Ministère de l'Ecologie, du Développement durable et de l'Energie Bureau d'Enquêtes et d'Analyses

pour la sécurité de l'aviation civile

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"Evolution of Aviation Safety from Reactive to Predictive"

BEA Safety Investigation into the accident on 1 June 2009 to the Airbus A330-203, flight AF 447

The crash of Air France flight 447 on June 1st 2009 marked the beginning of an exhaustive 3-year investigation conducted by the BEA. The peculiar circumstances surrounding the accident, namely a high level of international casualties, missing evidence and substantial media coverage, contributed to making this investigation exceptional. The analysis of data from the flight recorders, avionics systems and human factors led the Bureau to release its final report on July 5th 2012.

Flight Recorders issues

The flight recorders were recovered on May 1st and 2nd, 2011. They were brought to the BEA laboratory where the opening and readout operations started on May 12th. Those operations had previously been discussed and agreed with by all the participants involved, in particular the NTSB and Honeywell, manufacturer of the recorders. No one was sure what could be expected from flight recorders after almost 2 years 4,000 meters underwater. The worst case scenario had been considered, given previous experience with this type of recorder: after the A310 accident in Comoros, only a few weeks after the AF447, recorders of this type were found within 40 days at a depth of about 1,000 m. When they were opened, parts of the memory boards and some of the chips showed major damage due to corrosion. Data could be almost completely recovered only after exceptional efforts. The environmental conditions between the two cases, however, differed significantly. In terms of temperature and salt concentration -two major factors for corrosion -the very deep cool and almost fresh waters of the Atlantic were a real advantage over the very saline and relatively warm Indian Ocean waters surrounding the Comoros. When the first crash-protected module from AF447 was opened and the memory board removed, all the witnesses were amazed at the appearance of the board almost pristine. There was therefore not much doubt left: if the data was still there which was not sure -it would be recovered. And that is the way things went, after having dried the boards and replaced some damaged components on the CVR's boards.

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One unresolved question was about the functioning of the Underwater Locator Beacons (ULB) on each of the recorders, which were not heard during the first phase of the sea searches. Though both crash-protected modules were retrieved, only one was still attached to its casing ; what is more, only this one had its ULB still in place though damaged. The remaining ULB was tested at the BEA -resulting in no tangible evidence. It was not transmitting as per design, but some physical damage may have been the result of a chemical rather than mechanical aggression. In any case, other tests had been going on with the French Navy to better understand the way the signal propagates with the ULB still attached to its crash-protected module. These demonstrated that the presence of that module, and the recorder casing, may affect the strength of the signal in some directions.

Operations to extract the data storage medium and prepare the readout were, as usual in France, videotaped and logged. The presence of the judicial experts and other judicial representatives was however easily accepted by the investigation authorities, mainly because themselves considered to be witnesses rather than actors. The BEA used, for the first time, four IP cameras to film, record and broadcast images from various places in the laboratory: opening room, electronic room, X-Ray machine, plus a movable camera. Apart from getting a trace of what had been done throughout the process, this allowed other people (typically from the manufacturer or the airline) to follow the on-going operations without disturbing the tranquility required to undertake this type of operations.

The data was then fully recovered and the analysis could begin. Again, paradoxically the investigation team was lucky enough to have ample time available to prepare the different tasks before the data was available. Whereas several hours or one day are generally given to preparing the lab, testing the tools and configuring the analysis software, ten days could in this case be efficiently used to prepare the protocol and analysis (including plots and listings). In the end, it saved a lot of time: where investigators often struggle to get the least piece of validated information from the flight recorders, they were in this case overwhelmed with the amount of data provided in a single day or two. As usual in such cases, care had to be taken at the preliminary stage of the data analysis. However here, another facilitating factor was the knowledge that was gained from the ACARS messages -whose analysis had been going on for months. As a consequence, a lot of what was observed in the flight data was more or less expected, and none of the preliminary conclusions was called into question by the flight data.

However, as so often, the devil is in the detail and though the investigators had time, they did not have all the parameters they would have liked to have. Understanding what happened had taken a matter of hours, but it already appeared that it would require more time than usual to have a chance to understand why. In the absence of image data from the flight deck, additional work had to be done in order to try to reconstruct the information displayed on the right side PFD -the PF ’s. k from the computer standpoint. It finally helped and it was possible to compute or approximate the flight directors ’ guidance or determine, at least partially, the Pitot probe #2 blockage history. This information was then made into in a 2D-animation and provided to the human factors group. Despite the limitations -in terms of interpretation -associated with this type of representation, by combining it with the CVR, it was at least possible to show how fast the events happened in the sequence. Without basing their analysis on the animation, the quantity of information available in a limited space made it possible for the human factors group members to consider a wide range of aspects in a short time.

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Human Factors issues

Methodology

Based on the work already performed by the other working groups, and particularly since the download of the flight recorders in May 2011, a HF working group was launched three months later. The HF analysis was carried out by three BEA safety investigators and four HF experts, two of whom were pilots and provided the group with reasonable expectations that may be held regarding crew reactions and skills. The two other contributed by their experience and by their knowledge on the psychomotor, cognitive, social, emotional and cooperative responses of human operators in general and of airline pilots in particular.

Coordination with other working group was also essential to take into account the safety provisions that were supposed to guarantee the safety of the accident flight in the situation encountered. These provisions include among others explicit areas, such as regulation, procedures to follow or design features, which were designed to keep the flight safe. They also include implicit areas that are more or less clear: “basic airmanship”, “best practice” or “reasonable expectations” regarding the crew behaviour.

The aim of the HF group was therefore to determine the set of these safety provisions that affected the expected behaviours and skills of the crews in this situation. This involved identifying the failures that occurred during the flight, in relation to the explicit or implicit safety expectations. It also involved explaining these failures in the situation, by analysing the interactions experienced by the crew with the flight environment, the procedures available, and the information from the instruments and aeroplane, as well as the interactions between crew members (SHELL model).

Beyond the simple discovery of a psychologically probable, likely or plausible explanation for the behaviour recorded, the HF study also involved assessing the degree of specificity or generality of the behavioural responses recorded: are they specific to this particular crew, shared by all the airline’s crews, or can they be generalised to all crews? With regard to human factors, the behaviour observed at the time of an event is often consistent with, or an extension of, a specific culture and work organisation. To put it another way, it involves answering the question: “if another crew were substituted for this one, would the same responses be observed?” The final aim is in fact to contribute to identifying what should be modified in the whole of the safety provisions to significantly increase their effectiveness in a similar situation or in a generic situation including the same fundamental characteristics. For investigation authorities, the safety recommendations to be issued depend partly on the answer to the previous question.

Analysis

Close coordination with the IIC and other working group leaders enabled to close the HF working group in February 2012. HF work was mainly used for the analysis part of the Final Report and particularly for the accident scenario. It notably brought out the fact that when crew action is expected, it is always supposed that they will be capable of initial control of the flight path and of a rapid diagnosis that will allow them to identify the correct entry in the dictionary of procedures. A crew can be faced with an unexpected situation leading to a momentary but profound loss of comprehension. If, in this case, the supposed capacity for initial mastery and then diagnosis is lost, the safety model is then in “common failure mode”.

During this event, the loss of airspeed information due to obstruction of the Pitot probes by ice crystals during cruise completely surprised the pilots of flight AF 447. After initial reactions that depend upon basic airmanship, it was expected that it would be rapidly diagnosed by pilots and managed where necessary by precautionary measures on the pitch attitude and the thrust, as indicated in the associated procedure. But the apparent difficulties with aeroplane handling at high altitude in turbulence led to excessive handling inputs in roll and a sharp nose-up input by the PF. The destabilisation that resulted from the climbing flight path and the evolution in the pitch attitude and vertical speed was added to the erroneous airspeed indications and ECAM messages, which did not help with the diagnosis. Thus, the initial inability to master the flight path also made it impossible to understand the situation and to access the planned solution. The crew, progressively becoming de-structured, likely never understood that it was “only” faced with a loss of three sources of airspeed information.

In the minute that followed the autopilot disconnection due to the obstruction of the Pitot probes, the failure of the attempts to understand the situation and the de-structuring of crew cooperation fed on each other until the total loss of cognitive control of the situation. The aeroplane went then into a sustained stall, signalled by the stall warning and strong buffet. Despite these persistent symptoms, the crew never understood that they were stalling and consequently never applied a recovery manoeuvre. The combination of the ergonomics of the warning design, the conditions in which airline pilots are trained and exposed to stalls during their professional training and the process of recurrent training did not generate the expected behaviour. For example, recognizing the stall warning, even associated with buffet, supposes sufficient previous experience of stalls, a minimum of cognitive availability and understanding of the situation, knowledge of the aeroplane (and its protection modes) and its flight physics. However, an examination of the current training for airline pilots does not, in general, provide convincing indications of the building and maintenance of the associated skills.

Thus, based on the double failure of the planned procedural responses (loss of indicated airspeed and stall), the HF analysis enabled to show the limits of the current safety model. This led to safety recommendations in the Final Report to enable improvements notably in crew training and the ergonomics of information supplied to the crews.

Although the lack of crucial information hindered the safety investigators from determining the chain of events leading to the accident for two years, the analysis of data available from the flight recorders, the avionics systems and human factors enabled the BEA to determine the causes of the accident.

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Victims' families, media issues & innovations

The BEA made it a priority to provide information to the victims' families. The Bureau sometimes encountered challenges in establishing swift and direct communication due to a particular set of circumstances, reflecting the very nature of the accident.

A complex framework

32 different nationalities were counted among the 228 victims and 12 of these countries requested the status of Observer State. The 4 main countries affected by the tragedy -namely France, Brazil, Germany and Italy, witnessed the creation of large associations of victims' families, thus requiring the implementation of broad communication procedures in foreign languages. France lost 73 nationals, Brazil 58, Germany 26 and Italy 9. In accordance with the provisions of Annex 13 and the European regulations, any information to be published (reports or findings), must first be released to the victims' families. Therefore, the time difference between Europe and South America required setting a specific time (approximately 1pm GMT) to hold press briefings, after the families were made aware of the latest findings. Lastly, the 23-month gap between the accident, the localization of the wreckage and that of the flight recorders, combined with leaks, online rumors and media speculations led some family members to become disenfranchised with the BEA, and in some instances accused it of a lack of transparency. The BEA thus worked to restore confidence in the Bureau. Another aspect of the communication strategy was to put an emphasis on the objective nature of the safety investigation to prevent any party from using findings or quotes in the legal framework.

Communication with the victims' families

The communication strategy developed by the BEA was straightforward. It was designed to ensure the victims' families would be informed of any finding over the course of the undersea search operations, the publication of the three interim reports and that of the final report. This was performed both electronically, with over 50 emails sent directly to the families prior to press releases; and physically with periodic meetings with families associations' representatives In addition, resources were dedicated to making validated documents available in French, English, German, and Portuguese. This was paramount to ensuring the families' understanding of the safety investigation at an extremely difficult time.

Leaks, misinformation and the media

The duration of the investigation combined with partial leaks and resulting speculations created a media buzz which at times hindered the BEA's work with the victims' families. Three events should be highlighted, which, far from having any scientific basis, simply contributed to perpetuating a sort of 'blame game'. On May 16th 2011, Le Figaro cleared the aircraft of any manufacturing defect. Later it pointed the finger at the pilots by including partly erroneous quotes from the crew. On August 2nd 2011, a few days after the publication of the third interim report, the confidential draft of this document was leaked to the press, further fueling an already existing controversy over a proposed safety recommendation, which did not appear in the official version. Lastly, Jean-Pierre Otelli released a book entitled Erreurs de pilotage (Piloting errors) on October 14th 2011, in which he attempted to reenact the chain of events that took place based on a CVR transcript he had previously obtained.

Another factor, online rumors and speculations, proved counterproductive to carrying out an efficient communication strategy by dedicating resources to crisis communication. Indeed, social networks and forums contributed to rapidly spreading false information -thus reflecting Marshall McLuhan's Global Village concept, and from which the international press based a great deal of its headlines to further the debate over who was to blame for the accident. This phenomenon seemed to arise from the dynamic of prioritizing the creation of information over its accuracy. This, in turn, left the victims' families confused, in distress and sometimes suspicious of the work of the BEA.

Information and innovations

To improve the release of information, the BEA implemented new online and multimedia capabilities. A technical team was assigned to record life aboard ships in the course of the 5 different sea search and rescue operations as well as to conduct multiple interviews with investigators to further public understanding of the nature of their work. Following the discovery of the wreckage and later of the flight recorders, pictures were sent electronically from the vessels and posted overnight on the BEA's website.

Another initiative was to stream online both the presentation of third interim report and that of the final report. Although this was initially intended to be accessible only to the families, the procedure was extended to include BEA's international partners and counterparts, with the hiring of two English speaking interpreters. Lastly, such an online presence required the BEA to increase its website capabilities. Each of the 4 reports were downloaded over 100,000 times, with over 75,000 downloads of the English version. Today the site contains 4 sections dedicated to covering 3 years of investigation: Chronology, Reports, Sea Search Operations; and Press Releases & Media library.

The BEA investigated the first major aircraft accident within the new age of digital communication technologies. It had to work its overall communication strategy in a complex environment, but remained dedicated to its mission and to the victims' families with complete, accurate and validated information. Crisis communication and communication strategies were both used extensively to contain and enable a safe, swift and direct release of information, which proved to be crucial to the safety investigation and to preserving its integrity.

Léopold SARTORIUS

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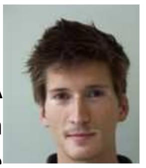

Léo joined the BEA Engineering Department in 2002 immediately after graduating as an engineer from the French National Aeronautical Construction Graduate School. He was initially deeply involved in the development of the BEA’s in-house flight data analysis software, and since 2003 has participated in numerous international investigations as flight recorder, performance or systems group leader and as accredited representative. In 2011 Léo was named head of the Flight Recorders and Avionics Systems division. He holds a PPL and has a Masters degree in Human Factors.

Sébastien DAVID

Senior Safety Investigator, BEA, France Head of the AF 447 Human Factors working group

Sébastien graduated in 1997 as an engineer from the French National Graduate School of Civil Aviation and joined the BEA Engineering Department in 1998 to work initially on flight recorder readouts and performance studies. He then worked as safety investigator for the BEA and during his career with BEA he has participated in many major investigations as accredited representative, recorders, operations and human factors working group leader and Investigator-in-Charge. He also holds a CPL, has been type rated on Dassault Falcon 7X and holds a Masters degree in Human Factors.

Martine DEL BONO

Head of Public Affairs, BEA -France

Graduated from the CELSA (Graduate School in the Information and Communication Sciences, Sorbonne, Paris). Martine acquired substantial knowledge and experience in the fields of intercultural management and communication as head of International Communications at Sciences Po Paris. Martine joined the BEA in 2002. Her field of expertise encompasses all aspects of communication strategy. Her primary targets are access to information, crisis management and aviation safety interests.