NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY (AS-50)
Washington, D.C. 20594

July 17, 2000

HUMAN PERFORMANCE/OPERATIONS SIMULATION STUDY

A. ACCIDENT: DCA-00-MA-006

Operator: EgyptAir Flight 990 (MSR 990)
Location: Off Nantucket, MA
Date: October 31, 1999
Time: 0148 Eastern Standard Time
Airplane: Boeing 767-366ER SU-GAP

B. SIMULATOR STUDY GROUP

Malcolm Brenner, Ph.D., Bart Elias, Ph.D., Captain P. D. Weston, Kristin Bolte, Ph.D.,
National Transportation Safety Board (NTSB)

Captain Shaker Kelada
EgyptAir

Captain Moshen El Missiry
Egyptian Civil Aviation Authority

Rick Howes, Captain John Cashman, Captain Buzz Nelson, Simulator staff
Boeing Commercial Airplane Company

C. SUMMARY

About 0150 eastern standard time (EST), on October 31, 1999, a Boeing 767-366ER, SU-GAP, operated by EgyptAir, as flight 990, crashed into the Atlantic Ocean about 60 miles south of Nantucket, MA. EgyptAir flight 990 was being operated under the provisions of Egyptian Civil Aviation Regulations Part 121 and United States Title 14 Code of Federal Regulations Part 129 as a scheduled, international flight from John F. Kennedy Airport (JFK), New York, New York to Cairo International Airport in Cairo, Egypt. The flight departed JFK about 0122 EST, with 4 flightcrew members, 10 flight attendants, and 203 passengers on board. There were no survivors. The airplane was destroyed by impact forces.

D. DETAILS OF INVESTIGATION

On March 30, 2000, as part of week-long investigative activities at the Boeing simulator facility and Boeing Field, Seattle, Washington, a human performance / operations group performed a series of demonstrations in the B-767 engineering simulator ("E-cab simulator") to make observations and obtain measurements that might assist the group at evaluating human performance and kinematic aspects of the accident situation. The E-cab is a fixed-based engineering simulator of the B-767 cockpit designed to analyze and evaluate systems, procedures and performance of the actual aircraft.

The simulator was configured like an EgyptAir B-767 cockpit and included temporary partitions to reproduce the dimensions of the EgyptAir cockpit entry area, including the cockpit door, forward lavatory door, and passageway between the forward galley and lavatory (directly outside the cockpit).

For purposes of this demonstration, the simulator display included computer generated information that displayed the changing physical forces computed to have been required to generate the split elevator condition recorded on the DFDR as well as the changing physical forces being applied to the column of the simulator at the same moment. This information was shown on the windscreen in front of each pilot position (heads-up-display or HUD) and consisted of three analog dial displays, with one showing the stick force computed on the left column, one showing the stick force being applied by the pilot in the simulator, and one showing the stick force computed on the right column. This display made it possible for a simulator pilot to attempt to match the physical forces estimated to have produced the split elevator condition.

The group performed a series of backdriven recreations of the accident sequence subject to the following limitations.

Limitations of the simulation

a. The E-cab simulator demonstration was not a scientific study or test of the sequence of events and actions that took place on MSR 990. Rather the demonstration was a tool to help investigators observe and study the scenarios described in this document.

b. The E-cab simulator was fixed base. Therefore, aircraft motion and G-forces could not be recreated in the simulation. The visual landscape consisted of featureless terrain with a visible horizon. Jumpseats and the cockpit entry area were mocked up from available seats and materials and were not identical to the construction used in the actual aircraft. No Mach or stall buffet was modeled. EICAS information did not accurately reflect information presented in the accident aircraft. There was no metric displays for fuel quantity and fuel flow. Thrust reverser isolation lights were not displayed. There was no stand-by compass in the E-cab and the mode control panel was different than the MSR990 airplane. Finally, the E-cab configuration had no control column steering.

c. The control columns in the cab only moved symmetrically. Demonstrations of control forces for the left and right seats were made individually in turn, but could not be evaluated simultaneously. There was no hydraulic decay model or elevator blow down model that simulated the decay of hydraulic pressure as the engines windmill and speed decreased. The aerodynamics of stalls was not accurately represented in the E-cab model. The low oil pressure light did not illuminate, nor did the caution alert (beeper) function during the FDR low oil operation. The Ship's Air Data Computer calibration had not been verified at speeds in excess of Mach .91.

d. For back-drive, throttle handles could only move at the autopilot rate (about 10 deg./sec.). However, engine information (EPR, N_1, N_2) was displayed at the rates recorded by the DFDR. During the back-drive, the speed brakes had to be armed manually.

e. Aerodynamic data were modified to better simulate flight conditions above Mach .91.

Phase 1: Demonstrations Using Synchronized Cockpit Voice Recorder (CVR) and Digital Flight Data Recorder (DFDR) Backdrive[1]

For purposes of the demonstrations, pilots who resembled specific members of the accident crew in height and weight dimensions were selected. Captain Shaker Kelada (EgyptAir) was used to resemble the command captain of MSR 990, Captain Buzz Nelson (Boeing) was used to resemble the cruise first officer of MSR 990, and Captain P.D. Weston (NTSB) was used to resemble the EgyptAir Boeing 767 chief pilot.

The following demonstrations were performed with observations as noted:

Demonstration 1

With the captain's seat set in the full-back position, Captain Kelada tested several positions that a pilot might use to make emergency input on the control column if he entered the cockpit around 1:50:06.

[1] Bart Elias did not attend the E-cab simulator session.

Captain Kelada reported that it was physically very difficult for him to reach the control column, located in its neutral position, when he attempted to do this while standing behind the seat. He reported that if he touched the column or tried to pull on it, this action tended to make him slide forward (rather than making the column move backward). Captain Kelada, standing behind the seat, was unable to reach the column when the column was located in its full forward position.

Captain Kelada was able to sit in the Captain's seat without difficulty and apply back pressure on the column. He demonstrated his ease at moving in and out of the seat several times. He found that, for an emergency application, he would opt to sit sideways in the seat at first and then brace himself with one foot against the "doghouse" structure below the seat.

Captain El Missiry and Dr. Brenner suggested that, in an emergency situation, a pilot might kneel on the floor, grab the control column with the left hand, and brace against an available structure with the right hand. Both are taller than Captain Kelada, and, in the case of Dr. Brenner, this emergency position was preferable because he found himself too large to enter the seat easily. Captain Kelada, however, indicated that he preferred to sit in the seat and that he found kneeling uncomfortable. Captain Kelada noted that the accident cruise captain had a shorter and heavier build than himself, and suggested that the accident captain would almost certainly have chosen to sit in his seat following an emergency return to the cockpit if this option was available.

Demonstration 2

First Captain Nelson (sitting in the right seat), and then Captain Kelada (sitting in the left seat), attempted, while holding the column, to execute the following series of actions as swiftly as possible with the hand closest to the central console: shut down left engine by use of the left fuel control switch, shut down right engine by use of the right fuel switch, advance throttles to full forward (from neutral), and deploy the speed brakes. As timed by a stopwatch, Captain Nelson executed these four actions in 3.7 seconds on his first attempt, in 2.6 seconds on his second attempt, and in 2.3 seconds on his final attempt. Captain Kelada executed these actions in 3.5 seconds on his first attempt (but failed to shut fuel to one of the engines), and in 2.5 seconds on his second attempt. These results indicated no kinematic or timing problems that would prevent a single pilot from performing all four actions within the time period shown on the accident DFDR.

Demonstration 3

Captain Nelson (sitting in the right seat) pushed the right control column forward attempting to match the physical forces computed to have been required to generate the split elevator condition recorded on the DFDR (varying his applied force to track the

HUD indicator developed as part of the simulation, as described above). During this demonstration, he used his left hand to shut the left and right engines about the times these actions were shown on the FDR. Captain Kelada entered the cockpit about the time the CVR indicated the verbal presence of an additional crewmember, sat in the left seat, and placed his hands on the control column but did not apply force. He used his right hand to advance the throttles and deploy the speed brakes about the times these actions were indicated on the FDR.

This demonstration was repeated several times. Captain Nelson reported that it was not difficult for him to match the column forces shown on the cockpit indicator, even when only one hand was present on the control column during the early part of the demonstration. Several seconds after the engines were shut, however, he found it necessary to return a second hand to the control column to continue matching the forces. He reported that his right elbow was locked during most of the demonstration.

Demonstration 4

The preceding demonstration was repeated, except, this time, Captain Kelada (seated in the left seat) attempted to match the left elevator forces indicated on the cockpit indicator while Captain Nelson (seated in the right seat) placed his hands on the control column but did not apply force. The pilots performed the respective control actions described above.

The demonstration was repeated several times. Captain Kelada reported that it was difficult and required a lot of pressure for him to match the pulling forces shown on the cockpit instrument. He noted a large decrease in his pulling ability when he was required to pull with only his left hand since his right hand was removed from the control column to move the throttle and speed brake. Other members of the group concurred with the observations of Captain Kelada.

Demonstration 5

The group performed numerous trials in which CVR sounds were played aloud in conjunction with the corresponding simulator motion beginning about the time the captain left the cockpit and, subsequently, just before the airplane departed from level flight.

Captain Cashman observed that one sound noted on the CVR transcript, about [0148:34.8], resembled that of a seat belt buckle hitting the cockpit floor. Captains Kelada and El Missiry suggested that such a sound might have been produced by the cruise first officer if he released his seat belt in order to more easily remove his food tray from his lap to store it on the jumpseat between the pilot seats at the rear of the cockpit.

Demonstration 6

The Boeing simulation team changed the lighting in the simulator to that which would apply as a result of a shutdown of both engines. It was observed that the standby flight instruments (located on the captain's side) remained illuminated.

Demonstration 7

With the captain's seat set in the full-back position, Captain P.D. Weston tested several positions that a second crewmember might assume if he entered the cockpit along with the captain and attempted to assist in the emergency response (assuming that the right seat was occupied).

Captain Weston reported that he was too tall to stand upright in the area behind the pilots' seats, although he was able to lean over and brace himself with one hand against a pilot seat. From a kneeling position, he reported being unable to find any airplane structure on which to brace himself. He found it was easy to sit in the jumpseat between the two pilot seats and that, by leaning forward and bracing against the back of a pilot seat, he could comfortably reach and manipulate controls on the central console.

It was observed that Captain Weston blocked Captain Kelada's path to the captain's seat when he was the first person to enter the cockpit rather than the second.

Demonstration 8

For this simulation, Captains Kelada and Weston entered the cockpit around the CVR time of 1:50:06, with Captain Kelada entering first and sitting in the captain's seat and Captain Weston sitting in the jumpseat. Captain Weston shut off the left and right engines, Captain Nelson (seated in the first officer seat) advanced the throttle, and Captain Kelada deployed the speed brake about the times shown on the FDR. It was observed that the participants could easily manipulate the respective controls without interference from other participants.

Demonstration 9

Captain Nelson, seated in the right seat in a full back position, stood up and departed from the cockpit at a fast pace in response to a command. It was found that he required about 7.7 seconds from the time of the command was issued until he completely passed the forward lavatory door in the cockpit entry area. On a second trial, he sat in the seat with a tray containing a glass of water in his lap. In response to a command, he placed the tray on the jumpseat, stood up, and departed the cockpit. It was found that he required about 10.4 seconds to completely pass the lavatory door.

Demonstration 10

The last demonstrations were held in the cockpit of an actual B-767-400 airplane cockpit at Boeing Field, WA, configured to demonstrate column forces necessary to produce an actual elevator split.

Members of the group tested the column forces necessary to pull the left column and to push the right column sufficiently to produce results similar to those recorded on the FDR. Several members, including Captains El Missiry and Weston, indicated that it was much easier to produce the necessary push forces rather than the necessary pull forces. It was noted that some participants displayed a muscle-tremor consistent with high force output when they performed the pull action. Participants tended to lock their arms when performing the push action.

Phase 2: Biodynamic Measurements

Two individuals[2] were chosen to represent the command captain and cruise first officer from Egypt Air 990. The following table shows the height and weight for the captain and co-pilot on Egypt Air 990 and their representatives used for the simulator investigations.

	Egypt Air Flight 990 Flightcrew		**Simulator Representative**	
Position	**Height (inches)**	**Weight (lbs.)**	**Height (inches)**	**Weight (lbs.)**
Command Captain	67	232	69	218
Cruise First Officer	71	198	72	190

Both the representative command captain and cruise first officer adjusted their seats to comfortable positions. The horizontal distance from the approximate seating reference point (SRP) to the neutral control column position was measured. For the representative command captain occupying the left seat, this distance was 18 inches and for the representative cruise first officer occupying the right seat this distance was 17 inches.

[2] Captain Buzz Nelson represented the cruise first officer, Captain Kelada represented the command captain, and Captain P.D. Weston the 767 chief pilot.

The distance from the SRP to the neutral control column position for the captain's seat in the most rearward position was also measured. This value was 25 inches.

During demonstrations 3 and 4 (described above), the column surfaces were moved to represent the forces exerted by the pilots of MSR 990. The horizontal distance from the SRP to the control column was measured at the maximum displacement of the column for both the representative command captain's and representative cruise first officer's positions. The distance from the SRP (with the left seat repositioned in its rearmost position) to the left control column in its rearward most position (pulling) during this re-creation was 18 inches. At this position, the representative command captain's arms were bent at a 130 degree angle at the elbows. The representative command captain used leverage at his legs to help pull on the column. He stated that he was not fatigued by the activity and felt he could pull harder. Toward the end of the re-creation he stated that it was necessary to use two hands to produce the required pulling force. The distance from the SRP to the co-pilot's control column in the forward most position (pushing) during this re-creation was 24 inches. At this position, the representative cruise first officer locked his elbows (180 degree angle) and pushed against the seat back to obtain the required force. After the fuel cut-off switches were engaged, the representative co-pilot needed to replace two hands on the column to continue producing the required pushing force.

Investigations have been performed in the past to determine the maximum force exerted on a control column for both pushing and pulling actions.[3] Typically the maximum values vary based on the horizontal distance from the SRP to the control column. The following table summarized from Weimer[3] reports the maximum one- and two-handed static forces exerted on an aircraft control column in the neutral or 90 degree left position.

Column Distance from SRP (in)	**Column Rotation (deg.)**	**Push (lbs.)**		**Pull (lbs.)**	
		Right Hand	**Both Hands**	**Right Hand**	**Both Hands**
		50th %	**50th %**	**50th %**	**50th %**
10 ¾	0	86	147	66	126
13 ¼	90 left	54	88	67	112

[3] McDaniel, JW. Strength Capability for Operating Aircraft Controls, F. Aghazadeh (Ed.), *Advances in Industrial Ergonomics and Safety VI* (pp 705-712), Bristol, PA: Taylor & Francis.
Weimer, J. *Handbook of Ergonomic and Human Factors Tables*, Englewood Cliffs, NJ: Prentice Hall, 1993.

15 ¾	0	90	177	94	154
19	0	121	265	106	196
23 ¼	0	171	265	125	234

Other data referenced by McDaniel[3] reported forces as high as 275 lbs. for a strong pilot using two hands. In addition, McDaniel referenced another study that examined elbow angle as related to strength. The range of angles was between 60 degrees and 180 degrees, finding that the maximum strength occurred at approximately 120 degrees, in general. Reported maximum forces were higher for pushing (123 lbs.) than pulling (88 lbs.) motions. In McDaniel's study, the subjects were either from the US Air Force Academy (AFA) or from the US Air Force Officers Training School (OTS). The reported 50th percentile push force for both hands (control column 24 inches forward of SRP) was 213 lbs. for AFA males, 196 lbs. for OTS males, 123 lbs. for AFA females, and 101 lbs. for OTS females. The reported 50th percentile pull force for both hands (control column 14 inches forward of SRP) was 176 lbs. for AFA males, 169 lbs. for OTS males, 115 lbs. for AFA females, and 97 lbs. for OTS females. The maximum force value reported, 347 lbs., was for the 99th percentile AFA males pushing on the control column.

Several additional measurements were made during the simulator investigation. The horizontal distance from the throttle handle in the neutral position to the front edge of the right jumpseat was 44 inches. An unrestrained person (tested a 71 inch, 220 lb. male) sitting in the jumpseat could reach the throttles in the neutral position by stretching. In addition, the time required for two people to enter the cockpit from the hallway, and sit in the captain's seat and the jumpseat, respectively, was approximately 4.5 seconds.

Additional measurements were provided by Boeing and are listed in Appendix A. These measurements detail the control location information (as designed) for the Egypt Air 767. These may not be the exact locations due to tolerance stack up in the manufacturing process. ('Sta' refers to the station line which represents the dimensions along the longitudinal axis of the fuselage. 'Bl' refers to the butt line which represents the horizontal dimensions left to right. 'Wl' refers to the water line which represents the vertical dimensions.

[redacted]

Malcolm Brenner, Ph.D.
Senior Human Performance Investigator

7/18/00