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INVESTIGATION REPORT

Serious incident to the Airbus A320-214 registered EC-HQJ
on 17 November 2017
en route between Geneva and Barcelona

Time	Around 08:20[1]
Operator	Vueling Airlines
Type of flight	Commercial air transport (passengers)
Persons on board	Captain; first officer (FO); 4 cabin crew; 150 passengers
Consequences and damage	Partial incapacitation of captain and first officer

[1] Except where otherwise indicated, the times in this report are in Coordinated Universal Time (UTC). One hour should be added to obtain the legal time applicable in Metropolitan France on the day of the event.

Flight crew partial incapacitation, emergency diversion

1 - HISTORY OF THE FLIGHT

Note: the history of the flight is based on the air traffic control radio and radar recordings, statements and the aeroplane's FDR and CVR data.

At 08:41, the crew of flight Vueling 6204, operating an Airbus 320 registered EC-HQJ, departing from Geneva-Cointrin airport (Switzerland) bound for Barcelona El Prat (Spain), were cleared to taxi to runway 05. The Vueling flight taxied behind a Cessna Citation Excel. The two planes held their position at the holding point of runway 05.

At 08:51:25, the Cessna Citation was cleared to take off.

At 08:51:32, flight Vueling 6204 was cleared to line up. One minute later, it was cleared to take off. There was a calm wind.

At 08:56, shortly after the retraction of the landing gear, the flight crew discussed the thick exhaust gases emitted by the Cessna Citation. The captain said that he felt almost nauseous because of them. The FO confirmed that it was a very strong smell[2].

[2] Source: CVR.

At 08:57:41, while climbing through FL100 and in contact with Geneva approach, the captain asked the controller for information about the aeroplane preceding them, he wanted to know what type of Cessna Citation it was. The controller replied that there was no traffic ahead of them. The captain replied that there had been a Cessna Citation in front of them at departure and that he was going to file a report following odours in the cockpit. The FO told the captain that he also felt unwell and intoxicated.

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At 08:58:40, the controller told the crew that the aeroplane which had preceded them at departure was a Cessna Citation Excel and that it was on another departure path.

At 08:59:29, the captain informed the FO that he did not feel well and proposed that they increase the air intake.

At 08:59:40, flight Vueling 6204 was transferred to the Marseilles en route control centre. It climbed through FL150[3] to FL290.

[3] Flight Level.

At 09:00:08, the purser, called by the crew, entered the cockpit. Questioned by the flight crew, he said that he had not smelt anything and that all was fine in the cabin. The FO indicated that the exhaust gases from the plane which had been in front of them while they were taxiing had made him feel physically ill. The captain then asked the purser to both leave the cockpit door open and ask the cabin crew to keep an eye on him and the FO.

At 09:04:51, the captain told the FO that he was starting to feel nauseous. The FO suggested that the captain should get a little more air and deployed the oxygen masks[4]. The captain donned the mask.

[4] Noise identical to that made on opening the oxygen mask compartment heard on the CVR.

The discussions between the captain and the FO along with the movements of the seat identified on the CVR seem to indicate that the FO left the cockpit to use the toilet facilities. At 09:06:50, the captain asked the FO, back in the cockpit, how he felt. The FO replied that he was feeling a little better and that he had felt very nauseous.

At 09:07, the flight crew discussed the choice of an alternate aerodrome should the situation get worse. They chose Marseilles-Provence airport. At 09:12:33, the FO also donned his oxygen mask. The two crew members wore their masks up to the end of the flight.

At 09:13:36, stable at FL290, the captain made a "PAN PAN" call and asked to divert to Marseilles-Provence airport, specifying that it was for crew incapacitation. Runway 31 was in use at Marseilles.

At 09:17, the crew asked if it was possible to land on runway 13. The meteorological situation was CAVOK and the wind calm. This request was cleared by the air traffic control three minutes later. The flight was then vectored for an ILS[5] approach to runway 13L with a slightly extended path, requested by the crew in order to intercept the ILS in an optimum manner.

[5] Instrument Landing System.

At 09:30, while intercepting the ILS, the captain and FO discussed their respective states and both said that they felt a little better. They kept their oxygen masks on. The approach was flown with the autopilot. It was disconnected at a height of 195 ft. The speed was 135 kt at this point which corresponds to the Vapp target speed[6]. The aeroplane landed without further incident at 09:36.

[6] Information based on FDR.

The flight crew were met at their arrival on the apron and taken to hospital. After a blood test and a short period of monitoring, they left the hospital two hours later. Nausea and dizziness alternating with periods of respite, nevertheless continued for several days.

2 - ADDITIONAL INFORMATION

2.1 Flight crew statements

At the start of the flight, the captain was the PF and the first officer (FO) was the PM. The crew said that the APU[7] had been started up around ten minutes before departure. At the holding point, the aeroplane had remained at a standstill for a few moments behind a NetJets Cessna Citation, at a distance corresponding to around twice the length of their aeroplane[8]. The crew had then smelt a strong, quite acrid odour of exhaust gases. They initially thought that it seemed quite similar to what is sometimes smelt when taxiing, but the smell became more powerful, becoming very unpleasant, strong and acidic. The crew stated that, from that moment, they experienced tickling in the nose and throat and opened the air nozzles. The odour disappeared once the Cessna Citation had lined up. The crew thus agreed that the odour came from this aircraft. This odour was not accompanied by smoke in the aeroplane. The crew called the purser and asked him if he could also smell this odour and if he felt well. He replied that everything was fine for him and in the passenger cabin.

During the climb, the captain started feeling dizzy. He asked the purser to stay in the cockpit for safety reasons. The crew decided to stop climbing at FL290 in order to keep a low cabin altitude. On arriving at FL290, the FO also started feeling dizzy, nauseous and had a pressing need to urinate. This led him to leave the cockpit to use the toilet facilities. The captain's state, alone in the cockpit with the purser, got worse. He then donned his oxygen mask and decided to divert to Marseilles-Provence airport, which was close, reporting the problem to the ATC[9] and giving instructions to the purser should his state become worse. The FO returned to the cockpit saying that he did not feel well and also donned his oxygen mask.

During the descent, the ATC asked them to squawk 7700 on the transponder. The ATC informed them that the runway in use was runway 31 with wind calm. Given their respective states, they asked if they could fly an approach to runway 13 which was accepted. They then mutually assessed how they were feeling. As the state of the FO had improved with the oxygen, the captain wanted to transfer tasks and asked him to take control of the aeroplane (PF) while he managed communications (PM).

The landing proceeded normally. After vacating the runway, there was no accompanying vehicle (Flyco) to guide them. On arriving on the apron, the emergency services were present. They continued to feel nauseous despite opening the cockpit's side windows. The crew were taken to hospital, which they left two hours later after carrying out a blood test which proved to be "normal", there being no sign of carbon monoxide poisoning. No other toxicological analysis was carried out and the samples taken were not kept. Nausea and dizziness alternating with periods of respite, nevertheless continued for several days.

[7] Auxiliary Power Unit. Designed to produce power on board aeroplanes to supply on the ground, the different onboard systems (electrical power, pneumatic and hydraulic pressure, air conditioning) when the main engines are shut down. The APU on the A320 is located at the rear of the aeroplane, in the tail cone and supplied with kerosene from the aircraft's fuel tanks.

[8] i.e. around 70 m.

[9] Air Traffic Control.

2.2 Holding aeroplane at Marseilles to look for source of intoxication

The aeroplane stayed on the ground at the airport in order to carry out the following maintenance operations:

- TSM Task 05-50-00-810-831-A - Identification of the Cause of Cabin Odors or Smoke[10].
- Engine tests.

No anomaly was found.

Flights made in the subsequent months did not give rise to any particular technical incidents or reports with respect to suspicious onboard odours.

2.3 Tests and research

The investigation focused on various cabin air contamination hypotheses. The hypothesis of possible food poisoning was dismissed because firstly, the symptoms appeared following odours in the cockpit clearly mentioned by the crew on the CVR and secondly, there were no digestive problems.

2.3.1 Twenty-month maintenance inspection on EC-HQJ

A maintenance inspection corresponding to the 20-month inspection, took place in November 2017, a few days after the incident. Additional searches to locate the origin of the odours were carried out at this time. Particular attention was given to the leaktightness of the seals which confine the lubricants of the rotating parts of the two engines and the APU.

No anomaly was found.

2.3.2 Searches on aeroplane situated in front of Vueling flight at holding point

The aeroplane which had preceded the Vueling flight when taxiing and at the holding point was a Cessna 560XL Citation XLS operating for NetJets. Searches were carried out on the aeroplane and the crew were interviewed.

The aeroplane had gone into maintenance on 16 August 2017 for a major inspection which lasted until 29 September 2017. At this time, the right engine was removed and underwent a scheduled maintenance operation carried out by the engine manufacturer, Pratt and Whitney. The engine was released for service on 15 September 2017 and reinstalled on the aeroplane. The aeroplane then flew 53 hours up to the day of the incident.

After this maintenance period, only one event was recorded during a pre-flight inspection carried out on 19 November 2017, i.e. two days after the incident. The crew observed that the metal chip detector on the left engine oil system had been activated. This finding was recorded in the Aircraft Technical Log, subsequent to which, the oil filter was replaced and an oil sample analysed. The analysis did not reveal any anomaly[11].

(10) Possible causes (excerpt from TSM task)
- APU
- ENG 1, ENG 2
- Bird strike
- PACK 1, PACK 2
- Leakage in the hydraulic system
- De-icing fluid ingestion
- Cabin items (coffee maker, hot plate, oven, dry ice, toilet, ballast unit, reading light, extract fan, heated floor panel, light bulb)
- Cockpit items (rain repellent fluid, reading light, extract fan, avionics blower, MCDU, GPCU, TRU, RMP, ELAC, light bulb, FCU, VHF1)
- Chlorine odors.

(11) The chip detector does not detect a leaktightness fault on the oil system seals. Its activation is not related to the incident.

(12) Minimum Equipment List.

On the day of the incident, the aeroplane was not flying under special conditions (under MEL[12] or with an open item in the Aircraft Technical Log).

Following the incident, the BEA asked NetJets to search for a potential oil leak. No leak was found.

The two crew members had not observed anything abnormal while taxiing and taking off from Geneva-Cointrin on 17 November 2017.

2.3.3 Exogenous contamination of cockpit air

2.3.3.1 General

The air inhaled on board aeroplanes is partly composed of the air bled at the engine compressors or the APU. It is called bleed air. This unfiltered air is then pressurized to meet the needs of the cabin, cooled by the PACKs and lastly, mixed in the mixer unit with previously-filtered recirculated cabin air.

On the A320, the proportions of bleed air/recirculated cabin air is approximately 60 %/40 % with the PACKs in the normal position. The selected temperature has very little impact on this proportion. It is identical for the cockpit and for the cabin. However, the origin of the bleed air is different in the cockpit and in the cabin: when the cross bleed valve is closed and the two PACKs are operating (as at the time of the occurrence), 60 % of the air in the cockpit comes from PACK 1 (left engine) and 40 % is recirculated cabin air whereas 60 % of the air in the cabin comes from PACKs 1 and 2 (with a greater proportion coming from PACK 2) and 40 % is recirculated cabin air. In addition, relatively speaking, the air flow per occupant is slightly higher in the cockpit than in the cabin: on the ground or in cruise, in standard conditions (Delta ISA 0) and with the PACKs operating normally, the air in the cockpit (bleed air from PACK 1 + recirculated air) is renewed approximately every minute whereas the air in the cabin (bleed air from PACKs 1 and 2 + recirculated air) is renewed approximately every two to three minutes.

2.3.3.2 Contamination by exhaust gases

The CVR playback revealed that there was a concomitance between odours perceived by the crew and the presence of the Cessna Citation ahead of them while taxiing and at the holding point. This led the BEA to look into the hypothesis of a crew intoxication caused by the Cessna Citation's exhaust gases.

The analysis of the Geneva ground radar recording found that the Vueling flight had remained at a standstill, at the holding point, behind and in line with the Cessna Citation, from 08:46:33 to 08:50:14, i.e. nearly four minutes.

The centreline of the Cessna Citation engines, situated at the rear of and adjacent to the fuselage, and that of the A320 engines is at an approximate height of two metres from the ground. The ground wind was calm at the time of the occurrence.

These conditions were conducive to the formation of a concentration of exhaust gases in front of the Airbus. The exhaust gases could thus have been taken in by the A320 engines with a greater concentration in the cockpit (probably due to a greater ingestion by the left engine).

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When kerosene is burnt, the substances emitted by the aeroplane engines are composed of carbon dioxide (CO_2), water (H_2O), nitrogen (N_2), oxygen (O_2) and sulphur dioxide (SO2). In certain combustion conditions, nitrogen oxides NOx ($NO + NO_2$), carbon monoxide (CO), unburnt hydrocarbons (HC) and volatile organic compounds (VOC) are also very often emitted[13].

[13] Source: Service Technique de l'Aviation Civile (STAC).

The distinctive character of NOx is its acrid smell and of SO_2, its "*stinging*" smell. The crew mentioned, in their statements, odours perceived as acrid and acidic.

The chemical compounds responsible for the odours perceived by the crew are not, however, necessarily those which might have caused their symptoms. In particular, carbon monoxide, which has effects consistent with those seen on the aircraft, and can even result in a crew incapacitation, is odourless.

The negative result of the analysis carried out at the hospital could be explained by the time which had elapsed before the analysis (more than one hour), and by the administration of oxygen via the use of oxygen masks which might have resulted in eliminating or considerably reducing the rate of carbon monoxide in the blood.

2.3.3.3 Contamination by de-icing fluid

The onboard air can also be contaminated during aeroplane de-icing procedures. Splashed glycol-based de-icing product may get into either the engine air intake or the APU air intake where it is then heated and directed into the cabin via the bleed air system. In the present case, there had been no de-icing and this hypothesis was not, therefore, retained by the investigation.

2.3.4 Exogenous contamination of air on board aeroplanes

2.3.4.1 General

The contamination of cabin air by products arising from the breakdown of hydraulic liquids and other particles is the subject of international studies.

In the engine, seals confine the lubricants of the rotating parts. It is generally acknowledged that in the event of wear or damage to these seals, oil leaks may occur and small quantities of oil may become mixed with the air heated by the compression system. Part of this pyrolyzed oil may then pass through the pressurization system and contaminate the cabin. The size of the oil leaks varies according to the condition of the seals, maintenance of the engine, rough speed changes, and depends on the engine design.

The engine oil includes TCPs (tri cresyl phosphate) at a proportion of around 3 %. In the event of the oil being pyrolyzed, a small proportion of these TCPs may be transformed into ToCPs (tri ortho-cresyl phosphate), ortho-isomers of the TCP and neurotoxic, organophosphorous compounds. Although there is no scientific consensus, certain studies into the quality of cabin air suggest that the ToCPs could be behind various symptoms such as those experienced by the crew.

When there is such a contamination of the onboard air, a characteristic smell of "*wet socks*" is often perceptible. It may be accompanied by smoke or an opacification of the surrounding air. However, the odour is sometimes not perceptible and such an event can only be identified by the detection of associated symptoms.

The BEA thus decided to look at the possibility of TCP or ToCP contamination, a hypothesis which had already been considered in the scope of investigations into crew partial incapacitation and in studies on the subject.

2.3.4.2 Filter and plastic samples

A property of ToCP is that it fixes itself on certain plastics. It is also possible to find traces of it in the filters. The BEA took certain samples from the aeroplane before its return to Barcelona in order to search for possible traces of this product.

These were the avionic filters, air conditioning filters, sun shields and a table from a cockpit seat.

The analyses, carried out by the independent laboratory, INERIS, proved negative. ToCP was not detected in any of the samples.

2.3.4.3 Hair samples taken from crew

2.3.4.3.1 Context

At the end of the flight, the crew were met by the Bouches du Rhône airport emergency care services. These services take charge of those whose physical and mental integrity may be threatened or impaired, but there is no provision for detailed medical investigations into the causes (etiological investigations) except if such an investigation is likely to affect the immediate treatment. In particular, only the acts which directly contribute to the care of the person are carried out, and the biological samples taken are not kept. This situation meant that data potentially useful to the safety investigation was not collected.

2.3.4.3.2 Method

The crew left the care facility before the intervention of the investigation team and too much time had elapsed to reasonably hope that any possible toxic substances would still be present in the pilots' bodies. The BEA thus decided to take hair samples, the only biological material (biological matrix) capable of fixing any possible lipophilic substance present at the time of the presumed contamination during the flight and holding it while growing for several weeks or months, i.e. until being cut off.

2.3.4.3.3 Technical aspects of sampling

The aim was to collect the part of the hair potentially contaminated once it had sufficiently grown and was no longer under the scalp skin, with a sufficient "safety" margin in order to be able to distinguish a portion of the hair "before" the occurrence and a portion of the hair "after" the occurrence, and thus potentially free of any suspected substance. The optimal growth time before taking a sample is between 15 days and 1 month. Samples were taken from the four members of the cabin crew and the two members of the flight crew on 22 December 2017 on the Vueling premises at Barcelona.

They had agreed to these samples being taken after the BEA had guaranteed the complete confidentiality of the results. To prevent any other nominative use, the samples were pseudonymized.

The analysis technique used was ultra-performance liquid chromatography coupled with quadrupole/time-of-flight mass spectrometry (UPLC/QTOF). This high-performance technique is the latest reference technique in analytical toxicology. The preparation of the sample is simplified as it does not depend on what products are being searched for. The method does not target precise products but determines the overall content (spectra) of a sample; it is thus possible to discover unexpected or even unknown molecules. Spectra can be compared in retrospect without needing the initial sample.

2.3.4.3.4 Result

The analyses did not find substances in quantities corresponding to a one-off significant exposure in relation with the event. Contaminants were found, such as TCP for example, but with rates corresponding to environmental pollution phenomena. No peak of one of these pollutants was observed anywhere along the length of hair analysed. In particular, no differences between the quantities observed in the hair sections "before the occurrence" and the hair sections "after the occurrence" were found. The possibility of the crew being contaminated by TCP or ToCP was therefore excluded. This result does not rule out, however, any hypothesis that the crew were contaminated by a substance inducing effects similar to those encountered and which rapidly disappeared.

2.3.5 Crew accounts

In exploratory situations such as this one, where the agent and the action mechanism remain unidentified, criteria, tables and questionnaires, on the face of it, may prove insufficient for understanding the phenomenon. This is why the BEA also obtained the crew's statements and in particular, their personal experience and how they were affected, in the form of a free narrative in the language of their choice. Unlike formatted documents such as ASRs, this procedure allows information to emerge which may be omitted when using "*conventional*" reports. This information, cross-referenced with the cockpit voice recorder information, can reveal consistencies or telling differences.

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3 - STUDIES INTO CABIN AIR QUALITY

3.1 Study carried out by the BFU[14] (Germany)

The BFU published in May 2014, a study of reported occurrences in conjunction with cabin air quality[15] notified by crews between 2006 and 2013. This study examined 663 events linked to cases of smoke, fume or odours on board an aircraft of which 180 had an impact on the crew's health. According to this study, no case had a significant impact on flight safety.

The BFU issued four safety recommendations. They concern:

- improving the identification of and the actions against cabin air contaminants which could potentially be health hazards;
- standardization of notification procedures;
- improvement in the demonstration of compliance of cabin air quality during the certification process of commercial air transport aeroplanes;
- assessment, by a qualified institute, of the potential causal connection between fume events and the long-term impacts on health.

[14] Bundesstelle für Flugunfalluntersuchung (German Federal Bureau of Aircraft Accident Investigation).

[15] Study available on the BFU website: www.bfu-web.de/EN/Publications/Safety Study/Studies

3.2 Statistics established by CAA UK[16]

The CAA UK has compiled statistics covering 1,672 fire, smoke and odour occurrences notified by British companies between 01 December 2014 and 30 November 2016. This represents 3% of all the notifications received by the CAA UK in the same period.

The examination of these notifications found that:

- 5% of the occurrences (i.e. 82 notifications) might be related to engine bleed air.
- 10% of the occurrences gave rise to technical searches on the ground. No cause related to the aeroplane was identified.
- 36 % of the reports provided by companies did not indicate real conclusions.

The CAA mentioned that such incidents are transient and that it is very difficult to determine their cause at a later date. It specifies that air contamination sources are various and can have numerous causes: food, cleaning products, toilets, etc.

[16] Civil Aviation Authority United Kingdom.

3.3 Studies and research carried out by EASA

EASA devotes a considerable amount of attention and effort to the topic of cabin air quality and has taken concrete actions to better understand all the facets of this topic, including the health and safety aspects. EASA considers that the research and scientific reviews conducted over the past decades have concluded that the cabin/cockpit air quality is similar or better than what is observed in normal indoor environments (offices, schools, kinder gardens or dwellings). In addition, to date, a causal link between exposure to cabin/cockpit air contaminants and reported health symptoms is not supported by scientific evidence. Consequently, EASA has not identified concerns which would justify imposing general design changes or modifying product certification specifications. However, the agency continues to investigate the composition of cabin air and its potential implications for health and safety.

EASA commissioned two studies that were initiated in 2014 and 2015:

- The purpose of the first study was to define a cabin air contaminant measurement method and to conduct a number of measurements on commercial flights.

After defining adequate and reliable air contaminant measurement methods for cockpit and passenger cabin areas, in-flight measurements were conducted on a number of commercial flights.

In total, 69 measurement flights were performed between July 2015 and June 2016 on 8 types of aeroplane/engine configurations. These flights were made up of 61 flights on aeroplanes equipped with bleed air systems, and 8 flights on the Boeing 787 with a 'bleed free' system. For all flights, measurement equipment was installed in the cockpit and in the cabin. Special attention was paid to organophosphates, in particular Tri Cresyl Phosphates (TCP) with the use of high-sensitivity analysis techniques.

The results show that the cabin/cockpit air quality is similar to or better than what is observed in normal indoor environments. No occupational exposure limits were exceeded.

- The purpose of the second study was to investigate the toxicity of engine oil contamination via the aeroplane bleed air system, in view of supporting the analysis of the flight measurements results.

This study characterised the chemical composition of certain aviation turbine engine oils (including pyrolysis breakdown products) and the toxic effects of the chemical compounds which may be released in the cabin or cockpit air. Two oil brands were used in this study and new and used oil samples were analysed.

The study concluded that neuroactive products are present, but that their concentration in the presence of an intact lung barrier is that low that it could not be appointed as a major concern for neuronal function. TCP was present in the oils analysed but no ortho-isomers could be detected. Finally, the analysis of the human sensitivity variability factor showed that the complete metabolic pathway and the contribution of inter individual variability in the metabolic enzymes is still largely unknown for the majority of industrial chemicals, including cabin air contaminants.

The final reports of these studies were published on 23 March 2017[17].

Further research was initiated by the European Commission with technical support from EASA. It took into account the findings and recommendations from the two studies above to develop a comprehensive understanding of the cockpit and cabin air quality, with a particular focus on engine oil contamination incidents. This study ("*FACTS*") came to an end in December 2019 and some related information and documents are available on the dedicated website[18] pending the issuing of the final report in the course of 2020.

[17] Final reports available at: https://www.easa.europa.eu/newsroom-and-events/press-releases/easa-publishes-two-studies-cabin-air-quality

[18] https://facts.aero/

3.4 Studies and research carried out by Airbus

The manufacturer, Airbus, uses in-service experience, i.e. information reported by the operators in the event of "smoke, odours or fumes", as part of the daily support activity to the Airbus product support department, to define or improve good practices or diagnostic procedures. The sources leading to this type of event are varied and can be internal or external to the aeroplane and of a transient nature[19].

Good practices or diagnostic procedures help the operator's maintenance teams to minimize the risk of this type of occurrence being repeated or aggravated when carrying out subsequent flights. These good practices were distributed in 2019 through an "*In-Service Information*" bulletin[20].

Technical solutions reducing the risk of the quality of the cabin air being degraded by certain identified sources following the analysis of in-service experience, are available and communicated to operators via *"In-Service Information"* bulletins. This information bulletin helps the operators to deal with occurrences of "smoke, odours or fumes" more effectively.

Technical solutions based on air filtering and sensors are also being studied or developed to reduce the cases of the quality of the cabin air being degraded by other sources identified in the in-service experience analysis.

Airbus indicated to the BEA that as an active member of the standard-setting scientific committees regarding cabin air quality, it examined and supported in collaboration with the civil aviation authorities, industry and scientific bodies, studies aiming to improve knowledge about the potential impacts of the thermal decomposition of engine oils, hydraulic fluids or anti-icing fluids on the quality of the cabin air.

(19) See note 10 page 4.

(20) Ref.: ISI 21.00.00139.

4 - CONCLUSIONS

After taxiing and holding behind a Cessna Citation, the pilots of the Airbus A320 operated by Vueling complained of an unpleasant smell and irritations. During the initial climb, they experienced some physical disorders leading to a partial incapacitation. Given this partial incapacitation, the crew asked a cabin crew member to monitor them and donned oxygen masks which allowed them to divert and land without further incident.

Despite the wide range of actions undertaken, the investigation was not able to factually identify what caused the flight crew's symptoms and physical discomfort. The hypothesis of them having inhaled an excessive quantity of carbon monoxide, contained in exhaust gases emanating from the Cessna Citation which had been in front of the A320, is consistent with the information collected and can explain the symptoms observed (dizziness and nausea). Nitrogen oxide and sulphur oxide compounds present in exhaust gases may also have contributed to the acrid and irritating odours smelt while taxiing. However, it cannot be excluded that the crew were intoxicated by another substance which either quickly disappeared or which was not specifically searched for in the samples taken from the aeroplane as to date, not identified, even in the most recent studies.

Toxic substances were searched for in the hair samples using the most effective, innovative techniques to date. The BEA believes that the use of these techniques on matrices such as saliva, blood or urine, sampled as quickly as possible after the symptoms, and in particular as soon as possible after landing, would increase the chances of detecting a wider range of potentially toxic substances.

A safety investigation into flight crew incapacitation caused by the inhalation of toxic products could provide information by trying to establish the link between the presence of chemical compounds and the symptoms reported by crew members. This action is in addition to other areas of study and research which may be carried out by other organizations.

The occurrences for which safety investigations are opened must be targeted in order to optimize the use of substantial investigation resources. The criteria for undertaking the investigation should include the salience of the symptoms and the presumed accessibility of factual data.

5 - SAFETY LESSONS

As it is necessary to collect biological samples from crew members, useful to the safety investigation process, at an early stage, investigation authorities cannot act in isolation.

The implementation of prior local agreements between aircraft operators, airport authorities and emergency medical structures - present at airports where this is justified by the amount of traffic - would facilitate the performance of etiological medical examinations immediately after incidents linked to the quality of cabin air.

To be effective, this type of contribution should be anticipated and prepared. For example, the operators' and the crews' representatives, and in particular the pilots' representatives, could reach agreements so as to guarantee the conditions in which samples are taken, which are acceptable for everyone. In addition, possible synergies with "*peri-airport*" health care structures, to which crews can be directed, could be studied.

The occurrences which are not the subject of a safety investigation can be the subject of an identical process on the initiative of air operators or oversight authorities.