time to see birds filling windscreen
One or more birds impact and damage right engine
Birds impact fuselage and wings
Crew notes burning smell
Both engines lose power
Captain declares emergency and takes control of the aircraft
Flight crew unable to restart either engine
Flight crew declares to ATC an intention to perform an air turn back LaGuardia, but later rejects that option
Flight crew considers, then rejects the option of diverting to another nearby airport in Teterboro, NJ
Crew declares to ATC an intention to ditch the aircraft in the Hudson River
Flight crew warns cabin crew and passengers to brace for impact
Cabin crew provides additional emergency instructions to passengers
Flight crew and cabin crew supervise evacuation
One emergency slide, which doubles as a life raft, deployed and inflated normally, and a cabin crew member had to manually inflate another slide.

Notes:

- While both engines lost power, it is unclear if there it was a complete or partial power loss
- Captain had never flown into the Teterboro, NJ airport
- From early findings, it is unclear when engine restart efforts began or ended, or if the decisions to reject options to either turn back to LaGuardia or divert to Teterboro occurred before, during, or after engine restart efforts

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