U.S. Summary Comments on Draft Final Report of Aircraft Accident
Flash Airlines flight 604, Boeing 737-300, SU-ZCF
January 3, 2004, Red Sea near Sharm El-Sheikh, Egypt

INTRODUCTION

This letter and attachment relate to the January 3, 2004, crash of Flash Airlines flight 604, a Boeing 737, into the Red Sea near Sharm El-Sheikh, Egypt. As the State of Design and Manufacture of the 737 airplane, a U.S. Accredited Representative and advisers[1] participated in the Egyptian Ministry of Civil Aviation's (MCA) investigation. On November 8, 2005, the U.S. Accredited Representative received the MCA's draft final report. The U.S. investigative team's comments are submitted to the MCA pursuant to section 6.3 of Annex 13 to the Convention on International Civil Aviation.

SUMMARY

During the investigation, the accident investigative team, which consisted of Egyptian, French, and U.S. investigators, adopted a "scenario tree" methodology to determine the accident sequence of events. As part of this methodology, the investigative team identified possible accident scenarios, and sufficient evidence existed for the team to rule out most of the identified scenarios. The team then examined the remaining scenarios and the evidence collected during the investigation to determine which scenario most likely explained the accident sequence of events.

The only scenario identified by the investigative team that explained the accident sequence of events and was supported by the available evidence was a scenario indicating that the captain experienced spatial disorientation, which resulted in his making inadvertent actions that caused the accident. The remaining scenarios and possible causes were not consistent with the evidence and did not explain the sequence of events identified by the investigative team.

Specifically, no evidence of any airplane-related malfunction or failure was found. The exhaustive examination of the 737's autopilot and lateral control systems identified no fault that could explain the airplane's motion during the accident flight. In fact, as the MCA's draft final report properly concludes, the accident airplane's motion is consistent with the flight control movements recorded on the flight data recorder.

The MCA's draft final report stated, "no conclusive evidence could be found from the findings gathered through this investigation to determine a probable cause." Instead, the draft final report offered a list of findings, including "possible causes," even though the identification of possible causes is not consistent with international protocol concerning aviation accident investigations. Specifically, International Civil Aviation Organization Annex 13, paragraph 3.2.5, stipulates, "a list of possible causes should not be given." The report also indicated that

[1] Advisers to the U.S. Accredited Representative included representatives from the National Transportation Safety Board, Federal Aviation Administration, Boeing Commercial Airplane Group, Honeywell, and the Naval Aerospace Medical Research Laboratory.

"any combination of these findings could have caused or contributed to the accident." Three of the four possible causes identified in the MCA's draft final report were an aileron trim fault, an autopilot actuator fault, and a spoiler jam, none of which were supported by the evidence collected during the investigation.

The MCA's investigation of the operational and human factors related to the accident was minimal. Further, its documentation of the captain's training history and performance and issues related to flight crew proficiency, fatigue, and crew resource management (CRM) were not fully developed and analyzed in the draft final report, despite being pertinent to the circumstances of the accident. If the MCA had obtained additional information about these areas, the investigative team could likely have identified specific corrective actions that would prevent recurrence.

This letter provides the U.S. investigative team's position on the cause of this accident, which is consistent with the available evidence, and an overview of the primary areas of concern with the MCA's draft final report. The attachment to this letter provides comments and suggests specific corrections, clarifications, and/or additions for each area of concern in the draft final report. As discussed further in this letter, the U.S investigative team concludes the following:

(1) no evidence indicated that an airplane-related malfunction or failure caused or contributed to the accident,
(2) the aileron inputs and the corresponding right roll precipitating the upset resulted from inadvertent flight crew inputs,
(3) the captain experienced spatial disorientation as the right roll inputs occurred,
(4) the first officer did not assume timely control of the airplane, and
(5) the airplane remained fully controllable and responsive to the flight controls throughout the flight.

1. No evidence indicated that an airplane-related malfunction or failure caused or contributed to the accident.

To fully evaluate the role of the airplane and its systems in this accident, the investigative team relied on evidence such as cockpit voice recorder (CVR) and flight data recorder (FDR) information and flight performance and simulation evaluations. The operating aspects and potential failure modes of the various systems were also reviewed. Evidence from the investigation does not indicate that a failure of the airplane's autopilot or lateral control systems occurred. Further, during flight simulator evaluations, Egyptian, French, and U.S. investigators were able to maintain airplane control with relatively minor inputs during the demonstrations of all but one of the simulated system failures. This simulated failure involved a quintuple failure within an autopilot actuator that would result in an uncommanded roll input and require up to 80 pounds of control wheel force to overcome. FDR, CVR, and flight simulations data showed no evidence that such a failure occurred.

During subsequent meetings of the investigative team, the MCA presented numerous additional system failure scenarios for consideration. Factual evidence presented during these meetings and in followup correspondence with the MCA and discussions between team members and MCA personnel eliminated all but two of these scenarios from consideration. The hypothetical failures that could not be fully ruled out because of a lack of associated data were the possibility that an aileron trim runaway had occurred or that an uncommanded autopilot flight control actuator hardover fault had occurred. Analysis of FDR data and simulation studies of the effects of these two failure scenarios (each of which required two or more system failures) indicated that it is highly improbable that these failures occurred. Further discussion of these two hypothetical failures follows.

Aileron trim runaway. The MCA's draft final report accurately stated that an aileron trim runaway had not occurred before the autopilot was disconnected. After the autopilot was disengaged and as the airplane continued to roll to the right, FDR data showed aileron deflection rates well in excess of the aileron trim actuator rate of 0.6° per second. The rates recorded by the FDR could only have been achieved through manual wheel input because they exceeded the capabilities of the aileron trim system. Further, during flight simulations in Boeing's Multipurpose Engineering Cab (M-cab) simulator, investigators easily identified and controlled the aileron trim runaway and demonstrated that only 15 pounds of control wheel force were required to return to and maintain the aileron surfaces at the neutral position.

Autopilot flight control actuator hardover. The MCA's draft final report accurately stated that an aileron autopilot flight control actuator hardover most likely had not occurred. An autopilot flight control actuator can only provide an uncommanded aileron control system input if three separate faults occur simultaneously within the actuator: the arm solenoid must be commanded open, the detent solenoid must be commanded open, and the transfer valve spool must be jammed off center. This failure scenario would result in a hardover to the autopilot actuator authority limit, ultimately commanding the aileron surfaces to a maximum position of ±15° and the control wheel to 60° (in the absence of manual input). The effects of this failure scenario were inconsistent with the FDR data. Further, during M-cab flight simulations, investigators easily identified and controlled the hardover and demonstrated that only 17 to 20 pounds of control wheel force were required to counter the hardover effects.

The MCA subsequently proposed two additional hypothetical failure scenarios: a temporary spoiler wing cable jam and a temporary first officer control wheel jam. The MCA's draft final report properly concluded that the accident airplane's motion is defined by FDR-recorded control surface deflections, including spoiler and aileron (control wheel) deflections. The effects of a temporary spoiler wing cable jam or of a temporary first officer control wheel jam would render the previous statement (and the simulation data analyses upon which it is based) false. Therefore, considering these hypothetical failure scenarios is illogical.

Further, the MCA's draft final report did not explain how the airplane got to the point in the right roll at which the temporary jams supposedly occurred. Initially, the airplane was in a left bank, but it then started banking right. The MCA proposes that the fault occurred as the airplane was increasing through a bank angle of about 25°; however, the airplane's initial departure from the 20°-left-bank attitude occurred about 45 seconds before the hypothetical faults would have started. In addition, the first officer's comment, "turning right, sir," occurred about 9 seconds before the hypothetical faults would have started.

2. The aileron inputs and corresponding right roll precipitating the upset resulted from flight crew inputs.

The MCA's draft final report correctly stated that FDR data and flight simulation analyses of the 737 showed that the lateral control inputs required to reproduce the airplane's recorded motion closely matched the aileron deflections recorded on the FDR. As discussed in the previous section, the data were not consistent with a jam or runaway of the aileron actuators or a spoiler or control wheel jam; rather, the data revealed that the ailerons remained active and available until the end of the recording. The airplane's left and right roll inputs, including the maximum right roll of 111°, resulted from left and right wing aileron surface deflections during the time in which the autopilot was disengaged. The evidence indicates that the aileron inputs were commanded by the flight crew.

3. **The captain experienced spatial disorientation as the right roll inputs occurred.**

Investigators sought to understand how a professional flight crewmember could have initiated and sustained the manual flight control inputs that resulted in the unintentional loss of the airplane. Available evidence suggests that the captain guided the airplane into an overbanked, airplane-nose-down attitude because he lost spatial orientation during the departure. Evidence consistent with factors that can contribute to spatial orientations were present before the crash. This evidence includes the following:

(1) dark night conditions,
(2) misleading vestibular cues,
(3) flight crew distraction, and
(4) inappropriate control inputs.

Dark night conditions. At the time of the accident, dark night, visual meteorological conditions prevailed. The only external visual references were lighted areas on the coast near Sharm El-Sheikh. Soon after takeoff, the airplane passed over the coastline, and these external visual references were no longer visible to the flight crew.

Misleading vestibular cues. Studies performed by U.S. and French authorities, which were conducted at the MCA's request, revealed that the vestibular sensations experienced by the flight crew would have been misleading throughout much of the flight. The flight crew's vestibular systems would have provided them with little or no information about the changes in the airplane's bank angle until after the right bank angle exceeded 30° because the gradual changes in the airplane's attitude would have been below the threshold of perception. As the airplane became fully involved in the right overbank and the angle of the bank continued to increase, the vestibular sensations of the bank angles would have underrepresented the actual bank angles, and the flight crew might even have felt brief vestibular sensations leading them to perceive that the airplane was banked slightly to the left. These findings indicate that, after the airplane passed over the coast and the external visual cues were lost, the captain could only have maintained an accurate awareness of flight attitude by continuously monitoring the attitude indications on his flight instruments.

Distraction. A few seconds before the captain called for the autopilot to be engaged, the airplane's pitch began increasing and airspeed began decreasing. These deviations continued during and after the autopilot engagement/disengagement sequence. The captain ultimately allowed the airspeed to decrease to 35 knots below his commanded target airspeed of 220 knots and the climb pitch to reach 22°, which is 10° more than the standard climb pitch of about 12°. During this time, the captain also allowed the airplane to enter a gradually steepening right bank, which was inconsistent with the flight crew's departure clearance to perform a climbing left turn. These pitch, airspeed, and bank angle deviations indicated that the captain directed his attention away from monitoring the attitude indications during and after the autopilot disengagement process.

Changes in the autoflight system's mode status offer the best explanation for the captain's distraction. The following changes occurred in the autoflight system's mode status shortly before the initiation of the right roll: (1) manual engagement of the autopilot, (2) automatic transition of roll guidance from heading select to control wheel steering-roll (CWS-R), (3) manual disengagement of the autopilot, and (4) manual reengagement of heading select for roll guidance. The transition to the CWS-R mode occurred in accordance with nominal system operation because the captain was not closely following the flight director guidance at the time of the autopilot engagement. The captain might not have expected the transition, and he might not have understood why it occurred. The captain was probably referring to the mode change from command mode to CWS-R when he stated, "see what the aircraft did?," shortly after it occurred. The available evidence indicates that the unexpected mode change and the flight crew's subsequent focus of attention on reestablishing roll guidance for the autoflight system were the most likely reasons for the captain's distraction from monitoring the attitude indications.

According to CVR information, 24 seconds elapsed after the airplane entered the right bank before either flight crewmember acknowledged or attempted to correct the steepening right bank. However, as the airplane was rolling from 16° to 40° right bank, the first officer stated, "turning right sir," and the captain replied, "what?" The first officer repeated, "aircraft is turning right," and the captain asked, "ah...turning right...How turning right?" The surprise evident in the captain's responses to the first officer's announcements about the airplane's attitude indicate that he was distracted from monitoring the attitude indications for at least 24 seconds after entering the right bank.

Inappropriate control inputs. The control wheel inputs made by the captain after the first officer told him about the right turn indicate that the captain had become spatially disoriented and that he had experienced some delay in reacquiring an accurate sense of his (and the airplane's) orientation with respect to the Earth's surface.

An appropriate response to the first officer's advisories about the right turn would have been for the captain to direct his attention to the attitude indications, confirm the airplane's attitude, and apply sufficient left control wheel force to stop the right roll and sustain a roll back toward the left. However, such corrective inputs did not begin until 17 seconds after the flight crew's exchange about the right turn. Instead, the captain made inappropriate, oscillating control wheel inputs, with rightward control wheel inputs being dominant, which caused the airplane to roll to a right bank angle of 111° and a pitch attitude of 46° airplane nose down.

The persistent inappropriate nature of the captain's right control wheel inputs suggest that he was unable to immediately regain an accurate awareness of spatial orientation. Studies indicate that pilots may require some time to recover from an unknown attitude and transition to stable instrument flight after a lengthy period of distraction from flight instruments. Investigations of roll upset accidents and incidents involving commercial airline flights have also revealed that from 4 to 18 seconds may elapse between the time that a pilot becomes aware of a problem with airplane attitude and the time that sustained, appropriate control wheel inputs begin.

4. The first officer did not assume timely control of the airplane.

The first officer's lack of assertiveness during the accident sequence indicated that he had inadequate CRM skills. The first officer's verbal communications indicated that he had an accurate awareness of the airplane's flight attitude during the upset sequence. However, he did not escalate his assertiveness to prevent the captain from overbanking the airplane to the right. The first officer could have offered suggestions, issued commands, or attempted to take control of the airplane. Instead, as the airplane's bank angle exceeded 40°, the first officer began repeatedly calling out, "overbank," and issuing routine responses to the captain's requests for autopilot engagement.

<u>Differences in flight crewmember status.</u> Disparities between the captain's and first officer's aviation experience likely produced differences in perceived status between the two men, which might have reduced the first officer's willingness to escalate his assertiveness to the point of taking control of the airplane. The 53-year-old captain had been a pilot for over 35 years, held an airline transport pilot certificate, and had accumulated about 7,400 flight hours. He had retired from the Egyptian Air Force in 2000 with the rank of Air Vice Marshal (equivalent to a U.S. brigadier general). He had served as a pilot and flight instructor in high-performance military jets, and he had flown as pilot-in-command on four different types of transport-category airplanes. The 25-year-old first officer had been a pilot for 7 years, held a commercial pilot certificate, and had accumulated about 800 flight hours. The first officer had no prior experience with transport-category airplanes before joining Flash Airlines.

<u>Flash Airlines CRM training.</u> Many previous accidents have occurred when captains' errors went unchallenged by first officers. Aviation studies have provided further evidence about the role of poor CRM in accidents and about the importance of emphasizing CRM skills in airline training. Guidelines for CRM training encourage carriers to train their pilots how to promote a course of action they feel is best, even if it involves conflict with others. This is a difficult issue for many carriers, because encouraging flight crewmembers to challenge a captain's authority could increase disagreements between flight crewmembers, potentially creating a new set of safety concerns. However, the accident record suggests that safety benefits may be obtained by encouraging first officers to be appropriately assertive if a captain does not appropriately address an imminent threat to flight safety.

Flash Airlines' training manual contained a CRM ground training course outline marked, "effective January 2, 2003." The manual stated that CRM training would be provided to pilots during initial and recurrent training and would consist of 12 hours of instruction over 2 days. One of the topics included in this training was "communication skills of inquiry, advocacy, and feedback." The airline's Flight Operations Manual stated, "During flying training on aeroplanes with a flight crew of 2 particular emphasis will be placed on the practice of Line Orientated Flying Training (LOFT) with emphasis on Crew Resource Management (CRM) and the use of correct crew coordinated procedures." Despite the existence of these documents and policies, the MCA's report stated that Flash Airlines did not provide CRM training to either of the accident pilots. Therefore, the first officer did not receive training in skills that could have helped him play a more active role in the airplane's recovery.

5. The airplane remained fully controllable and responsive to the flight controls throughout the flight.

Analysis of the FDR data revealed that the airplane remained controllable throughout the entire flight. The maximum recorded bank and pitch angles during the airplane's descent were about 111° right wing down and 46° airplane nose down, respectively. As a result of flight crew corrective roll and pitch inputs, the airplane began to recover; however, the recovery attempt began too late to prevent the accident. FDR data indicated that, just before impact, the bank and pitch angles had decreased to about 14° right wing down and 23° airplane nose down, respectively.

CONCLUSIONS

In summary, the evidence collected during this investigation strongly supports the conclusions that no airplane-related malfunction or failure caused or contributed to the accident and that the accident can be explained by the captain's spatial disorientation and the first officer's failure to assume timely control of the airplane.

The attachment to this letter provides detailed comments on individual sections in the MCA's draft final report.