Black Swan events – examples from Airbus history

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Stéphane Cote is an accident investigator within the Product Safety team of Airbus. As one of the investigation team, he is an Airbus technical advisor to the Bureau d'Enquête et d'Analyse of France (BEA) and to international agencies on a number of investigations. His scope of activities involves any aircraft of the Airbus fleet whatever the nature of the investigation.

Prior to becoming an accident investigator, Stéphane was a senior design office engineer within Airbus systems engineering, in charge of the development of the A350-XWB Handling Qualities from the launch of this program up to its certification. Prior to the A350, Stéphane was involved in the A330/A340 continued product development and A400M initial development. Since joining Airbus in 2000, he has accumulated over 19 years of experience within flight physics, systems engineering and product safety domains.

Stéphane was the Airbus technical advisor to the BEA in the investigation of an A319 which experienced the loss of its right windshield whilst in cruise over China (Himalaya region) on 14th of May 2018. Such an event is extremely rare in aviation (well outside the realm of usual design and risks considerations), had severe consequences, and was not predictable, therefore it was considered as a Black Swan case. Following this incident, Airbus has reviewed the Black Swan events from its history throughout its fleets.

This technical paper provides a technical summary of these events. It will focus on the lessons learnt (design, manufacturing, procedures and training) and the product safety enhancements which were developed post-events.

Black Swan Events

Introduction

What defines a Black Swan event?

Black swan events are characteristically :

- extremely hard-to-predict, or rare
- beyond the realm of normal expectations

In ancient Greece, it was assumed a black swan could not exist … until it was unexpectedly discovered in the wild much later.

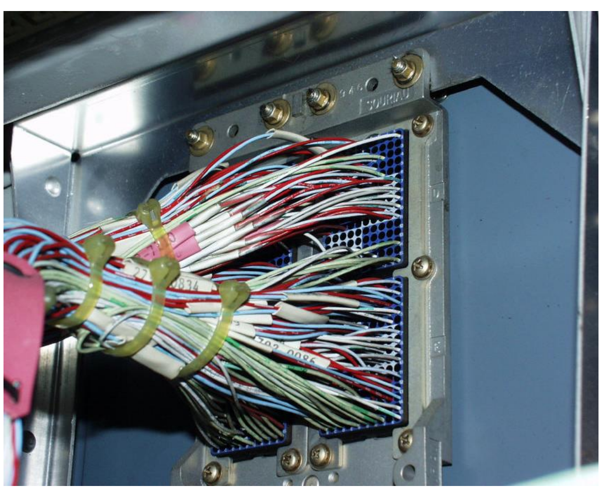
"Houston, we've had a problem..."

The Apollo XIII mission is a typical example of a Black Swan event in the aerospace industry. The objective of this mission was to land on the Moon, but following an unexpected failure leading to the loss of the primary oxygen in the Service Module, the mission had to be aborted. Direct return to Earth was not possible, so the Lunar Module was used as a lifeboat while going around the Moon. During the investigation into this event, the NASA highlighted the effectiveness of crew training, especially in conjunction with ground personnel. Many lessons were learnt from this accident and all Apollo spacecraft were modified to incorporate safety enhancements.

Airbus Black Swan events - some examples

We will now review the Black Swan events which occurred in the Airbus history. For each event, we will detail the lessons learnt and the product safety enhancements which were developed subsequently.

<u>Crossed Roll Controls</u>, A320 (2001)



The root cause of this event was that one flight control computer (ELAC) input wires had been inverted during maintenance. This resulted in the Captain's sidestick to be inverted in roll.

The issue remained undetected during maintenance and the pre-flight control check.

At take-off the Captain (PF) applied a lateral sidestick input to the right but the aircraft banked to the left.

The F/O took over aircraft control promptly, without the captain's expressed demand.

Post-event, AMM improvements were introduced regarding flight control system maintenance and the Flight Control Check procedure was modified.

The main lessons from this event are the importance of a flat cockpit hierarchy, F/O empowerment and Crew Resource Management (CRM).

Total loss of hydraulics, A300 (2003)

This event was caused by a terrorist act. The left wing was hit by a missile during the initial climb (around 8000ft).

This resulted in the loss of all 3 hydraulic systems in ~20s. Subsequently all flight controls were lost and slats & flaps were frozen at their current position.

In addition, a significant amount of the left wing surface was missing, a fire had started and the associated fuel tank was emptying.

However, both engines were still running. The crew managed to learn how to control the aircraft pitch & roll using thrust only.

The main lessons learnt here are the remarkable airmanship and team working of this flight crew, who demonstrated that flying with engines only was possible in the current aircraft configuration. This also showed that on some occasions, you may have to learn as you go, as such situation is unique and cannot be trained for in advance. Finally, this event highlighted the importance of learning from previous events, as this crew had knowledge of the Sioux City accident where all hydraulic systems had also been lost.

Rudder loss, A310 (2005)

During this event, the rudder was lost due to weakening of its structure (composite sandwich disbonding leading to reduced torsional stiffness).

The flight was normal until the cruise, when sudden vibrations and loud noise were experienced and dutch-roll oscillations started.

The dutch-roll decreased and stopped when descending. On ground, a major part of the rudder was found missing from the aircraft.

The product enhancements which were developed following this event focused on reinforcing the inspections, and enhancing the design of sandwich rudders. Technology and design evolution (monolithic rudders) were introduced on new programs.

Two important lessons were learnt from this event :

- The importance of flight crew academic knowledge : in this occurrence, the crew knew from their UPset and Recovery Training (UPRT) that they needed to *“slow down and go down”* if faced with dutch-roll in flight
- Regarding the structural aspects : it was determined that rudders needs a health check inspection program, even when they are designed to be damage tolerant

Emergency water landing, A320 (2009)

This aircraft encountered a flock of birds after take-off, resulting in multiple bird strikes impacting both engines, with subsequent significant loss of thrust on both engines.

The APU was proactively started by the crew, which allowed retention of the NORMAL Law, and thus all the flight envelope protections.

The landing strategy had to be determined with limited or no time to prepare.

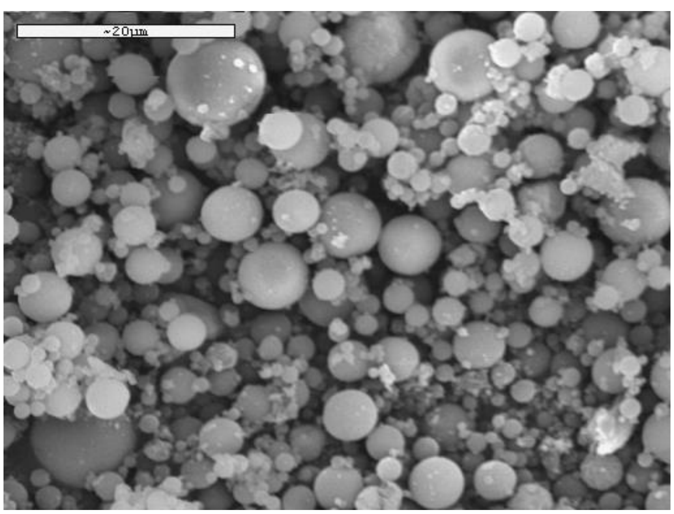
The flight crew focused on the essential task of flying the aircraft given the emergency. The aircraft was flown occasionally within the alpha protection range, until an emergency water landing was performed.

Following this event, a new QRH procedure “EMER LANDING - ALL ENG FAILURE” was developed, new engine birdstrike certification requirements were issued and an APU auto-start function was introduced on A350.

The lessons learnt from this event were the following :

- decision making may be time-critical - in this case, due to the proximity with the ground
- the importance (again) of appropriate task-sharing & CRM : the Captain flew the airplane and the F/O managed the engines
- flight crew knowledge of the systems, as the decision to start the APU ensured that the flight envelope protections remained available throughout the event

Fuel contamination, A330 (2010)



During descent, approach and landing this aircraft encountered a loss of thrust control affecting both engines.

The investigation determined that the root cause was fuel contamination, which was traced back to the refuel dispenser (truck).

As a result of the contamination, both engines’ fuel metering valves were blocked. The engine 1 remained at ~70% N1, the engine 2 at sub-idle.

The fuel contaminants were composed of Super Absorbent Polymer (SAP) combined with salt and water.

An emergency landing was made (Ground Speed~240 kts, Flaps 1).

After the event, new operational guidance (QRH procedure) was developed to assist flight crews.

At industry level, it confirmed that fuel uplift quality was critical as it may affect several or all engines, therefore IATA Fuel Working Groups were formed. This resulted, as a lesson learnt, in the decision to phase out SAP from fuel filters (deadline January 2020).

Uncontained engine disc failure, A380 (2010)

This A380 aircraft experienced an Intermediate Pressure Turbine (IPT) disc failure to engine #2 during climb.

The airframe was impacted by disc debris, resulting in multiple structure and systems damage.

An In-Flight Turn Back was performed, during which numerous ECAM alerts had to be processed.

A safe landing was performed, followed by a controlled disembarkation.

Several product enhancements were developed following this event :

- IPTOS function : automatic engine shutdown in case of IPT overspeed
- Enhanced engine design and manufacturing process
- ECAM enhancement, equivalent to scroller introduced on A350
- Additional Fuel Shut Off Valves wiring routing precautions on new programs
- OIS optimized landing distance calculation based on actual aircraft capability

In terms of lessons learnt, the investigation confirmed that such event are best managed with effective work-sharing consistent with the cockpit design, here 2 crew members. The aircraft proved to be resilient to the uncontained engine failure. It maintained the autopilot and the flight envelope protections due to the systems redundancies. In addition, the ECAM functioned, even if operating beyond its design envelope : the Flight Warning System managed to process an unforeseen high number of failures.

AoA probes blockage, A330 (2012)

This A330 experienced a blockage of all 3 Angle-of-Attack (AoA) probes. They were fitted with a new configuration known as the conic plates.

The 3 AoA became blocked during climb (~FL100). When reaching FL310, the AP disconnected and the high AoA protection was unduly triggered, resulting in a commanded pitch down.

The flight crew switched all 3 ADRs OFF and stabilized the aircraft at FL300.

A diversion was then performed with the 3 ADRs switched back ON.

As a result of the event, the conic plate configuration was removed. Enhanced AoA monitoring by the flight control system was introduced and development of new AoA probes was initiated.

In terms of lessons learnt, this event shows the importance of flight crew :

- continuous system monitoring : they detected an unusual characteristic speeds display on the PFD during the climb, which limited the startle effect at the AP disconnection
- aircraft systems knowledge : they were aware of the systems which use AoA information, which allowed to take immediate and effective action

<u>Loss of RH windshield in flight</u>, A319 (2018)

40 min after take-off, while in cruise (FL321), the RH windshield of this A319 separated. An immediate descent towards a lower altitude was conducted, followed by a diversion to the nearest airport (Chengdu, China), where an uneventful landing was performed.

The first officer and one cabin crew suffered minor injuries.

An official ICAO Annex 13 investigation, led by the Civil Aviation Administration of China (CAAC), is currently on-going on this last event.

An update will be provided in coordination with the CAAC and the BEA.

Conclusion

Black Swan events are part of the aviation industry, and as unpredictable as they are, these exceptional events will happen in the future.

Industry safety efforts (design precautions, SOPs, crew training, …) have allowed minimizing the impacts of such events.

When relevant, Airbus will develop Product Enhancements (design, maintenance, procedures, …) after such events.

To sum up, the main lessons learnt from these events are the following :

- Respecting the golden rules remains applicable
- All trained pilot competencies (education & training) are key and will be needed
- All available resources shall best be used
- Capability to think outside the box may be required, taking the best of the available procedures