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IDENTIFYING THE FACTORS THAT CONTRIBUTED TO THE UEBERLINGEN MIDAIR COLLISION

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On the night of July 1, 2002, a Boeing 757 collided with a Tupolev-154 at 35,000 feet, resulting in 71 fatalities. Initially, this accident was immediately blamed on two individuals. First, the pilot of the Tupolev aircraft whose command of the English language was questioned when repeated descent instructions from ATC were not immediately responded to. The second individual was the controller on duty, who was accused of not exercising the abilities needed in order to detect the presence of a conflict between aircraft and resolve them. In this paper, we provide an analysis of the event, highlighting fundamental human and system errors that occurred that night: errors that contributed to the worst midair collision in recent history.

INTRODUCTION

The primary goal of the air traffic control (ATC) service is to provide for the safe, orderly and expeditious movement of traffic through the national airspace system. In performing this critical task, the controller relies on a variety of tools that include but are not limited to a radar screen that provides a top-down view of the airspace, an assigned radio frequency which may be used to communicate with the pilot and various forms of conflict alert systems that provide notification of potential aircraft collisions. This synchrony between man and machine has for the most part ensured that the cycle of air safety is maintained. On the night of July 1, 2002, this cycle was broken when a DHL Cargo airliner collided with a Bashkirian Airlines jet over German skies. This paper represents a systematic effort on the part of the authors to identify the underlying 'human' and 'system' factors that led to this midair collision, bridging the gap between theory and application, in an attempt to illustrate that systems can and do fail, sometimes with devastating consequences.

Known Sequence of Events

The Boeing 757 (registered to DHL) was en route from Bergamo (Italy) to Brussels on a heading of 004 degrees at FL 260. The Tupolev-154 (registered to Bashkirian Airlines) was flying from Munich to Barcelona on a heading of 254 degrees at FL 360, correcting its heading twice within the last minute to end up on heading of 274 degrees. Both aircraft were equipped with the Traffic Collision and Avoidance System (TCAS) and their trajectories put them on a converging course at a 90° angle in airspace above Lake Constance, Germany. Under a contractual agreement between the German and Swiss government, this airspace was under the authority of the Zurich Area Control Center (ACC). After making contact with the B757, the Swiss controller issued two clearances to the B757. First he cleared the B757 to climb to FL 320 and at time 21.26.36 to climb to FL 360. At time 21.30.11 the T-154 called in. After that, the Swiss controller did not initiate any contact with either aircraft until just seconds before the TCAS system aboard gave both pilots a traffic advisory. Following this, the controller instructed the T-154 to descend from FL 360 to FL 350 to avoid collision with the B757. However, the TCAS on board the T-154 and B757 instructed the pilots to climb and descend respectively. After receiving contradictory instructions, the T-154 pilot opted to obey controller orders and began a descent to FL 350 where it collided with the B757, which had followed its own TCAS advisory to descend. All 71 people were killed.

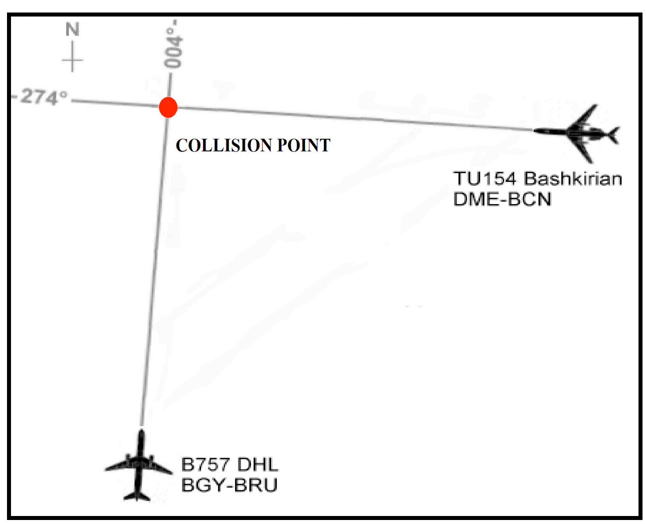

Figure 1: Trajectories of B757 and T-154

At first glance, knowledge of the timeline of events would suggest that there were two individuals who were solely to blame for the accident. Firstly, the Russian pilot who disobeyed his TCAS system and followed controller instructions to descend instead of climbing. Second and more importantly, blame should lie on the controller who was fully aware of the presence of both aircraft in his sector but waited for more than four minutes before issuing a descent clearance and a traffic information report to the Russian pilot. The controller's most important task is to ensure safety in the sector. The controller failed in that task: or did he?

Identification of Contributing Factors

Contributing Factor 1. Single Man Operations

On the night of the accident, there were two controllers on duty working. Only one controller works at a given time, while the other controller is on break, an accepted and long standing arrangement. The presence of only one controller working the radar screen represents one of the underlying causes of the accident, namely lack of supervision or assistance in safety-critical situation. This Single Man Operation (SMOP) was a controversial procedure implemented in 2001, despite numerous protests from the controller union. Whereas during the day there are a greater number of controllers on duty, making it easier to catch potential errors, the policy did not specifically state that the SMOP should not be used at night; a period during which staffing levels are extremely low, making it harder to catch errors. This procedural lack of clarity puts greater monitoring burden on the controller at night. Procedures did state however, that when the SMOP is in effect, a conflict detection system be on and fully functional. The Zurich ACC's system, known as the Short Term Conflict Alert (STCA), provides the controller with a two-minute alarm, which visually indicates the presence of a conflict.

Contributing Factor 2. Downgraded Radar

On that night, maintenance work was being done on the main radar system, which placed radar services in their fallback-mode. As a result, separation minimums between aircraft were increased from 5 miles to 7 miles (corresponding to approximately one minute). The fall-back radar mode also meant that the STCA was not available. Here again, we identify a contributing factor to the accident. Given the limits, of human perceptual ability (Hopkin, 1995), controllers may rely on conflict detection aids to help them identify potential problems before they occur. Unit procedures specifically mandated that the STCA be available when SMOP were taking place: but it was not.

Contributing Factor 3. Dual Frequency Responsibility

The en route controller is generally responsible for monitoring an assigned frequency using a single radar display. However, at night, it is not uncommon for sectors to be amalgamated, resulting in the controller having to monitor more than one frequency. The division of auditory attention across multiple frequencies does not result in any performance costs that warrant concern given the low traffic load observed at night. On the night of the accident, the controller was monitoring two radio frequencies, the first used by en route aircraft and the second for aircraft on approach to the Friedrichshafen airport (FHA) in Germany. There are two important issues to note here. Firstly, arrival traffic at that airport at night was extremely rare. Secondly, the controller chose to have the radar information for traffic approaching the airport displayed on a separate monitor. As a result, the controller had to monitor two display consoles that were separated by over a meter, resulting in the maintenance of divided attention for a sustained period of time. As fate would have it, there were two aircraft on approach that night to the airport. The controller had earlier coordinated the approach for the first aircraft to land on runway 06. Following this, the second aircraft on approach requested runway 24 at FHA. In order to provide this clearance, the en route controller first had to obtain permission from the airport tower. To do so, he had to use the automated phone system

Contributing Factor 4. Phone System

The automated phone system used in the Zurich ACC enables controllers to communicate with one another at the touch of a button. In addition to inter-facility coordination, the controller can also communicate with ATC facilities in Germany to coordinate local approaches such as that to the FHA airport. On the night of the accident the main telephone system was also out for maintenance and the back-up system had a software failure, which no one in the company had noticed, not even during tests run three month before the accident. As a result, when the controller tried to contact the FHA tower to inform them that the second aircraft was requesting a different approach, he could not get through. Given that the phone system had worked perfectly since its implementation (more than four years ago), the controller had a high degree of trust in the system and as a result did not think the system had failed, rather believing he had dialed the wrong number. He continued his attempts to reach the FHA tower while neglected to maintain his usual scanning pattern on the other radar console, which depicted the B757 and T154 converging at the same altitude. The severity of the malfunctioning phone system cannot be underestimated. Two minutes before the collision occurred, controllers working the Upper Area Sector at Karlsruhe, Germany noticed the situation unfolding, given that their own STCA had gone off, and tried to contact the Swiss controller to warn him. Despite numerous attempts, they could not get through to him because of the malfunction in the phone system. The controller's communication with the outside world was essentially cut-off. The next line of defense at this point was TCAS.

Contributing Factor 5. TCAS

TCAS is designed to provide not only traffic advisories but also resolution recommendations to avoid a midair collisions and it was in fact this system that alerted the pilots of both aircraft to the pending conflict a full seven seconds before the controller, who was busy vectoring another aircraft in for landing using a separate radar screen. After the pilots were alerted to the collision, the TCAS instructed the DHL pilot to descend and the T154 pilot to climb. However, note that the T154 had already been instructed by the controller to descend. This choice exacts that two technical issues be considered. Firstly, TCAS does not provide the controller with information regarding resolution advisories: the pilot only knows these advisories. Therefore, the controller had no way of knowing that the system had instructed the T-154 to climb, resulting in an 'honest' decision error (Shappell & Wieggman, 1997) on the part of the controller. Second and more importantly, TCAS does not account for situations where one of the aircraft does not follow its instructions. In the present case, T-154 disobeyed its own TCAS instructions to climb (the pilot opting to follow controller instructions) and descended to FL 350. The result in the B757 cockpit, was an instruction to increase the rate of descent rather than remaining level at its original altitude of FL 360. Had this been done, safe separation would have been maintained. This inability of TCAS to make the controller aware of what resolution advisories were issued to the pilot or account for the execution of alternative actions by the pilot represent major limitations of the system; limitations that we postulate played a role in this event. Another piece of the puzzle is to understand the pilot actions before the collision

Contributing Factor 6. Corporate Culture

Data analysis suggests that whereas the B757 pilot followed the TCAS advisory to descend, the T-154 pilot opted out of following this advisory to climb and followed controller instructions to descend. This raises the issue of why the pilots of two separate aircraft would respond to the system in such a different way. When presented with conflicting information between ATC and TCAS, European pilots are advised to follow TCAS whereas Russian pilots are trained to take both into account before rendering a decision. In most instances, the latter group will follow ATC. This may help explain why the B757 pilot (who was British) and the T154 pilot acted in the manner observed.

A 'CLEARER' PICTURE

In light of this information, one now gains a clearer picture of what exactly happened that night. When the second controller left the workstation to take a break, the first controller was working his shift without any assistance. Notwithstanding issues related to lack of supervision and vigilance effects that are associated with monitoring under low traffic load (the effects which may be magnified at night), the primary conflict alert system, whose use was mandated in that situation was turned off. The dynamic event began at 21.20.08 when the controller made radar contact with the B757 as it entered the sector at FL 260. Shortly thereafter the B757 was cleared to FL320 and at 21.26.36, the aircraft was cleared to climb to FL 360 as per the pilot's request. At this point, the controller had not made radar contact with the T-154 until 21.30.11.

After both aircraft had entered the sector, the controller became preoccupied handling the approach of an aircraft (Airbus A320) to a separate airport that required him to use a different radio frequency and more importantly a different monitor: this act in itself pushed the limits of divided auditory and visual attention. In handling the approach, the controller had to call a tower using a phone system that had been reliable since it was installed. As a result the controller had high trust in the system. Therefore, when the controller experienced problems using it, he did not question its effectiveness but rather his own abilities in using the system. First the controller experienced an automation surprise (Dekker, 2002) and this resulted in cognitive tunneling (Wickens & Hollands, 2000) on the part of the controller as he struggled to get the system to work in one workspace, while neglecting the radar screen in another, a radar screen that depicted two aircraft converging at the same altitude. In Karlsruhe, which has overlapping radar coverage with the Zurich ACC, the STCA went off at 21.33.34. At this point the controller working the sector notified his supervisor and tried in vain for over a minute (from 21.33.36 to 21.34.45) to contact Zurich ACC to notify the controller of the pending conflict, but was unable to do so given the phone system malfunction. Note that as per standard procedure, whereas it would have been possible to use the worldwide emergency transmission code of 121.5 to warn the aircraft in question directly of the possible collision, this required prior approval from the Zurich ACC (which currently had responsibility for the aircraft), and this was not possible for the aforementioned reasons.

When the controller finally noticed the conflict, he immediately instructed the T-154 at 21.34.49 to descend not knowing that the aircraft's TCAS had instructed the pilot to climb. This lack of knowledge represents a possible design flaw in the TCAS system, which does not provide the controller with sufficient information about aircraft maneuver recommendations, leaving the controller 'out-of-the-loop' in terms of knowing the pilot's perceived maneuver choices. Similar design 'flaws' also led to the TCAS's system's inability to account for non-compliance on the part of one user, evident when it continued to instruct the B757 aircraft to increase its descent rate even after the T-154 had begun to execute the same maneuver, putting both aircraft on a collision course. Finally, cultural differences led the crew of one aircraft to following TCAS recommendations and another to ignore it, under high temporal pressure. This series of events culminated in the mid-air collision.

Other Factors

It is important to note that the factors identified here are by no means comprehensive. There were in fact many other elements that may have contributed to the accident. For example, one issue has been that the fact that the aural STCA that sounded when both aircraft were 6.5 nm (32 seconds) away from one another was not heard by anyone in the control room, raising concern over its audibility. Although this is a valid argument, it is worthwhile noting that the aural STCA system sounded at 21.35.00, well after the controller had already started reacting to the evolving conflict situation. Therefore, in the event that someone had heard the alarm go off, it would have only pointed out the urgency of the situation: one which the controller had already started dealing with. Therefore, the factors listed above are what we consider to have contributed substantially to the event and the absence/reversal in any one of them may well have averted the collision. For example:

- Had the first controller not been on a break (Factor #1), the impending conflict may have been pointed out a lot sooner, giving more time for conflict resolution.
- Had radar service not been downgraded (Factor #2), the STCA system would have provided the controller with over a two-minute visual warning of the collision instead of the 32-second auditory alarm that he received.

Therefore, it is a reasonable assertion that whereas there were multiple factors that contributed to the mid-air collision, the effects of some of these factors were more profound than others.

CONCLUSION

The mid air collision over Ueberlingen, Germany on the night of July 1, 2002 is the worst in recent history, and many of the factors that contributed to it (such as communication shortcomings), mimic those of seen in previous mid-air collisions (Zagreb, 1976; Delhi, 1996). Analysis of the event based on technical reports and operational experience, clearly shows how multiple human and system factors can conspire to produce the observed outcome and it provides empirical support for theories that highlight the difficulty associated with divided attention across single channels, trust in automation, and decision-making under time pressure. And ultimately, it is testament to the supposition that in this profession, time is a luxury that the controller cannot afford.

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