BIRD STRIKE COMMITTEE EUROPE

BSCE23/WP13
London, May 13-17 1996

ASSESSMENT OF BIRD STRIKE ACCIDENT RISK USING EVENT SEQUENCE ANALYSIS

by
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Summary

Reports from five bird strike related hull loss accidents involving large jet transports were analysed in order to develop an event sequence analysis based assessment of the risk of a hull loss due to bird strikes. The five accidents all had birds ingested into one or more engines during take-off and in two of the accidents crew actions were directly involved in the sequence of events that led to the accident. From those five accidents, two groups of events were identified that should be part of a bird strike risk assessment. The first group included twelve events that were directly involved in past accidents. The second group included four events that were not directly involved in those accidents but could be directly involved in future accidents. The paper also includes a brief overview of the event sequence analysis method and a discussion of ways to expand upon the results of this study.

Key Words: Statistics, Risk Assessment, Civil Aviation, Mishap Investigation

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study uses event sequence analysis to develop a risk assessment of a bird strike during off that leads to the hull loss of a large jet transport. An analysis of prior bird strike studies of five previous bird related large jet transport hull losses revealed two things. First, flight y action played a significant role in the outcome of these accidents and second, major ies of bird strike effects do not deal with the role of crew actions. Event sequence analysis potentially useful model for bird strike risk assessment because it can include human ons and environmental conditions that influence the outcome of an aircraft encounter with ls. This method can also accommodate common cause and dependent events.

s study will examine past bird strike related accidents to create a minimum set of cumstances, including those involving the role of decision making, that should be included a bird strike risk assessment model. This set is not meant to be exhaustive, but rather to ve as a foundation for further development of a risk assessment model.

ast Research

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

nformation on the human element in serious bird encounters can be inferred from other tudies. In 1992, a joint industry and government effort, described in FAA Advisory Circular 20-62, 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 lecisions, are directly relevant to the assessment of the risk of bird strikes during takeoff.

Method

This study relied primarily on official accident investigation reports or other published accident reports to determine the sequence of events that led to five bird strike related large jet transport hull losses. These were:

1. 11/12/75,	DC10, USA	- Rejected takeoff and went off the side of the runway
2. 4/4/78,	737, Belgium	- Rejected takeoff and overran the runway
3. 9/29/86,	A300, India	- Rejected takeoff and overran the runway
4. 9/15/88,	737, Ethiopia	- Both engines failed and aircraft crashed during turn back
5. 9/22/95,	707 AWACS, USA	- Crashed about a mile after takeoff after one engine failed and second engine on same wing lost at least 50% of its thrust.

The sequences of events for these accidents are detailed in the Appendix. Factual data and conclusions of the accident reports were used as a guide to building the event sequence. The events include those that directly contributed to the aircraft accident and those that did not. For example, in the DC-10 event, the crew saw birds prior to impact and engine three was damaged by a bird strike. Seeing the birds did not have any bearing on the final outcome because the crew did not respond to that stimulus in a way that contributed to the accident. However, the engine damage was key because it led to an uncontained failure of the engine and the loss of other aircraft systems.

Event sequence analysis allows the analyst to use some judgment when ordering the sequence of events. For example, in that same DC-10 event, the wet runway surface was listed as the first event in the sequence, but one could argue that it should be placed before the captain's decision to reject the takeoff because that is the time when the crew may have considered the runway condition along with other aircraft and environmental factors.

Once the sequence was constructed, the task was then to choose those elements that should be included in a more general event sequence analysis based risk assessment. Part of that process was deciding which events had a direct bearing on the outcome of the five analyzed accidents and which events might have a direct bearing on future accidents.

A Brief Overview of Event Sequence Analysis

Figure 1 shows the basic structure of an event sequence map for a series of events that lead to a consequences of interest. This illustrates both the layout of a typical map and how human decisions can be incorporated into the analysis.

Figure 1: Event Sequence Map Structure

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Event 1
        Event 2
                Event 4A
                |       Event 5A
                |               Consequence 1
                |
                Event 4B
                        Event 5B
                                Consequence 2
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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 probability of any one event may be dependent on the sequence of events that preceded it. For example, in a simple event sequence consisting of the flight crew spotting birds, the engine instruments indicating a substantial drop in thrust, and the crew rejecting 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.

The line connecting Events 4A and 4B 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 sequence associated with Consequence 1 and 2, but both sequences would share Events 1 and 2.

If every event in the event sequence map has a probability associated with it, then multiplying the probabilities of each event in all possible sequences from the initiating event to the final consequences will produce the probability that those consequences will occur. The combination of a consequence and the probability of that consequence constitutes the risk. Therefore to complete the risk assessment, each consequence of interest must be coupled with the product of the estimated probability of each event in the associated sequence.

Results

Construction of the event sequences of the five hull loss event made it relatively easy to compare the accidents for any similarities and differences and to select those elements that either had a direct effect on past accidents or could have an effect on future accidents. Table 1 illustrates some of those similarities and differences. Table 2 contains those events that had a direct effect on the final outcome of past accidents. 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 accident reports of the five hull loss accidents.

Table 1: Similarities and Difference in Accident Event Sequences

	11/12/75 DC10	4/4/78 737	9/29/86 A300	9/15/88 737	9/22/95 AWACS
Phase of Flight When Birds Hit	Takeoff	Takeoff	Takeoff	Takeoff	Takeoff
Birds Seen By Crew	Yes	Yes	Yes	Yes	Yes
Speed at Bird Impact	< V1	Vr	Vr	Vr	Vr
Captain Decided to Reject Takeoff	Yes	Yes	Yes	No	No
Human Decisions Reduced Accident Severity	Yes	No	No	Yes	No

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

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

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

	11/12/75 DC10	4/4/78 737	9/29/86 A300	9/15/88 737	9/22/95 AWACS
13. Crew Relying on Physical Cues (visual, auditory, kinesthetic)	X	X	X	X	X
14. Procedures for Transferring Aircraft Control		X	X	X	X
15. Loss of Directional Control					X
16. Aircraft Fire Before the End of the Flight	X				

Event Sequence Map For the Five Hull Loss Accidents

Using the insights gained from the analysis of the five hull loss accidents, the event sequence map depicted in Figure 2 provides the framework for assessing the accident risk due to a bird strike during takeoff. The consequences of interest are all in bold type and are associated with at least one of the five accidents. All of the 16 events identified earlier are included in this event sequence map. For example, the multiple engine failures of the accidents in Ethiopia and Alaska are implied in the event "Aircraft unable to complete flight".

Some of the four events in Table 3 are not associated with the particular consequence of the accident it was associated with. Specifically, event 14 - "Procedures for Transferring Aircraft Control" - was associated with the AWACS hull loss, but it is not in the path in Figure 2 that leads to that accident. In that case, the transfer of control from the copilot to the pilot were not clearly coordinated, but the transfer had no effect on the outcome of the flight.

Figure 2: Event Sequence Map for Accidents Due to a Bird strike During Takeoff *

- Crew initiates Normal Takeoff
  - Crew aware of bird (11, 12, 13)
    - Aircraft encounters one or more birds
      - Crew physically senses strike or strike effects (13)
        - Aircraft sustains damage (1, 2, 3, 4, 7, 8, 16)
          - Crew presented effects of strike damage through instruments
            - Flight crew does not coordinate actions (9, 14)
                - Aircraft beyond V1 speed
                  - Decision made to reject takeoff (10)
                    - **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 (4, 5)
                      - Aircraft unable to complete flight (6, 15)
                        - **Aircraft lands off runway (Ethiopia)**
                  - Aircraft unable to complete flight (6, 15)
                    - **Aircraft lands off runway (Alaska)**
              - Aircraft not beyond V1 speed
                - Aircraft has reduced braking capability (7)
                  - Crew unaware of full extent of braking losses (13)
                    - Aircraft unable to complete flight (6, 15)
                      - Decision made to reject takeoff (6)
                        - **Aircraft stops off runway or taxiway (JFK)**

* Numbers refer to the 16 events identified in Tables 2 and 3.

Conclusions

- Analysis of past bird strike related hull loss accidents identified twelve events that were directly involved in the outcome of those accidents (listed in 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 (listed in Table 3)
- These 16 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 using the 16 events from Tables 2 and 3 can be used to develop a concise summary of the sequences of events that led to the five accidents studied
- In all five accidents, decisions made by flight crews or air traffic control either directly contributed to the accident or were instrumental in reducing the severity of the mishap

Discussion

One logical step beyond this analysis would be the expansion of the event sequence map of Figure 2 to broaden the risk assessment model for hull losses due to bird strikes at takeoff. Such an expansion would allow one to illustrate how some sequences that have the possibility of leading to accidents compare with the sequences of events that led to a past accident. The biggest benefit of comparing risks in this fashion is that in a map such as that in Figure 2, is that it is easy to see how sequences of events can lead to accidents. One could take a completed event sequence map and compute the probabilities of the consequences of interest just by multiplying the probabilities of the events in that event sequence.

One could also expand the event sequence map by adding branches where appropriate. For example, a crew may see birds and hear one or more strikes on the aircraft without the aircraft performance being degraded. One consequences of interest might be injury or aircraft damage resulting from a high speed rejected takeoff when the cause of the rejected takeoff decision was based on missing or misleading readings from the cockpit instruments.

Another logical step that would be to estimate the probabilities of each of the events in the event sequence map of Figure 2 in order to estimate the likelihood of different consequences. These probabilities can be estimated through some combination of a review of accident or incident data, analysis, and engineering judgment. With this information, the risk of each consequence could be estimated. This would allow a direct comparison between the risks of the consequences that have occurred with consequences that have not occurred but have been identified through an expansion of the event sequence map.

Appendix: Event Sequences for Hull Loss Bird Strike Accidents

DC10, USA, 11/12/75
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 beyond certification limits
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 kt.
Aircraft leaves pavement during runway turnoff

737, Belgium, 4/4/78
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
FO stops rotation
Aircraft able to complete flight
Captain takes control without coordinating with the FO
FO applies brakes
CPT does not get desired elevator response
CPT performs RTO
Aircraft unable to stop on available runway

A300, India, 9/29/86
Passenger flight
First Officer flying takeoff
Aircraft speed above V1
Crew sees large bird on runway centerline
FO 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